Proceedings of the
2017 Christian Engineering Conference

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Foreword

Welcome to the 2017 Christian Engineering Conference! In this volume of proceedings you will find the 18 papers from the conference in the order they were presented. The associated slide presentations are also available at the Christian Engineering Society (CES) website. Many thanks are due to the authors who did such a fine job of preparing them. The conference featured a keynote address from Leslie Wickman, current president of the American Scientific Affiliation (ASA). Other conference content included an invited talk from Thomas Marshall, a panel discussion on the interaction of CES with other organizations, a panel discussion on diversity within Christian engineering programs, a poster session including poster displays from industry and academia, and numerous informal discussions with colleagues from industry, public universities, and other Christian institutions. A final highlight of the conference was the first official business meeting of the CES.

This is the third time the conference has been held as the “Christian Engineering Conference” (CEC) after previously being known as “Christian Engineering Education Conference” (CEEC). The first conference was held in 1992. Plans are for continuation of the CEC as the flagship event for CES with continued involvement from Christian higher education as well as industry, secular universities, etc. The submissions for the 2017 conference came from twenty-five authors affiliated with fourteen distinct institutions – one industrial, three secular colleges or universities, and ten Christian colleges or universities from a wide variety of faith perspectives.

The next CEC is planned for June 19-21, 2019, in the vicinity of Tampa, FL, following the ASEE Annual Conference in Tampa. As always, the Christian Engineering Society web page and associated links will have full details as they become available. We plan to meet for dinner and discussion in Salt Lake City, UT, during the ASEE conference from June 24-27, 2018. In addition, we also hope for a future joint meeting with ASA.

If you wish to be involved, informed, or to participate in discussions in the meantime, CES has a Facebook group, a LinkedIn group, and a newsletter.

Special thanks are due to Robert Chasnov (general conference chair), Danielle Wyenberg (assistant program chair), Thomas Thompson (local arrangements), and steering committee members Michael Foster, Melani Plett, and Steve VanderLeest. Thanks also to the reviewers who reviewed papers and abstracts for the Conference and other volunteers who helped in a multitude of ways (worship times, devotions, session moderators, and table hosts, to name a few).

Justin Vander Werff

CEC 2017 Program Chair
Twenty-Five Years of Christian Engineering: A Literature Survey

Steven H. VanderLeest

Abstract

This paper surveys the complete set of over one hundred published papers that have appeared in the previous proceedings of this Christian engineering conference, identifying the themes, questions, and issues that have been explored thus far. Major themes include Biblical principles and virtues, design norms, the great Biblical directives, vocation/calling, and attributes of God. Next, a taxonomy is proposed to organize the concepts into an overall structure. Finally, the paper identifies open questions and topics that deserve further discussion.

1 Introduction

The only established, regularly held conference to connect Christian faith with engineering and technology has been the Christian Engineering Conference (previously named the Christian Engineering Education Conference until 2013). With nine conferences and over one hundred published papers, this conference features a wide diversity of thinking and philosophy on the integration of Christianity with the discipline of engineering. After twenty-five years of intellectual travel, it is time to look at the roadmap to see where we have been and see where we might go next.

Before presenting the survey, the rest of this introduction summarizes the history of the conference and then explains the process of coding used to conduct the literature survey. Section 2 highlights major themes that appear in the literature, including key definitions, and areas of disagreement. Section 3 presents a proposed taxonomy of the cumulative thinking represented by the conference proceedings, along with a mind map visual representation. Section 4 suggests areas where more work should be done, and Section 5 offers some concluding remarks.

1.1 A Brief History of the Conference

In 1992, three professors from Calvin College in Grand Rapids, Michigan organized the first national conference for Christian engineering educators, hosting it on Calvin's campus. Retired Professor James Bosscher had suggested the idea of the conference at a meeting of Calvin’s engineering faculty and two other faculty agreed to join him to develop the event: Rich Van Andel and Steve VanderLeest. In order to draw Christian faculty from other institutions, the conference was scheduled in the days following the American Society for Engineering Education (ASEE) national conference, held in Toledo that year. Calvin arranged for vans to transport conference attendees from Toledo to Grand Rapids. Over 40 people attended the Christian Engineering Education Conference (CEEC) that first year.

Although there was great enthusiasm to hold another conference, the next one wasn't organized until the summer of 1995 when VanderLeest returned to Calvin after finishing his Ph.D. work. Bosscher and VanderLeest then worked with colleagues at Messiah College in Grantham, Pennsylvania to host the second CEEC on their campus in 1996. Although VanderLeest organized a dinner meeting in Milwaukee in 1997 during the ASEE conference to generate further interest, and Don Peter and his colleagues hosted another dinner with evening discussion at Seattle Pacific University in 1998, it was not until 1999 that another full conference was held, this time at the Jungle Aviation and Radio Service (JAARS) facility of Wycliffe Bible
Translators in Waxhaw, North Carolina. Faculty from Calvin College as well as Dordt College helped organize the conference this time, including a published proceedings for the first time.

Three years later, the conference went international, meeting in Montreal, Quebec, Canada in 2002 with leadership from Calvin as well as Baylor University. At this point the conference settled into a rhythm, held every two years (always following in the days after ASEE), with a more informal dinner meeting in the alternate years.

This year’s twelfth conference marks the twenty-fifth anniversary of the event. It also marks the year that a loose-knit community of Christian engineers formally established and incorporated the Christian Engineering Society that now provides a more official home for the conference\(^1\). The body of work represented in the nine preceding proceedings is now substantial enough that this also seems an appropriate time to look back and take stock of what has been said thus far.

1.2 Coding Process

An engineering survey of a plot of land documents the circumference and major points of the landscape. Hopefully this paper provides something similar, documenting the overall scope of the intellectual work represented in the proceedings of the Christian Engineering Conference.

The prospect of analyzing all the published papers of the conference is somewhat daunting, spanning twenty meetings, eleven conferences from 1992 to 2015, nine proceedings (from all but the first two conferences), 111 papers, and 114 unique authors. Most authors (75%) only appear once, though 25% returning authors can also be taken as a sign of health and continuity. The papers total to 1,182 pages and over half a million words. The average conference paper is 10 pages long and lists 18 references. Papers ranged in length between 4 and 25 pages. Some papers provided no end notes; the most in one paper was 54. Figure 1 illustrates the size of each proceedings by number of papers and number of pages.

![Figure 1: Number of Papers and Pages Per Proceedings](image-url)
As part of my preliminary analysis to identify and code the main concepts introduced in the proceedings, I first collated the individual words across all papers. After eliminating common “stop” words (such as “a”, “or”, “the”) and combining various forms of the same word (such as design, designs, designed, designing), the most frequently used ten words used in the proceedings appear in the table below.

Table 1: Most Frequent Distinct Words in Proceedings

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Word</th>
<th>% of all words (not counting stop words)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4824</td>
<td>engineering</td>
<td>1.69%</td>
</tr>
<tr>
<td>3051</td>
<td>student(s)</td>
<td>1.07%</td>
</tr>
<tr>
<td>2986</td>
<td>Christian(s, ity, ly)</td>
<td>1.04%</td>
</tr>
<tr>
<td>2482</td>
<td>God</td>
<td>0.87%</td>
</tr>
<tr>
<td>2199</td>
<td>design(s, ed, ing)</td>
<td>0.77%</td>
</tr>
<tr>
<td>2092</td>
<td>technolog(y, ical, ies)</td>
<td>0.73%</td>
</tr>
<tr>
<td>1822</td>
<td>universit(y, ies)/college(s)</td>
<td>0.64%</td>
</tr>
<tr>
<td>1802</td>
<td>work(s, ing, ed)</td>
<td>0.63%</td>
</tr>
<tr>
<td>1474</td>
<td>engineer(s)</td>
<td>0.52%</td>
</tr>
<tr>
<td>1419</td>
<td>develop(s, ing, ment, ed)</td>
<td>0.50%</td>
</tr>
</tbody>
</table>

The most frequently noted book of the Bible within the collected proceedings is Genesis (179). The most frequently cited authors are Borgmann (102) and Monsma (83). Just for fun, the most frequently mentioned body part is the hand, the most frequent food named is coconut, the most common celestial body cited is the sun, most common element mentioned is oxygen, most noted country is Uganda, and the most common metals mentioned are iron and then gold.

Although simply counting words provides some insights into the collective mind of the conference authors, a more useful, but more challenging analysis is to identify major themes and concepts. My process was to skim every paper at least once, documenting the major themes. My process of coding (categorization and labeling) had a narrow focus tied to the distinct central purpose of the conference: I included only concepts with explicit connection between faith and engineering/technology. Thus, concepts primarily discussed from a technical, engineering, or scientific perspective without reference to Christian faith or Biblical principles are not included. Not that such discussions are unimportant – they often serve as useful and interesting context in papers within the proceedings. Nevertheless, I left these out of my analysis. Likewise, concepts primarily discussed from a Christian faith or Biblical perspective without a connection to engineering or technology are not included. These discussions also serve as useful and interesting context in papers within the proceedings, but again, I left these out of my analysis. Occasionally the connection would be stated, but if no further scrutiny or discussion was provided, I left these out of my analysis. Even with this tight filter, I identified 75 distinct concepts, with every paper receiving at least one coding label, and some receiving dozens, averaging 7 to 8 code labels per paper. Examples of concepts I coded included vocation, stewardship, grace, serving the marginalized (poor, disabled, etc.), sacred vs. secular, and many
others. Some of these labels by themselves do not necessarily show the connection between faith and engineering, but I noted these concepts in papers where the connection was established.

Beyond this filter, I attempted to remain objective, but of course it is challenging for anyone to recognize points of view different than one’s own and surely my own biases slipped into the coding process. Ideally, I would read all papers closely and read them twice: first to find all concepts, then again, in case I hadn’t recognized a concept in the early papers. Sadly, the project was already ambitious, so I only re-read papers to establish examples of the major themes listed later. Even with collapsing some similar concepts into a single code, the 75 concepts I found are far too many to treat each one individually in this one survey paper. As a way to summarize while hopefully retaining some useful insights, I selected a few major themes, which I present in section 2, and then I attempted to create an overall taxonomy, presented in section 3. Perhaps just as important, in section 4 I identified some themes or important questions that seem underrepresented in the proceedings thus far.

2 Major Themes
This section describes some of the significant themes of the proceedings, focusing not only on areas of common agreement that serve as a foundation, but also on areas of debate or open questions that merit further exploration. The six selected themes are: definition of technology, definition of engineering, Biblical principles and virtues, great commandments, calling, and attributes of God.

2.1 Definition of Technology
Technology is a slippery thing to define and indeed, by some definitions it is not a thing, but rather an activity. Technology is a gift from God², a tool, a means to an end, a boon, a curse. It should be holistic, appropriate, sufficient, responsible. It might be high, modern, or cutting-edge. Humans deploy it, deplore it, develop it, transfer it, and design it.

The nuance between technology as thing and technology as activity is not always obvious in casual usage within the literature, hence some further discussion may be helpful. Most of the authors discuss technology with usage that implies it is a thing. In other cases, the usage is ambiguous. Some authors define technology to extend, amplify, reduce, or even amputate human ability³. In this thinking, technology is the result of an activity: “Technology is the product of the engineering design process.”⁴ An analogy to this usage of the term technology is how we use the term “composing” to refer to an activity and use the word “music” to refer to the result of that activity, where engineering equates to composing and technology equates to music.

Some authors clearly lean on the definition from the ground-breaking book Responsible Technology that defines technology as a cultural activity⁵, and subsequently names the results from this activity as “technological artifacts”. When conceived as an activity, the phrase “doing technology” implies engineering (and perhaps more). Thus, technology and engineering become nearly synonymous: “Technology is … a cultural activity – a creative process of designing the things …. Technology is often misperceived as including only objects and machinery …. A definition of technology, and therefore engineering, that reflects the ‘people-centeredness’ of it, and the opportunities it presents for serving God by providing for the needs of our fellow creatures, will be more attractive for all potential Christian engineers.”⁶ Although some authors in this camp maintain a strict separation of technology (as activity) and artifact (as the thing that
results), more often technology becomes a shorthand term for either the activity, or the result, or both. This usage is analogous to how we often use the term “science” to refer to both the activity and the result of the activity. Just as doing science results in science, doing technology results in technology. As a further nuance, Ermer defines the activity of technology to include the entire lifecycle of technological artifacts and interconnections, hinting at a relational aspect of technology: “This includes all the interactions between individuals and cultural organizations in which technological systems are embedded and the created environment from which we extract materials.” For reference, a few authors mention Philosopher Carl Mitcham, who expands the definition even further, naming four modes of technology: object, knowledge, activity, and volition (will). Though recognizing the value of the broader definitions, the remainder of this paper follows the more common usage of “engineering” to refer to the activity that results in the thing called “technology”.

While only a few papers offer definitions of technology, many more suggest faith-based guidelines for technological development and often offer an example application to a particular technology. Table 2 lists the technologies appearing in the proceedings most often. Some of these items not everyone would consider technology, but nevertheless, the list provides some interesting insights into the collective mind of the authors. The origins of the conference in the education community are certainly evident (textbook, curriculum, campus), though these are rarely examined critically as technological objects themselves.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>430</td>
<td>(hand, text) book</td>
</tr>
<tr>
<td>331</td>
<td>curriculum</td>
</tr>
<tr>
<td>284</td>
<td>computer</td>
</tr>
<tr>
<td>147</td>
<td>building</td>
</tr>
<tr>
<td>144</td>
<td>campus</td>
</tr>
<tr>
<td>141</td>
<td>machine(s)</td>
</tr>
<tr>
<td>104</td>
<td>pump</td>
</tr>
<tr>
<td>100</td>
<td>(the) web (page, site, search)</td>
</tr>
<tr>
<td>89</td>
<td>bridge</td>
</tr>
<tr>
<td>84</td>
<td>oil</td>
</tr>
<tr>
<td>72</td>
<td>fuel</td>
</tr>
<tr>
<td>72</td>
<td>equipment</td>
</tr>
<tr>
<td>64</td>
<td>furnace</td>
</tr>
<tr>
<td>56</td>
<td>digital</td>
</tr>
<tr>
<td>55</td>
<td>software</td>
</tr>
<tr>
<td>55</td>
<td>money</td>
</tr>
<tr>
<td>53</td>
<td>radio</td>
</tr>
</tbody>
</table>
2.2 Definition of Engineering
The conference papers are more uniform in their usage of the term engineering, with some variation in discussions that contrast the discipline or activity of engineering with other disciplines or activities, such as science or business. Engineering is a technical discipline, a body of knowledge, a helping profession, an activity. It is a gift from God, a calling, and a creational task of unfolding creation. In the face of sin, it intertwines “labor and redemption.”9 Engineering can be an adjective that defines tools, analysis, students, professionals, ethics, societies, courses, design, and books. It can be practiced, taught, and reversed. It is an activity that includes planning, problem-solving, creativity, and design. It is done for a practical purpose to produce a technical solution that helps individuals or groups to solve a problem. It uses math, science, economics, psychology, and other disciplines to refine the choice of problem, identify constraints, create alternative solutions, and objectively select the optimum solution in the face of trade-offs. Engineering is “the discipline that designs and develops technology.”10 It is “a creative endeavor, a fusion of science and technique.”11

Some authors argue against considering engineering to be merely applied science or a subset of it,12 while others start with application of science, but expand to human experience and note the problem-solving aspects, defining engineering as “the application of science and human experience to solve problems faced by people. This is often done in poorly understood or uncertain situations, using the available resources.”13

Definitions are important so that we understand each other, but definitions can contain biases that intentionally or unintentionally exclude, as Jewett VanAntwerp and Ermer point out regarding potential gender bias14 in definitions of engineering.

2.3 Virtues, Vices, and Norms, Oh My!
A number of spiritual attributes or virtues appear in the proceedings (Table 3), in far higher numbers than vices (Table 4). The most common use of the virtues or vices is in reference to personal or professional behavior. The papers less often apply them to technology design.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>746</td>
<td>faith</td>
</tr>
<tr>
<td>303</td>
<td>lov(e,es,ed,ing)</td>
</tr>
<tr>
<td>281</td>
<td>justice</td>
</tr>
<tr>
<td>184</td>
<td>care/mercy</td>
</tr>
<tr>
<td>178</td>
<td>wisdom</td>
</tr>
<tr>
<td>113</td>
<td>hope</td>
</tr>
<tr>
<td>95</td>
<td>hum(ble, ility)</td>
</tr>
<tr>
<td>62</td>
<td>honest(y)</td>
</tr>
<tr>
<td>35</td>
<td>diligence</td>
</tr>
</tbody>
</table>
Table 4: Frequency of Vices in Proceedings

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>pride(ful), egoism</td>
</tr>
<tr>
<td>23</td>
<td>greed(y)</td>
</tr>
<tr>
<td>9</td>
<td>lust(s)</td>
</tr>
<tr>
<td>9</td>
<td>sloth, laz(y, iness, ier)</td>
</tr>
<tr>
<td>6</td>
<td>glutton(y, ous)</td>
</tr>
<tr>
<td>6</td>
<td>wrath, rage</td>
</tr>
<tr>
<td>5</td>
<td>envy</td>
</tr>
</tbody>
</table>

Discussions on faith and love in the conference tend to be quite diffuse, often used as umbrella virtues. The next most frequently identified virtue in the proceedings, justice, finds application to behavior in a paper by Ermer\(^6\), where she explores questions of fairness in how gender influences behavior, acceptance, and respect in engineering; and in a paper by Sykes and VanAntwerp\(^15\), exploring justice as an aspect of character. An example application of justice to the design of technology (rather than to personal behavior) can be found in a paper by VanderLeest\(^16\). As an example of examining a vice, Schwindt\(^17\) provides an interesting analysis of the damage of the sin of pride (and compares to the virtue of humility).

While the virtues discussed above are mostly applied to behavior and not directly to technology design, by contrast, the design norms from the influential 1984 book *Responsible Technology\(^18\)* are quite commonly applied to technology in many of the papers. Ermer\(^19\) provides a brief overview of the norms and demonstrates using them in an enhanced decision matrix. Adams applies the norms to Information Services\(^20\). VanAntwerp\(^21\) and VanderLeest\(^22\) both identify tensions within the norms and suggest possible expansions.

### 2.4 The Great Commandments

Christians from many different traditions commonly recognize the key Biblical directives, which engineers might call requirements. In this section, we look at the two greatest commandments that Christ gives us in Matthew 22:37-39 to love God and love neighbor, along with two other significant Biblical directives, the Great Commission and the Cultural Mandate.

The greatest commandment, to love our God, is a multifaceted endeavor, even when limiting our focus to connections with engineering and technology. The 2015 conference provided several examples of one aspect of loving God: glorifying Him. Anson\(^23\) notes that we should glorify God because of the engineering skills he has given us and then called us to use. Rueben suggests the technology of “robots … as beautiful art that pleases and glorifies God (e.g., kinetic sculpture, theater)…. ”\(^24\) In describing the principles underlying the civil engineering program at Dordt College, Sikkema and Vander Werff\(^25\) note the “unfolding potential of technology and how it manifests God’s glory.” Another aspect of loving God is worshipping him. Some of the literature examines misdirected worship – worship of anything other than God – such as directing our adoration towards idols of nature\(^26\), work, technology\(^27\), or science, for example. One can also find plentiful examples of properly directed worship connected to technology. One paper\(^28\) mentions technological aids to worship, such as projected music slides, microphones, or lights.
Another mentions construction of a house of worship\textsuperscript{29}. Career choice, rightly done, can be “viewed as an act of worship.”\textsuperscript{30} Ben Kelley explores multiple aspects of worshipping God through technology in his helpful paper “The Use of Technology in the Global Church.”\textsuperscript{31}

The second greatest commandment, loving our neighbor, is also multifaceted. Within the proceedings, the most common connection of this command to engineering and technology is via serving the marginalized of our society, including the poor, the hungry, the disadvantaged, and the disabled. This charge is so significant and direct that over a third of all papers in the conference make this connection. The thread of providing service to the destitute runs throughout the proceedings, from the very first published paper\textsuperscript{32} that makes the case for serving our marginalized neighbor as a matter of justice, to Bradley’s zealous analysis of coconuts to serve the poor\textsuperscript{33}, to one of the most recent papers\textsuperscript{34} making the case for engineers to serve our neighbors who lack clean drinking water. Within this frequently discussed theme, one particular form is most common: humanitarian projects for the poor and oppressed in international locations. One example is a study\textsuperscript{35} of the spiritual impact of humanitarian projects from four different engineering academic programs. Using our engineering skills as an act of service to those that likely cannot repay our kindness is surely a way we can be the hands and feet of Christ in the world and fulfill our particular calling to design technology. However, some authors have noted that this calling holds true even when we design technology for those that are not impoverished. That is, engineering is a helping profession and we ought to love our neighbor through the instrument of our technology. Shaw puts it this way: “Love for my neighbor involves doing all within my power for his good. This includes the development and refining of life-improving and life-saving devices and technologies.”\textsuperscript{36}

The conference literature suggests obedience to the Great Commission (Matthew 28:18-20) in at least two distinct ways. First, engineers can develop technology that aids in bringing the gospel message to the ends of the earth, such as designing navigation aids for aviation-based missions to remote regions\textsuperscript{37}. Second, engineers can bear witness to the gospel to those around them in their professional capacity as they work. That is, engineers have access to distinct segments of our society and can gain a hearing within cultural segments where other Christians might not. For example, Helweg discusses Christians in academic administration in public institutions, suggesting a two-fold benefit: “First, a Christian in a highly visible place has the opportunity to show the world a standard of excellence that brings glory to God. Second, the higher one ascends in administrative positions, the wider the area of influence in communicating the Gospel.”\textsuperscript{38}

Christians are generally familiar with the three New Testament great commands discussed thus far. We hear them preached from the pulpit on Sundays; we read about them in devotional books; much of our hymnology is built around these ideas. However, Jesus said he did not “come to get rid of what is written in the Law or in the Prophets. I have not come to do this. Instead, I have come to fulfill what is written.” (NIRV, Matthew 5:17) Thus we might also expect some guidance from the Old Testament regarding engineering and technology. Consider Micah 6:8, the well-loved summary of what God requires of us, directing us towards mercy, justice, and humility. The proceedings contain multiple instances of applying these virtues in engineering, with examples provided in the previous section. Another directive from the Old Testament that is less familiar to many Christians, but well established in these proceedings is the so-called cultural mandate that God gives all humans in Genesis 1:28: “Be fruitful and increase in number;
fill the earth and subdue it. Rule over the fish in the sea and the birds in the sky and over every living creature that moves on the ground.” This passage is also sometimes called the dominion or stewardship mandate. Reading the mandate literally, the human race has obeyed the command, perhaps too well—in the view of some, we have overpopulated the earth and overplayed our dominion, to the point that some of God’s creatures have been driven to extinction. However, in the literature of this conference, many authors read the mandate quite broadly and figuratively. They interpret the mandate to also include a command to steward the earth, to not only preserve and care for God’s creation, but also to cultivate and develop it. Thus, stewardship appropriately appears in the literature as one of the design norms. One example of a technology directed towards stewardship appears in Timmer’s description of a biomass cook stove. Developing God’s creation becomes a rich and ambitious assignment beyond physical cultivation: to create culture and society in all its diversity, composing music, developing government, establishing schools, writing stories, and importantly for this conference, designing technology. This task is sometimes described as unfolding creation, one that is assigned to all humans as stewards. For engineers, the task is rather directly connected to our skills at using creation’s resources as the raw material of our technological products. We see the Biblical narrative that starts in the garden of Eden and ends in the City of God as an affirmation of cultural development, and even more specifically, of technological development.

2.5 Calling
Of all the 75 concepts that I coded across the proceedings, the one that appeared the most frequently was the idea of calling, or vocation. More than simply a job or trade, broader than a career or profession, calling is the sense of God’s will for one’s life, the inner urge that connects one’s particular gifts with a deep sense of purpose. The frequent appearance of this topic is not surprising. Christians with a strong desire to honor their faith in all aspects of their lives are faced with an apparent paradox when their talents and gifts do not line up with society’s narrow definition of a religiously devoted career, which is limited to pastor/priest, foreign missionary (preferably in a destitute location requiring great sacrifice through physical hardship), or along the same lines of hardship, perhaps a Sunday School teacher for middle schoolers. However, a richer and Biblically-based understanding of calling encompasses much more. God’s calling extends to our roles as spouses, mentors, neighbors, parents, and citizens. It extends to our work, where work is understood as a creational good, part of our innate purpose.

The proceedings thus make the case that engineering is a legitimate calling from God. Tuinstra provides an in-depth justification, demonstrating why there is no distinction between sacred and secular callings and then pointing to specific examples of the unique calling of engineers. Others point to Colossians as the basis for legitimacy and encouragement “Work at everything you do with all your heart. Work as if you were working for the Lord, not for human masters.” (Colossians 3:23, NIRV).

2.6 Attributes of God
The proceedings are replete with explorations of the characteristics of God and application to the practice of engineering. Examples of God’s sovereignty include a paper on miracles and heat transfer, as well as a paper that points to sovereignty as the foundation of faith guiding technology development. Other authors look at God’s will and purpose, such as one paper pointing to common grace providing insights even from unbelievers in order to help Christians understand God’s will, and another paper that exhorts us with the words “only by obedience to his will that the creation can fulfill its purpose in the service of God,” then links this obedience
to the cultural mandate (discussed earlier section in this paper). This is only the beginning, with many more papers covering God’s wisdom, truth, love, grace, mercy, omniscience, and justice, to name a few.

An important subset of the papers that examine attributes of God choose to focus on a particular person of the trinity. While God the Father almost always appears within discussions in connection with the full trinity, the other two persons of the Godhead have been examined distinctly in search of insights for bridging faith with engineering and technology. For example, VanAntwerp’s paper\textsuperscript{51} is an excellent study of God in the person of the Holy Spirit. Other authors mining the depths of the distinctive attributes of God the Son have looked at the threefold office of Christ as prophet, priest, and king\textsuperscript{52}.

Having touched on a few important boundary stones pathway of the proceedings, we can now turn our attention to a suggested roadmap for the entire acreage.

3 A Taxonomy of Christian Engineering

One way to organize a large body of work is by classifying the constituent elements in the form of a taxonomy. What good is a taxonomy? It can be a tool to help us communicate more effectively by providing some common structure to a conversation. It can help organize our collective thoughts so that we notice where colleagues are working on similar or complementary topics that would benefit from cross-fertilization. It can also help us identify gaps in our thinking, where we should consider cultivating further thought and research.

My proposed taxonomy emerged out of the activity of coding the concepts with the proceedings. The exercise of coding, i.e., choosing which words and concepts to identify within a given paper, is always biased to some degree due to the worldview, opinions, and perspective of the coder. Even with stated guidelines and rules, the personality of the coder seeps in to sway the selections, though using multiple people to code the same documents can help balance the biases. The exercise of categorizing the coded concepts and arranging them into an overarching and organizing outline is likewise biased. With humility, I must allow that there are surely other ways to till the soil of concepts found in the proceedings into a systematic landscape. I myself considered several approaches, but offer only the following scheme as just one way to relate and contrast the diverse work of the conference. Further humility is required since these proceedings are not the only source of published work on the subject of bridging Christian faith with engineering and technology.

The focus of the coding influenced the broadest distinguishing factor of the taxonomy. Since the coding was limited to those concepts that bridged Christian faith with engineering and technology, I then used the direction of traversing this bridge as the fundamental way to organize the concepts: either faith influencing engineering or engineering influencing faith. One might instead consider choosing the divide between engineering and technology, or between engineering and science, or between various Christian traditions, or between various engineering disciplines. However, I suggest that none of these possibilities is as central to the conference as the bridge between our faith and our profession. Although this division may be central, it is not balanced. The vast bulk of our research focuses on one direction along the bridge: Christian faith influence on engineering and technology. The other direction – engineering/technology
influence on faith – has received less attention in the proceedings, and that seems appropriate. Yet making the distinction in this way also seems helpful, and in fact, a third category at the top level must then be recognized – the topic of appropriate terminology and ordering of this relationship.

This choice of organization frames the discussion in a certain way, and this author hopes that the framing itself gets attention from future authors. I propose that while the conference can benefit from work outside of this framing (such as work purely focused on engineering, or education, or theology, or science), we collectively benefit when most of the work lies within the suggested framework. This is more a matter of practicality than philosophy or theology. There are other, well-established conference, journals, and societies that provide a fertile and welcome home for the topics I suggest are peripheral to, but not excluded from, this conference. In the interests of building momentum, effective use of time, and effective communication of ideas, it seems prudent that this conference continue to focus on the unique combination that no other conference provides in such depth.

Having staked the claim for this overall framing, there are at least two problems with this choice that I could not easily resolve and thus leave as open questions for the reader. First, while some readers will interpret the words engineering and technology as nearly synonymous, others do not. I resorted in the taxonomy to listing “engineering/technology”, but this does not seem entirely satisfactory. A second, related problem is that while most authors and conference attendees would label themselves as engineers, technology is not the sole domain of engineers. Stop a person on the street and ask “who creates technology?” and the most likely answer is scientist, not engineer. Consider the mathematician, computer scientist, communications studies researcher, business owner, inventor, entrepreneur, artist, and others who might rightly consider themselves contributors to technology (if not directly, at least as stakeholders). Where should they go to discuss faith and technology, if not this conference? Does the use of engineering in the title of the conference deter them, and if so, is that OK? There are other conferences for non-engineering disciplines that at least occasionally touch on technology, and then connect discipline plus technology to faith, e.g., the American Scientific Affiliation and the Association of Christians in the Mathematical Sciences. Each level deeper into the outline was filled with additional difficult choices, but in the interest of brevity, I present my proposed taxonomy with no further background discussion.

I. Christian Faith influence on engineering/technology
   A. Legitimacy of this line of inquiry
      1. Legitimacy of faith to influence engineering
         a. God’s sovereignty (Christ’s Lordship)
            i. A Christian worldview ought to influence all of life, including one’s profession (such as engineering).
            ii. All creation falls under God’s rule, including engineering/technology.
            iii. God is the audience of our work, including engineering.
         b. God’s providence
            i. Provides His people with particular talents and gifts appropriate to their calling, including technical gifts for engineers.
c. God’s glory
   i. All work should be done as for the Lord. Good work is an act of worship, to the glory of God, including engineering
2. Legitimacy of engineering to be influenced by faith
   a. No sacred/secular divide
      i. All work (including engineering) is sacred and should be influenced by faith.
      ii. Engineering is a vocation and calling from God.
   b. Technology value-laden
      i. Technology is biased, value-laden, non-neutral (though some slight debate on this point, at least for technology as object), thus Biblical principles ought to guide its development.
      ii. Technology in creation-fall-redemption narrative
         (A) Christians should find the creational good and fight the taint of sin on technology.
         (B) Christian engineers should act as agents of redemption through the technology they design.
      iii. Technology is an act of will (volition) and Christians should align this willful act with God’s will.
   c. Engineering is part of human nature
      i. Work (including engineering) is part of human nature and should be influenced by faith.
      ii. Imago dei (humans bear the image of God) aspects related to engineering
         (A) Humans are distinctly tool makers among God’s creatures, reflecting God’s image via creativity, volition (free will).
         (B) We are co-creators when unfolding creation (cultural mandate), including technological cultural development.
      iii. Examples of creative activity and craftsmanship (e.g., Bezalel, Uzziah) show Biblical recognition of these skills (related to engineering), particularly for certain humans.
   d. Engineers adept at certain Christian duties
      i. Loving God
         (A) Along with scientists, engineers can particularly appreciate creation’s unity and diversity and appreciate God’s creation of unchanging, stable physical laws.
         (B) Stewardship of natural resources
            1. Preservation (including creation care, sustainability, environmental stewardship) are tasks engineers are skilled to pursue, though technology can also cause problems in this regard.
            2. Cultivation (including unfolding of creation, cultural development) are tasks engineers are distinctly skilled to pursue. Furthermore, engineers are distinctly prepared to appreciate technology as a gift of God.
      ii. Loving neighbor
         (A) Technology, by its very nature is practical and instrumental, can aid in loving others by solving their problems, improving their standard of living, helping them to flourish, providing safety, etc.
(B) Christians can serve the marginalized, including the poor, hungry, 
oppressed, physically challenged, and the stranger (cross-cultural, 
humanitarian projects). Compared to other Christians who also have a 
calling to serve the poor and otherwise marginalized, engineers are 
distinctly qualified to offer practical help, perform needs assessment, and 
design appropriate technology as part of the solution to their problems.

(C) Engineers act as redemptive agents
1. Engineers are distinctly qualified to design technology to ameliorate 
the effects of sin, to restore justice, and to bring shalom through their 
technological products.
2. Technology itself is tainted by sin, but engineers can act to redeem it.

(D) Engineers have prophetic witness opportunities related to technology, 
helping society understand the implications of technology.

iii. Gospel witness (Great Commission)
(A) Engineers have access to certain parts of society by virtue of their 
profession and can thus have prophetic witness/influence, e.g., 
corporations, professional societies, standards committees, etc.
(B) Engineers have skills to provide help (solving practical problems) and 
serve where others cannot, and thus gain access to that audience for the 
gospel.
(C) Engineers can have fellowship and share unique perspectives on faith with 
other engineers (to encourage believers and witness to non-believers).

iv. Serving the church: Engineers are part of the body of Christ and can use their 
God-given talents to aid the church in appropriate use of technology (in 
worship, in mission, in service, etc.).

B. How Christian faith influences engineering/technology
1. Faith influences personal behavior
   a. The virtues (love, mercy, etc.) and spiritual disciplines (prayer, Sabbath, 
fellowship, etc.) guide our behavior, sometimes in distinctive ways for engineers.
      i. Faith guides the personal moral choices of Christian engineers, i.e., 
         professional ethics.
   b. A worldview that recognizes the sovereignty and authority of God …
      i. … influences the engineer’s choice of career direction and project selection
      ii. … bolsters resistance to worldly influences prevalent in engineering, 
         including post-modernism, secularism, technicism, materialism, dualism, 
         naturalism, instrumentalism, abstractionism, compartmentalism, etc.

2. Faith influences professional activity
   a. Engineering design influenced by faith
      i. Faith principles influence design of technology
         (A) Principles that align design choices with God’s direction
            1. Biblical virtues and fruits of the spirit, such as justice, love, wisdom, 
               honesty, self-control, etc.
            2. Spiritual practices and discipline, such as prayer, fellowship, etc.
            3. Threefold office
               a. Prophet giving witness regarding technology
               b. Priest providing mediation and service with technology
c. King claiming dominion over technology

4. Design norms from *Responsible Technology*, derived from Christian philosopher Dooyeweerd’s aspects of reality, based on God’s will as expressed in command to love God and neighbor\(^53\)
   a. Cultural appropriateness: (dis)continuity, differentiation/integration, (de)centralization, (plur/un)iformity, large/small scale
   b. Open communication: including lingual and social, also called transparency\(^54\)
   c. Stewardship
   d. Delightful Harmony: form fits function, also called integrity\(^54\)
   e. Justice
   f. Caring
   g. Trust: pistic (faith) aspects

(B) Biblical narratives that mention technology

(C) Restraints and limitations that faith points out
   1. Sin/fall/curse calls for redemptive/transformative agency
   2. Recognize impact of specific sins
      a. Sin of pride in technology
      b. Sin of substituting technology for divine grace
      c. Sin of idolizing/worshipping technology
   3. Finiteness (because we are created, not creator) requires humility
      a. Learn from failures
      b. Use cautionary principle, lest we take undue risks because we cannot completely predict consequences
      c. Beware designs that we cannot fully understand consequences and thus negligently harm our neighbor or creation, e.g., Borgmann’s warning about device paradigm (separation of technical means from technical ends), or designs that are too complex
   4. Culpability for technological harms due to both our fallen and finite nature

ii. Engineering design practices and tools influenced by faith
   (A) Design decisions and trade-offs influenced by Biblical principles
   (B) Design processes broadened by respect of persons and creation, e.g., holistic design, sufficient design, appropriate technology
   (C) Choice of problem directed by God’s will
   (D) Creativity inspired by Holy Spirit
   (E) Teamwork enhanced by fellowship, love of neighbor, collaboration with fellow image-bearers

b. Education of engineers influenced by faith
   i. Curriculum, pedagogy, liberal arts, service learning, interpretation of standards such as ABET Engineering Criteria 2000
   ii. Mentoring, advising, discipling, especially regarding calling

c. Profession of engineering influenced by faith
   i. Ethics codes and standards influenced by faith
ii. Faith encourages fairness in organization, seeking justice for all, recognizing diversity (race, gender, economic status, etc.)

iii. Faith influences choice of issues that organizations choose to address

II. Engineering/technology influence on Christian faith

A. Engineering helps us understand Christian faith
   1. Scientific or engineering principles as analogies to help clarify faith principles
      a. God as the ultimate engineer
   2. Scientific or engineering principles (design evidence, finely tuned universe, beauty) pointing to God’s handiwork
      a. Appreciation of the Creator
      b. Enrichment of faith
      c. Apologetics based on evidence in the Creation
      d. Inspires innovative design
   3. Application of engineering principles to understand and be inspired by miracles

B. Common grace allows Christian engineers, with discernment, to accept cheerfully the good help and good ideas of unbelievers.
   1. Christians may choose to honor societal standards such as a professional society code of ethics or ABET EC 2000

III. Proper name and ordering of the relationship between Christian faith and engineering/technology

A. Terminology: integration, bridge, foundation, synthesis, etc.
   1. Niebuhr’s categorizations of Christ and Culture (against, subsumed, above, in tension, transforms)

B. Primacy: if faith has primacy over profession, then which label is best? “Christian engineer”, “engineering Christian”, “Christian who happens to be an engineer too”, “engineer who is also a Christian”, etc.

As one might guess, any attempt to map such a complex web of ideas into a sequential and segregated taxonomy will fall short of representing the true intellectual landscape. As an alternative view, the following figure provides a mind map of a subset of the ideas that appear in the proceedings, visually demonstrating the complexity of the relationships.
One of the purposes of the taxonomy is to help us identify gaps, where more thought is warranted. As a start, the next section mentions nine areas that deserve additional research.

4 There is More Work to Be Done: Missing or Poorly Addressed Concepts

With hundreds of papers over decades of time, we have jointly covered much of our chosen topic to integrate Christian faith with the profession of engineering. However, the topic is so rich and deep that more remains to be done. Although the concepts that have been explored multiple times still merit further study, this section identifies gaps – topics that the existing literature covers poorly or not at all. Before continuing, I note that the discussion presented in this section could easily feel like a critique of the conference in general, or even a critique of specific papers. That is not the intent, but rather this analysis is meant to show gratitude for the work thus far and provide encouragement to extend the work further.

A first area of weakness is that the proceedings rarely attempt to define fully and completely the central terms that form our identity, such as engineering, technology, and design. There are a few
examples, but even these mostly accept definitions from other sources rather than defining them on our own terms. This perhaps implies a common notion that the terms are self-evident. However, as noted earlier in this paper, there appears to be some differences in understanding, which would thus be healthy to examine, contrast, and compare.

As a second area of weakness, consider that the proceedings contain only a few examples of authors tackling current issues or attempting to analyze a novel technology from a faith basis, such as climate change, sustainability, artificial intelligence, genetic engineering, or changes to ABET accreditation criteria. Applying faith principles to concrete, specific cases provides a very useful test of our thinking. Trade-offs and prioritization inherent in design decisions seem easy in the abstract, but become vexing challenges in actual, concrete problems. Thus, more papers should be written that tightly focus on one problem, plumbing its depths and exposing the real struggles we ought to address.

As a third area of weakness, consider that while we have many papers devoted to aid to the marginalized in under-developed countries, there is much more to be said on this topic. In particular, (a) we need more analysis and more examples of cooperation with those being served. In humility, we need to remain teachable and ready to learn from our neighbor. We have paid lip service to the blessings received in the act of service; it is now time to articulate those blessings in full. (b) Many of the projects seem to be geographically distant from the home of the serving engineers. Since most of our authors are from highly developed and richly blessed countries, this makes sense in some ways – our poorest neighbor is likely across the border. However, surely the poor and homeless are also nearby. Why have we spent less time looking at local missions? More explanation of the choice of project (particularly its location) would be helpful so that the glamor and adventure of international travel (even when traveling to impoverished regions) does not tarnish our altruistic motives. (c) We should recognize the tension between two spiritually motivated goals: international travel to aid the poor and stewardship. Does the enlarged carbon footprint and use of energy resources justify the good that comes from such mission trips? Yes, in many cases. However, it would be healthy to examine this question in more detail. This is not an easy equation to balance and will require careful thought. For example, is the benefit of such a trip by a college student transient, or does it extend beyond the immediate time frame of the trip in a sustained improvement that is permanent? Does the benefit extend into the student’s own career with further mission work? Is the benefit to a single village or does it extend to other communities with replication of the appropriate technology?

A fourth area of weakness is the coverage in the proceedings of the Great Commission by the particular means of witnessing to others during a mission trip. There are at least two areas worthy of further assessment here. (a) For US-based authors, we do not sufficiently recognize that our neighbors are not necessarily in need of salvation simply because they live in countries that are economically disadvantaged compared to the US. For example, one commonly mentioned destination for humanitarian mission trips in the proceedings, Uganda, has a purportedly higher percentage of Christians (88%) than the US does (71%)\(^6\). (b) Far more papers have addressed gospel witness through foreign mission trips than have addressed witness of the engineer in the corporate workplace, in professional societies, or in society at large. This bias is understandable, since most of the contributors at the conference are faculty from engineering programs at Christian institutions of higher learning, with far fewer participants
from industry. The proceedings appear to have far more authors experienced with international humanitarian mission trips than authors experienced with work for pay in corporate settings. This is almost the polar opposite of the experience of the vast majority of the Christian engineering population, who participate in mission trips rarely (perhaps once during college, perhaps occasionally later), but who work full time for decades within a for-profit engineering business. The conference cannot help but self-select for this bias. For faculty at Christian engineering schools, their home institution not only funds their attendance at the conference, but also encourages such research and perhaps even requires it. For faculty from institutions that are not faith-based and for engineers working at for-profit businesses, it is unlikely that their home organization would fund attendance at the conference and even more unlikely that it would require or simply accept such research. We should collectively address this challenge, working to diversify participation in the conversation and working to address the topic of gospel witness for all Christian engineers in all aspects of their lives and careers.

A fifth area of weakness is that while the proceedings tend towards application of Biblical principles, virtues, and spiritual discipline to the engineer as an individual, there could be more work on the specific application of these principles to the actual activities of engineering (problem solving, design, ideation, etc.). Furthermore, whether applied to personal behavior or professional activity, there could be more work on the challenge of applying the principles identified already in the proceedings in the context of real-world, for-profit businesses that employ engineers, that are managed by engineers, or that are owned by engineers.

A sixth area of weakness is that there could be more work on prophetic influence on organizations where engineers often have membership, such as professional societies, student clubs, or committees that set standards and codes. Equally important, explicitly faith-based organizations, such as mission agencies, could be the subject of a paper on how engineers can bring a prophetic voice and a technological helping hand.

A seventh area of weakness is that while much has been said on the implications to engineering and technology in regards to the Great Commission, the Great Commandments, and the Cultural Mandate, there is more work to be done here. For example, we should look further at loving our neighbor by serving them with technology. Our focus has mainly been on solving the immediate issues of hunger, need for clean water, mechanical assistance for physically challenged, and so forth. These are important and right. Is there more? What about technology that enhances relationships, addresses injustice beyond the physical, that amplifies our ability to respect, understand, and attend to one another? Furthermore, there are other core directives in scripture that could be fruitfully studied, such as the ten commandments, the fruits of the spirit, and spiritual disciplines such as fasting, to name just a few.

An eighth area of weakness is that while much has already been said on the implications to engineering and technology in regards to certain attributes of God, there is more work to be done. We have made some beginning attempts, such as God’s sovereignty or his providence, and should continue that work. There are other characteristics of God that have been examined very little to date, such as analysis of the first person of the trinity, God the Father, or analysis of the so called hypostatic union of Christ, i.e., he is fully human and fully divine.
Finally, a ninth weakness is also an exhortation to my siblings in Christ: let us find joy in our work. Within the proceedings, joy is mentioned as part of the design norm of delightful harmony, occasionally implied by the term enjoyment, discussed briefly by Schwindt and briefly in connection with hope by Sykes and VanAntwerp. There is more work to be done. Let us find joy that is not simply human pleasure, but rather joy that is existential delight in the unity and diversity of creation, joy that is divinely inspired gladness in loving our God and our neighbor with the gifts God has bestowed on us. Many of us feel that joy in our daily work; it is now time to express it more fully in our writing so that others may share in that Godly joy.

5 Conclusions
I am humbled by the breadth and depth of work represented by the proceedings over twenty-five years. My prayer is that God has been glorified and the saints have been edified by all this faithful thinking and writing by our siblings in Christ. Humbling me further, I had hoped to expand this survey to also include more of the literature from outside the conference, but alas, the project was ambitious enough simply with the proceedings of this conference, so only a few other important manuscripts are mentioned.

I ended the previous section with a call to find joy in our work, so I end this paper in an expression of joy in having surveyed the good and faithful writing of all these authors. May our Master look at our work and may we take joy in his response “You have done well, good and faithful servant! You have been faithful with a few things. I will put you in charge of many things. Come and share your master’s happiness!” May that kingdom come and may his will be done, to the praise of his glorious grace.

6 References
A survey paper necessarily contains many citations to previous work. In order to make the listings a bit more concise, I have foregone the usual format of listing the full name of the proceedings (except in the first instance) along with the location of the conference (omitted in every case).

12 De Boer, Douglas F., “Using Design Hierarchy in Digital Logic to Illustrate the Scientific Method as a Human Invention,” Proc. of 2013 CEC, p. 100
18 Monsma, pp. 71-75.
41 Vander Werff 2013, p. 62.
Dyer, John, *From the Garden to the City: The Redeeming and Corrupting Power of Technology*, Grand Rapids, MI: Kregel Publications, 2011. (Though this is not a conference paper, Dyer was the keynote speaker at the 2013 conference and spoke on the topics of this book.)


VanderLeest 2008, p. 47.

Che 2013, p. 5.

Vander Werff 2013, p. 58.

VanAntwerp 2008.

Shaw 1999, p. 11.

Monsma, p. 68.


Schwindt 2011, p. 20.

Theology and Engineering Practice: Models of Reality
William Jordan*

Abstract
To a Christian engineer both faith and engineering practice are very important. As we work through what we believe about God and how we practice engineering, we find that they have something important in common. Both systematic theology and engineering practice are human models created in our attempts to understand reality.

When theologians attempt to systematize the faith, they are coming up with human models of how they see God acting in human history. When engineers design new products, they use models of how materials act when they have various forces applied to them.

For example, in discussing end times theologians have created models such as pre-millennial, post-millennial and a-millennial. Similarly, as an engineer I accept the model of Newtonian mechanics to describe the behavior of solid materials under stress. However, this is just a model (though a good one) of how things behave.

While these models are human abstractions concerning ultimate reality, they need to be precise enough upon which to base fundamental choices in life. If we are to experience the life God wants us to have we need to understand theology well enough to know what God expects of humans. While Newtonian mechanics is not a perfect model it is good enough for us to use as the basis for the design of a new airplane. In both situations, human life is at stake. Good theology can help us understand God better; good engineering can make human life more comfortable and help us understand science better.

With respect to innovations, both disciplines recognize their need, but also their limitations. Whatever we develop must match the reality that we already know. A good theologian needs to be able to help Christians who face new issues, such as privacy and the use of technology. However, too much innovation in theology can lead to models about God that are consistent with neither the Bible nor the experiences of Christians throughout history. Engineers are rewarded for creating new designs; however, whatever they create must still work in the real world. Their designs have to be grounded in the real physical world that exists.

Systematic theology and engineering practice are models of reality, not ultimate reality itself. However, they can become good enough models so that you can reliably use them to guide your life. This paper describes several ways that such models can be used by the Christian engineer.

Introduction
Christian engineers live in two worlds. During the week they live in the world of high technology and much of it appears unrelated to their spiritual lives. Many of their secular

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colleagues do not understand their perspectives, and may even belittle them. When they go to church they are in another world where spiritual topics predominate, and many of their church friends do not understand their love of technology and of solving technical problems. It is easy for the Christian engineer to assume that these two worlds never relate to each other. The purpose of this paper is to show some of the similarities between engineering and faith by examining how both engineers and theologians develop and use models to help understand their worlds. If our Christian faith is real, it must relate in some way to our engineering practice.

Every Christian believer should be called into her respective profession. This includes Christian engineers. Os Guinness writes (Guinness):

Calling is the truth that God calls us to himself so decisively that everything we are, everything we do, and everything we have is invested with a special devotion, dynamism, and direction lived out as a response to his summons and service.

For an engineer this calling is to practice engineering. It does not matter whether the Christian engineer is working for a secular company or a Christian ministry, the engineer is still called to practice engineering. Engineers have a great opportunity to use their skills to better the society around them. Within the context of engineers, Newberry has written (Newberry) that this call is a

divine call or summons to live a life of transcendent purpose—to use one’s distinct gifts in the service of God’s people and for the stewardship of God’s creation.

For a Christian engineer it is important to learn what the Bible does or does not say about engineering. What follows is a Christian perspective on engineering, not the Christian perspective on engineering.

Science based engineering as exists today did not exist in Biblical times. Builders learned from experience what worked and what did not work. Even in ancient times governments recognized the difference between competent and incompetent engineering. One fracture mechanics textbook by Hertzberg reports on an old way to ensure high quality bridge designs (Hertzberg). Whenever a new bridge was built the designer of the bridge had to stand under it while a team of chariots rode over it. This helped to ensure high quality designs as well as high quality in the construction.

There is therefore a need to infer a Biblical perspective on engineering based on what the Bible says about things such as building. The author has discussed some aspects of this in two earlier conference papers (Jordan [2008], Jordan [2013]). Building things is praised in the Bible. An example of this is in the building of the ark of the covenant. It is written in Exodus 31:1-7:

Then the LORD said to Moses, 2 “See, I have chosen Bezalel son of Uri, the son of Hur, of the tribe of Judah, 3 and I have filled him with the Spirit of God, with skill, ability and knowledge in all kinds of crafts—4 to make artistic designs for work in gold, silver and bronze, 5 to cut and set stones, to work in wood, and to engage in all kinds of craftsmanship. 6 Moreover, I have appointed Oholiab son of Ahisamach, of the tribe of Dan, to help him. Also I have given skill to all the craftsmen to make everything I have commanded you; 7 the Tent of Meeting, the ark of the Testimony with the atonement cover on it, and all the other furnishings of the tent.
It appears from this Exodus passage that the interest and skill in doing this work were gifts from God. Similarly, our interest in engineering, and our ability to solve engineering problems are gifts from God. This does not mean that hard work is not required for us to able to use our skills to their fullest potential. The competent practice of engineering is hard work. However, we do need to recognize that our engineering interests and abilities come from God.

While God commends building and creating, engineers need to recognize that what they build is not going to last forever. This is pointed out in Ecclesiastes 2:4, 6, 10-11, where the teacher states:

4 I undertook great projects: I built houses for myself and planted vineyards... 6 I made reservoirs to water groves of flourishing trees.

11 Yet when I surveyed all that my hands had done and what I had toiled to achieve, everything was meaningless, a chasing after the wind; nothing was gained under the sun.

Fortunately the above quotation is not a final statement about building. However, it makes the point, that if engineers only care about the things they create, they will inevitably be disappointed. This does not mean that building great structures is bad, only that this cannot completely satisfy your life. Engineers do not have unlimited time, so they need to be wise in how they choose to use it.

The Nature of Engineering

While there have been many attempts to describe the scientific method, there has been much less work done with respect to engineering. We are indebted to the excellent work done by Billy Koen from the University of Texas. Koen writes (Koen):

By the engineering method I mean the strategy for causing the best change in a poorly understood or uncertain situation within the available resources and the use of heuristics.

This is a very broad definition of engineering. One major point is that engineering attempts to provide the best possible solution to a problem, not a perfect solution. There is always some uncertainty with respect to any engineering design. Another major point is that engineers cause change. They are not just pursuing scientific truth for the sake of truth. They want to do something to make some situation better.

It is important to understand what Koen means by heuristics. A heuristic is something that provides a plausible aid to the solution of a problem, but which cannot be proved. Some examples of heuristics that engineers might use are:

- Rules of thumb, such as always use a safety factor of at least 2
- Make small changes in the state-of-the-art
- At some point in the project, freeze the design

At the heart of engineering practice is engineering design. Engineers design new things to solve real world problems. However, when engineers do design they need to recognize that there are
potentially multiple good solutions to the problem. Brad Kallenberg makes an important point about this. He writes (Kallenberg)

There is no single, correct design. There may be entirely wrong designs. But within the range of roughly acceptable solutions to a design problem, each proposed solution must be evaluated for its relative satisfactoriness.

The real world is messy. As wonderful and powerful as mathematics and the hard sciences are, they do not perfectly describe the actual world we live in.

Kallenberg recognizes that a discussion of engineering heuristics, such as has been done by Billy Koen may seem overly philosophical to many practicing engineers.

One might object that all this blather about heuristics doesn’t sound like it makes anything clearer. To this I can only say that if the water is muddy, it only makes things worse to report it is clear. Dealing with murky problems is what engineering is all about.

Kallenberg’s quote reinforced the point Koen made that much of engineering practice involves the best change in a poorly understood situation. The practice of engineering is clearly a process that involves making models of reality. The better the model, the better the design can become.

The Nature of Theology

For a Christian engineer who seeks to do justice to both faith and profession, figuring out theological details can be very confusing. What is good to know is that the most basic theological needs are not complicated.

The prophet Micah writes:

He has showed you, O man, what is good.
And what does the Lord require of you?
To act justly and to love mercy
And to walk humbly with your God

The apostle John makes the point that we need to know Jesus as our savior. He writes in 1 John 5:

Everyone who believes that Jesus is the Christ is born of God, and everyone who loves the father loves his child as well. This is how we know that we love the children of God: by loving God and carrying out his commands. This is love for God: to obey his commands. And his commands are not burdensome.

If the basics of the faith are not complicated it is a fair question to ask: Why should a Christian do a systematic study of theology? A good answer to this has been provided by John Calvin, who may be the first great systematic theologian of the Protestant Reformation. Calvin writes in the introduction to his famous Institutes of the Christian Religion (Calvin):

Although the Holy Scriptures contain a perfect doctrine, to which nothing can be added—our Lord having been pleased therein to unfold the infinite treasures of his wisdom—still every person, not intimately acquainted with them stands in need of some guidance and direction as to what he ought to look for in them, that he might not wander up and down, but pursue a certain path, and so attain the end which the Holy Spirit invites him.
Calvin’s point is that good theology can help the earnest Christian learn more about what God wants him to do. This good theology is not just a theoretical construct, but should be practical. Writing in the early 20th century, theologian August Strong writes (Strong):

*I make no apology for the homiletical element in my book. To be either true or useful, theology must be a passion...Theology is a science which can be successfully cultivated only in connection with its practical application.*

Strong emphasizes that the study of theology is important because it is very practical. The more people know, they better they are able to understand what God wants them to do to live the Christian life.

While the fundamentals of the faith are not complicated, there is no way humans can fully understand all there is to know about God. Theologians use models to describe their interpretations of it. Even among evangelicals there are different models of the end times (pre-millennial, amillennial, post-millennial) and baptism (believer’s baptism vs. infant baptism).

It is easy to find articles about Bible illiteracy in the church (Christianity Today). This article says that of those who attend church every week in the United States, only about 45% read the Bible as much as once per week. The article goes on to say:

*Because we don't read God's Word, it follows that we don't know it. But it's more than simply not knowing stories from Scripture. Our lack of biblical literacy has led to a lack of biblical doctrine.*

From articles like the one cited above, it is fair to say that many in the American church do not really understand much about their faith. This applies to Christian engineers as well. Their model of how God works in the world may be rather weak. It is hard to obey God if you do not know the details of how God wants us to live on a daily basis.

### Relating Engineering Models and Theological Models

There has not been a lot written about integrating faith with engineering practice. Two excellent books that deal with this in some fashion are those by Monsma and Hardy. Hardy relates vocation to work (Hardy):

*An initial attempt to formulate the principles of vocational choice was made by the Protestant reformers of the sixteenth and seventeenth centuries. They were...firmly convinced that all of life, even the life of everyday work, ought to be lived to the glory of God....The second step in vocational decision-making is locating the place where our native abilities and acquired skills can be put at the disposal of those who need them.*

In developing a basic theology of technology a good starting point might begin with answering the question: What does God want engineers to do? One starting point could be that God wants Christian engineers to use their skills to help others. Jesus speaks in Luke 12:48:

*From everyone who has been given much, much will be demanded; and from the one who has been entrusted with much, much more will be asked.*
Engineers have been given great talents by God, and God expects us to use them to help others. This using of our skills to help others is very consistent with engineering codes of conduct. For example, the ASME code’s very first Fundamental Canon states (ASME)

> Engineers shall hold paramount the safety, health, and welfare of the public in performance of their duties.

This statement shows ASME believes promoting human flourishing is at the heart of engineering practice. This is very consistent with a Biblical perspective.

There is a need for the church to understand how to relate their faith to the high technology world around them. A book that provides some real insight into this is by Jack Swearingen (Swearingen). He writes:

> All technologies have consequences that were not part of the original intent and are usually not anticipated.

These unintended consequences may have great impact on how we practice our Christian faith.

An example of this is seen in events at the start of the Protestant Reformation. There was a rapid response to Martin Luther’s posting of his 95 Theses on the Wittenberg Castle Church door on October 31, 1517. Luther was not the first reformer; there had been others in the preceding 200 years. However, it was his acts that triggered a revolution in Western society. There are many reasons for this, but a crucial component of this was something that had happened about 60 years earlier and only 250 miles away in Mainz.

In the 1450’s Johannes Gutenberg developed the first practical movable type printing press. This development has been proclaimed by many as the invention of the millennium. He combined two things that had already been created, the wine press and a coin punch. The result changed the world. Gutenberg’s press allowed Luther and the other reformers to spread their message much more quickly than could ever have been done before. Pamphlets could be rapidly printed and spread throughout Europe.

The printing press made several changes that were extremely helpful for the reformers:

- The Bible could be printed much more cheaply than ever before.
- Since most people were still illiterate, small, inexpensive pamphlets could be rapidly written, printed, and distributed. They could be read to the people in market squares all over Europe.
- The creation of these pamphlets could be done anywhere someone could get access to a printing press. This ended forever the monopoly the church and the various royal houses had on written communication. It helped bring in an era of individualism which is still with us.

Technology historian Steven Johnson makes a similar point when he writes (Johnson):

> Innovations usually begin life with an attempt to solve a specific problem, but once they get into circulation, they end up triggering other changes that would have been extremely difficult to predict....An innovation, or cluster of innovations, in one field ends up triggering changes that seem to belong to a different domain altogether.

It is not likely that Gutenberg’s goal was to create revolutions in both the religious and political order of Europe. However, that is indeed what his invention helped to ignite.
One of the problems we face is that many Christians do not base their life on the Bible. In his book about technology Swearingen makes the following important point (Swearingen):

*The Church needs a crash course in technology and culture... To grow as disciples of Jesus Christ we must discern how much our lifestyle, values, and worldviews are shaped by non-biblical influences.*

Swearingen then makes the point that the church needs to use Biblical values to confront the scientific-technological worldview. He says we need to create a theology of technology.

Our knowledge of the physical world is limited. We do not know everything that would be desirable to know about it. Scientists and engineers have created models to help them understand the world and create new things, such as modern technology. For example, while Newtonian mechanics has its limits it is good enough for us to use in many things.

In a similar way we can never know everything there is about God. However, we know enough to come to know Him personally and be assured of eternal life. As we study more of the Bible we can learn more about how He wants us to live our life. As our personal experiential models about God get better, we can know better and obey Him more consistently.

Some Christian engineers may be troubled over the fact that they do not know everything about God. However, we implicitly trust our models about the physical world, even though we know the world imperfectly. Our imperfect knowledge about it is good enough for us to create many wonderful technologies that help make life better for many people. Our knowledge of God, while not complete, is based on a standard that is trustworthy (the Bible).

**Conclusion**

Both engineers and theologians create models about the world. None of these models is a perfect representation of reality. However, they are good enough to base our professions and our life upon them.

An important question is when do we know our models of engineering and theology are good enough? With respect to engineering models the question is whether or not they reasonably represent what is observed in the real world. We need to recognize that we frequently simplify what appears to be happening in order to more easily model it. We therefore should not expect absolute correlation of our engineering models with reality. They need to be precise enough for us to use in a practical way.

With respect to theological models, we recognize that we will need to create new models to deal with new issues. For example, it is only recently that people have begun thinking about a theology of appropriate use of the internet. However, with respect to our theological models we have two things we can use as a standard to compare our models against. The first one is the Bible. Is our new model consistent with what the Bible teaches? If it is not, then it is a bad model and should not be pursued.
A second thing we can use to guide us is the work of previous Christians throughout church history. While this is not the absolute standard that the Bible is, it can give us guidance. For example as we more fully develop a theology of technology we may not have a lot of direct guidance from history. However, what other Christians have written about the nature of work and the nature of vocation can be very relevant to our work.

In summary, Christian engineers work with models both in their professional lives and in their lives of faith. In both cases the models are not perfect. However, they are precise enough upon which to base your life.

References

ASME Code of conduct


Christianity today article at this site:


On the significance of the biography and thought of Pilgram Marpeck for a responsible engineering perspective

Karl Heinz Kienitz*

Abstract: In the general scope of an aspirational approach to engineering practice and ethics, this article follows the paradigm of learning from biography and presents Pilgram Marpeck, an engineer and Anabaptist reformer of the 16th century, as a possible early role model for the engineering professional. A biographical review of his life and all-encompassing participation in the society of his time is followed by a self-contained summary of his thought on selected topics. When considering the bearing of these on engineering ethics and practice, Marpeck's thought and several of his concerns are found of current relevance.

Responsible approaches to technology have been investigated and discussed in and outside the engineering community for decades. As an example of discussion started in the engineering community, one may recall the one at Calvin College during the 1980s which resulted in the publication of Responsible Technology [1], a book frequently addressed in the literature as RT. As an example of discussion initiated outside the engineering community, one may cite the one entailed by the proposal of theologies of technology. Its significance for engineers has been pointed out in work done by the engineer and theologian Paul Heidebrecht (see [2] and references therein).

Discussion and debates on responsible approaches to technology are ongoing. The IEEE International Symposium on Ethics in Engineering, Science, and Technology, a major annual meeting of the world's largest professional association for the advancement of technology, the Institute of Electrical and Electronics Engineers (IEEE), is devoted to topics related to responsible technology and engineering practice. A regular meeting of related programmatic scope, smaller in audience and strongly connected to Christian faith traditions, is the biannual Christian Engineering Conference. Important conferences with connections to other faith traditions have also been held, e.g. the 2011 Petroleum Institute Conference on Engineering Ethics, in Abu Dhabi.

Results of such discussions have been: (a) a consensus that the ethical behavior of the engineer lies at the foundation of responsible technology approaches; (b) the adoption of codes of ethics by most engineering societies and professional engineering organizations; and (c) the inclusion of engineering ethics courses into the curricula of most engineering schools. Mainstream textbooks, such as those by Harris et al. [3] and Fleddermann [4] have experienced successive editions, evidencing the stabilization of concepts and approaches in engineering ethics. Though it is generally acknowledged that most ethical principles related to engineering practice come to us filtered through a religious tradition, these principles became cultural norms

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in Western society and are widely accepted regardless of their origin. For this reason, ethics courses in engineering schools often do not refer explicitly to religion.

The main approaches to engineering ethics are prescriptive, either prohibitive (i.e. what shall not be done by the engineer) or preventive (i.e. how can ethical problems be anticipated or avoided by the engineer). Both approaches have normative character and rely on a vocabulary of rules. However, many engineers embrace professional standards and goals for themselves that are not necessarily shared by all engineers. This is referred to as an aspirational approach to ethics and, as noticed by Harris et al. [5]:

- has a strong motivational aspect (that of doing good), which is not necessarily present in a perspective that focuses on prohibitions and avoidance of wrongdoing; and
- uses a vocabulary of character rather than that of rules.

The contribution of this article lies in the general scope of aspirational approaches to engineering ethics. It follows the paradigm of learning by biography, a paradigm well explored in education for leadership, but widely neglected in engineering education. A historic figure of the 16th century, rediscovered in the 20th, is portrayed herein and briefly presented as a possible early role model for the engineering professional: Pilgram Marpeck, an engineer and Anabaptist reformer noteworthy for his motivation and all-encompassing participation in the society of his time.

The remainder of this article is structured as follows. The next section is dedicated to preliminaries and further motivation. A section thereafter is devoted to biographical information on Pilgram Marpeck. Then follows a section that conveys Pilgram Marpeck's perspective on issues relevant to the understanding of his thought and life, which stood out for an all-encompassing societal engagement into which his engineering activities integrated without boundary distinction. A concluding analysis and final comments are found in the last section.

Preliminaries and further motivation

At the beginning of aspirational considerations pertaining to the engineer, it is important to characterize engineering and worthy goals of the engineering activity.

Kemper and Sanders [6] attribute the following characterization of engineering to the ABET\(^1\): “Engineering is the profession in which knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.” This characterization is compatible with a more literary one found in the memoirs of Herbert Hoover [7], who adds, though, two important aspects not considered in the characterization above: (a) creativity is required, “for engineering without imagination sinks to a trade;” and (b) administrative and organizational work is also part of an engineer's job.

In his memoirs, Hoover writes on life improvement as goal and possible outcome of the

\(^1\) ABET: Accreditation Board for Engineering and Technology
engineer's activity. He also points out the societal challenges it entails:

“There is fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life... Every time he [the engineer] discovers a new application of science, thereby creating a new industry, providing new jobs, adding to the standards of living, he also disturbs everything that is. New laws and regulations have to be made and new sorts of wickedness curbed.” [8]

In an article entitled “Do Engineers Improve Lives?” [9], Doug Lamm considers “improving lives” as providing an increase in satisfaction to the user of a technology or engineering solution. Satisfaction is understood by Lamm as having two components: pleasure and comfort. He concludes that “improvement” will depend on the potential of the engineering solution or technology to provide pleasure and comfort, but also on the user's wisdom when (s)he puts the new solution or technology to service. Lamm does not address the societal challenges in (re)defining pertinent legislation and regulations.

Jeremy Van Antwerp [10] explicates a much more refined goal for the engineering activity than Lamm does. It is based on the Judaeo-Christian tradition and defines the outcome of “improving lives” in terms of the Biblical “shalom” concept, meaning peace, harmony, completeness, prosperity, and welfare. Many engineers hold the view, expressed by Hoover, that in engineering nothing is free from moral nuance: a technology, design or solution will either promote good ends, or bad ends, or some of both. It makes engineering design a normed activity. With this in view, RT [1] introduced a norm based design tool that can help engineers achieving “shalom”-improving designs/solutions. It implements a preventive approach to engineering ethics, being quite compatible with the Systems Engineering approach, and has received much attention, e.g. in many contributions to the Christian Engineering Conferences and their predecessors, the Christian Engineering Education Conferences. However, in [13] VanderLeest points out that

“some authors have identified difficulties with the design norms. Van Antwerp raises a number of important concerns regarding use of the design norms in his 2006 CEEC paper [10], exploring some practical difficulties with using them in actual designs. VanderLeest explored humility as an additional norm needed in technology design in a 2006 ASEE paper [11]. Funk considers the design norms [12] and finds them lacking: 'I find an organization of principles based on a biblical hierarchy of value to be more conducive to thinking Christianly about things. Moreover, in my view, Monsma, et al. omit the most important ones or only address them secondarily.' Instead, Funk identifies three intrinsic, prioritized goods: (1) communion with God (individually and communally), (2) human welfare (based in part on being created in image of God), and (3) natural world (including cultural mandate and stewardship). In reflecting on these proposed priorities, he notes that 'Monsma, et al., RT, give inadequate emphasis to this principle [Principle 1], their principles focusing primarily on the two lower levels of the hierarchy of the good.'”
Van Antwerp recommends “presenting alongside the design norm approach the view that engineers are called by God to serve him and their neighbors and be stewards of the Earth through the technology they create. Engineers are to work as servants of God by serving others. ... The design norm view of trying to foresee all possible ends must be balanced with the reality that God in his sovereignty is in control of all history and through his providence works through us. Ultimately, Christian engineers must act as best they can” [10] (which might include using RT norms). Thus, Van Antwerp continues, a Christian engineer is not interested only in the sources of technical knowledge, but also in modeling Christian virtues and developing a Christian worldview and thoughtful reflectiveness. All of these are elements of an aspirational approach.

The approach to shape the process of judgment and evaluation that underlies engineering activity, summarized by Funk [12] and mentioned above, is particularly suitable for adoption by Christian engineers because it:

- is related to 3 general intrinsic goods, compatible with the Christian proposition;
- formalizes non reflected ad hoc approaches of Christians who understand their faith and engineering practice as integral parts of their life;
- does not lead to overspecialization in the discussion of responsible professional practice, allowing for the appropriation of insights offered by Christians from other professions;
- allows for the identification of role models in history (e.g. Pilgram Marpeck, the one advocated herein) and for appropriating lessons from such role models living under different circumstances; and
- constitues a robust setup that remains unshaken when the professional focus changes.

Furthermore, aspirational approaches are particularly interesting because they usually are of easy extension (generalization) to tasks performed by engineers beyond technical design, e.g. administrative, leadership and coordination tasks, related or not to the development, implementation and operation of engineering solutions. Although administrative, leadership and coordination involvement has been perceived by some (e.g. Hoover) as more recently becoming part of the engineer's job, it can be verified in all larger engineering type undertakings throughout history.

Learning from others and learning from example fits into aspirational approaches to ethics in general and engineering ethics in particular. Becoming a good engineer requires the understanding of the nuances of general and specific technical disciplines, working as a subordinate, peer and supervisor. To understand and successfully tackle such challenges, it is important to study and reflect. Study and reflection with focus on biographies covers many of the general facets encountered in engineering activity, since many of the challenges faced today do not differ from those faced by the men and women who went before us. Learning how they handled their challenges helps to be more effective with those faced by engineers today.

Herein fits the motivation to focus on Pilgram Marpeck for the remainder of this article, “a well-to-do and highly placed Tyrolese mining engineer... whose witness was obscured, his writings misplaced or overlooked.” [14] Only in recent decades has Marpeck's life reemerged.
Because of his views aligned with the radical wing of the Reformation, in early 1528 he interrupted his career as a mining magistrate and – in addition to his work as an engineer – acted as Anabaptist community leader and writer with connections and responsibilities in South Germany, Alsace, Switzerland, Austria and Moravia. Despite persecution, having acquired valued technical abilities and organizational competence through general education, as well as hands-on training and problem solving, he repeatedly held important engineering positions with responsibility in the wood and water supply of the cities Strasbourg, St. Gallen, and Augsburg.

A biographical note

Pilgram Marpeck was born ca. 1495 in the mining town of Rattenberg am Inn, a formerly Bavarian town in the Tyrol that became Austrian in 1504. Pilgram's father Heinrich Marpeck was a wealthy mine entrepreneur who had moved to Rattenberg in the early 1490s from the Bavarian town of Rosenheim. In Rattenberg, Heinrich served as city and district magistrate, later as councilman and mayor. Pilgram grew up in Rattenberg, and – either there or in Innsbruck – attended Latin school where he received a scholarly education discernible in his later writings.

His work life began in 1513 when the Rattenberg council, due to a lack of much-needed help in the city hospital, appointed him to serve there for an indefinite period. He was then about 18 years old. He must have proven himself at the hospital, because soon thereafter he was working for a hospice for disabled and aged miners established by the local Bergwerkbruderschaft, a corporation of the local mining entrepreneurs, into which he was received as a member in 1520. That year, together with a business associate, he started an ambitious, independent business of transporting ore.

Some time before 1520 Pilgram married Sophis Harrer, with whom he had a daughter, Margareth. The couple also took responsibility for three foster children, possibly orphans of men killed in the mines. Sophis died some time before July 1528, when Marpeck remarried.

Possibly as early as 1520, Pilgram became a member of the Rattenberg city council. He served as mayor in 1522 and represented the city repeatedly at Landtage and in negotiations with the government in Innsbruck.

In April 1525, Archduke Ferdinand of Habsburg, the ruler of Tyrol, appointed Pilgram as magistrate of the Berggericht Rattenberg. This was a salaried function, akin to that of a mining superintendent. It included the responsibility for: (a) adjudicating the rights and claims of the miners, investors and nobles; (b) the care of widows, orphans and retired miners in the community; and (c) the representation of Tyrolean government interests in the local mining activities. Pilgram's jurisdiction extended over Rattenberg and Kufstein with their mines, smelting works and forests (since lumber and firewood supply was essential for mining activities).

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2 Biographical information in this section stems from references [15]-[18].
3 Representative assemblies of cities.
In the Rattenberg City Council, Marpeck was involved in efforts to obtain the release of Stephan Kastenbauer, the prior of the local Augustinian monastery, who was arrested in 1522 for preaching “heretical” sermons inclined towards Luther's teachings. Apparently this was when Marpeck became aware of theological concerns related to the early Reformation movement. However, more defined expressions of the Reformation became noticeable in Rattenberg only in 1527, when the former Franciscan monk Leonhard Schiemer won followers in the Inn Valley for the Anabaptist movement initiated by Hans Hut. Marpeck apparently knew about an Anabaptist church that already existed in Rattenberg during the imprisonment of Schiemer, who was arrested in Schwaz, on November 25, 1527. By order of the Innsbruck authorities, Schiemer was executed in Rattenberg on January 14, 1528, on the castle yard behind Marpeck's house. Although Pilgram had no direct connection with Schiemer's process and execution, it fell into his jurisdiction to report to the Innsbruck authorities on the Rattenberg Anabaptists. To evade this task, Marpeck resigned his office by January 22, 1528, arranged his affairs and left the city. As a widower, and presumably because of his uncertain future, he entrusted the guardianship of his daughter to close Rattenberg relatives. Marpeck's Rattenberg properties were confiscated in 1530. If Margareth returned to her father's home in later years is not known, though likely.

From Rattenberg, Pilgram moved to Krumau in Bohemia, then a prosperous silver mining center, which attracted numerous miners from the Tyrol. There is evidence that in Krumau he was rebaptized, married Anna, his second wife, and was commissioned into church leadership by the Anabaptist church from Austerlitz, Moravia. Already in June and July 1528 he was on record, together with the former priest Virgil Plattner, in relation to the founding of an Anabaptist congregation among the miners. Forced to leave Krumau, Pilgram moved to the religiously tolerant Strasbourg, the main city in the Alsace, apparently commissioned to work on church unity between the Strasbourg and Austerlitz Anabaptists.

In Strasbourg, Pilgram joined the gardener-wagoner guild, and acquired citizenship on September 19, 1528. To acquire citizenship, it was necessary to reside in Strasbourg, be registered with a guild, pay citizenship tax and annually reaffirm the pledge of loyalty and obedience to the city council. Marpeck's decision to join the gardener-wagoner guild may have been motivated by his logistics experience in Rattenberg. By joining this guild, the largest and poorest among the guilds in Strasbourg, he became institutionally connected to the laboring people in the city and entered a circle that was most likely to give him a hearing, since the gardener-wagoner guild was one of the most prominent in the course of the early Reformation in Strasbourg.

Shortly after settling in the Alsace, Pilgram joined efforts to assist and shelter refugees who had come into Strasbourg. He also led a local Anabaptist community, and wrote and debated intensively on theological topics. This was all integrated with full professional activity. Strasbourg authorities had become aware of his technical competence and hired him early in 1530 as Holzmeister, i.e. as a municipal engineer with responsibility for managing the purchase of harvesting rights and the supply of wood. He apparently spent a substantial period in the Kinzig and Leber valleys securing and organizing Strasbourg's supply of firewood and timber, which was floated down the rivers towards the city. Furthermore he took part in the establishment of Anabaptist communities in these areas, and maintained pastoral correspondence.
with them over many years.

Strasbourg's departure from its policy of tolerating religious dissidents had the consequence that Marpeck was forced to leave the city in January 1532, after several weeks of investigation under the direction of the local leading reformer, Martin Bucer.

Evidence suggests that after leaving Strasbourg Pilgram and Anna settled in Switzerland somewhere between St. Gallen and Appenzell. In St. Gallen, Marpeck was involved in work on a system of water flumes for the local weaving industry. It is likely that this was connected to the conversion of a house and barn into a fulling mill, decided in 1535 by the St. Gallen city council. The conversion entailed the construction of water channels to divert water around a nearby mountain, in order to service the mill and to supply drinking water to the city.

The few references to Marpeck's whereabouts during the years following his expulsion from Strasbourg indicate that he remained continuously in touch with the Austerlitz Anabaptist church in Moravia. Several of his letters and edifying tracts of these years survived. Those writings reflect the clandestine networking of Anabaptist communities that stood in ecclesial communion with the Austerlitz mother church and extended from Grisons to Württemberg and from Alsace to Moravia and Vienna. To Marpeck apparently fell the task of maintaining the links between the communities. Thus, already in 1540 he traveled from Austerlitz to Grisons and directed letters from there to congregations in the Alsace area. But in 1541 he was back to Moravia, where he joined an effort to reconcile the Austerlitz Anabaptists and the Hutterian Brethren. During all this time, Pilgram also invested much of his time into a theological controversy started in Strasbourg with Caspar Schwenckfeld, a main representative of the Reformation current of radical religious subjectivism, known as “Spiritualism.”

From February 1544 until his sudden natural death sometime during the week between October 31 and November 6, 1556, Marpeck's resided in Augsburg. There he took a leading role in some of the city's most important public works. As a city employee and member of the city's building committee (Geschworene Werkleute), he oversaw and often coordinated important projects and operations related to the city's wood and water supply. At the same time, he secretly kept Augsburg's Anabaptist community life intact, and through letters and messages supervised and instructed the far-flung communities of the network of Anabaptist communities in which he participated.

A close-up on selected aspects of Pilgram Marpeck's thought

Although Marpeck's eclectic contribution to society was already thematized by Bender [14], it was Paul Peachey who first pointed to Marpeck as a role model in combining profession and faith [19]. His basic identity is anchored in Christ's order and Christ's people, which resulted in world affirmation: he designed engineering solutions, addressed social welfare challenges, and participated in the central religious discourse in the city. While he took covenantal responsibility in the civil as well as the religious realms, for the sake of his Christian commitment Marpeck was willing to sacrifice the security and prestige provided by his technical occupation. Furthermore, he illustrates the reciprocal character of freedom and covenant; to make their
interdependence clear is a particular vocation of every Christian. In addition, implicit in the idioms, which Marpeck embodied, we find a free church within a society that depends upon covenanted individuated action – a structured reality seen today.

Many writings of Pilgram Marpeck surfaced throughout the 20th century. In many if not most of them, Marpeck addressed Christian life encompassing all aspects and realms of daily life, which included his professional activities and challenges. The following paragraphs convey a summary of his thought on topics with special bearing to the Christian engineer.

*Gifts are given for the glory of the Creator and to serve others*

God is the giver of all gifts. They are given for two chief reasons. Firstly, in them we can learn to know God as Creator and Father so that we may glorify, praise, and thank Him. Secondly, we are not to use His gifts to rule over each other, but to serve each other. And, if in doing so we accomplish something to the Lord's praise and the neighbor's benefit, we do not rejoice over it. The very deed of showing love towards our neighbor with unshakable faith and certain hope, shall be our highest joy and the way we prove our love of God. [20]

Since everything has been given to us for service and to convey God's inexpressible goodness and grace, nothing should be capriciously wasted as if such were at our discretion. The reason we serve to the praise of God and not to indulge ourselves, is that the Lord Himself has served us. Hence, whoever does not serve in the voluntary spirit of Christ – even to the loss of her/his life – the same pursues his own satisfaction, reward or honor. To all his servants God promises reward and heritage with Christ. But His servants do not look to the reward as though it could be earned with their service; they look alone to the Giver and Rewarder. [21]

*On the intertwining of faith, love, God and human action to serve all creatures*

Witness, fruit, and work are manifestations of faith. Thus, love is faith in action; it edifies and improves. However, the power of love is available to us only to the extent it is given by God, and to the extent, we receive it.

Furthermore, the life and deeds of all true believers serve all creatures. Through Christ, their spirit is lord of all things, because whoever believes that all authority has been given to Christ moves, speaks, and acts by the authorization of Christ. For Christ never commanded: “Go forth, all power be committed to you;” rather, He instructed: “To me all power is given – therefore go forth.” [22]

*Reason and will seen with skeptical optimism*

Reason is a valued function of the human spirit, which Marpeck described as “a sensitive, sublime creature” and an “image of humanity's godlikeness.” However, reason “presumed to be a god” who “can be saved or condemned by her own power.” Marpeck's critique referred not to reason as created by God; he targeted its use by men in the hopeless search for ways to attain their own salvation, an arrogance, which was most pronounced among educated classes, who
despised “simple, uneducated, coarse, faithful people.” In Marpeck's perspective, salvation required that reason be humbled at Jesus' physical feet. [23]

The will, like reason, is a function of the spirit and admirable as created. Yet Marpeck criticized those who conceded “all power and ability to man's free will.” [24]

On the trust in human power

Exclusive trust in human power is “contrary to the true manner of the patience of Christ.” [25]

Means and wealth

Means and wealth may be gifts to serve others, however grasping is reprehensible and their ungodly handling gives way to injustice and suffering. Marpeck's position herein is aligned with that of Hans Denck (c. 1495-1527), who criticized poor as well as rich for grasping after wealth rather than preparing their hearts through Gelassenheit for Christ's filling [26], and with that of Peter Riedemann (1542-1556), who maintained that God is reflected in creation but that humans misuse creatures, seizing them for their selfish purposes [27]. In an anonymous tract attributed to Marpeck, we read: “It is the fear of losing possessions that deceives the whole world. It is that fear which binds up the love of God and the love of man on the earth. If Christ must leave, as he left the village of the Gadarenes, unrighteousness takes over. Love grows cold. Selfishness takes over and all men suffer.” [28] This detached but responsible standing lies at the foundation of Marpeck's successful enterprises and his concern with the socially weak or disadvantaged.

What drives us?

Serving others was one of Marpeck's chief concerns, and probing the motivation or drive underlying service became foundational to him. We see his concern with motivation extending to all individual action. He found it most important to recognize “whether our actions are impelled by the Holy Spirit, or flow from a carnal mind.” For instance, it happens quite often that natural impulse is against evil and zealous about the good. There are situations when men are overpowered and driven by zeal, exerting themselves considerably. Such is not a compulsion of the Holy Spirit, it is a servile compulsion. Thus, one should be able to perceive one's drive, or better from what source it stems. [29]

To inform perception, Marpeck suggests four criteria, which concern the practical, ethical life of the Christian rather than an application of specific passages of the Scriptures. However, Marpeck did not separate these domains: Scriptures were to be studied for practical application [30]. The four criteria (“things, or reasons” as Marpeck calls them) are:

1. Love for God and granting my neighbor that which God has granted and given me.
2. A devaluation of life and willingness to suffer for Christ's and the gospel's sake.
3. The (spiritual) discernment of God's open doors and refraining from entering where God has not opened the door.
4. Freedom and soundness in teaching and judgment and in truth (i.e. no mingling with interests incompatible with the realm of Christ).

Our relationships and reactions

In his later years, possibly after the unsuccessful effort to reconcile Anabaptist groups in Moravia, Marpeck became increasingly aware of the importance of neither taking nor giving offense or scandal. Diligent attention is needed in order that “our earthen vessel does not cause offense to anyone else. Otherwise, our own or our neighbor's vessel might be broken.” [31] Marpeck points out that arrogance, conceit and “room and place to the lust of the flesh” will entail such breakage.

An invitation

Aligned with a typical Anabaptist understanding of the missional dimension of God's new creation [32], Marpeck emphasized the all-encompassing reach of the Gospel's invitation, message and effect: “We invite all creatures to rejoice with us and to sing praise to our God.” [33]

Practicing it

Marpeck took all of his teaching on personally, as he explicitly states in his Confession, presented to the Strasbourg city council on January 18, 1532: “I have surrendered to God and all true believers, and try to serve all men with whatever I have and can accomplish through His Son Christ Jesus. I am prepared to show human love to everyone according to the word of Paul [34], to serve everyone from the heart and not to hurt anyone's feelings. If I have, unaware, not followed these strictures, I ask for forgiveness from everyone. However, I will in matters of faith, God willing, not yield to anyone for the sake of love.” [35]

Government

In Anabaptist circles, relationship to government has always been a subject of intense debate, very often bottomlined by some obedience formula. For engineers this is an important issue, since many engineering undertakings and/or solutions are either paid or regulated by government, or sometimes they imply other direct or indirect government involvement. Marpeck addressed the issue several times, e.g. in his Confession presented to the Strasbourg city council, wherein he admits civil authorities “as servants of God, in earthly matters.” [36] Taking into account this and his other known writings, it seems that Marpeck generally endorsed participation in government's socially beneficial functions, without including coercive ones [37].

Comments and conclusion

As put in an earlier section, aspirational engineering ethics can be shaped through study of biographies, which is the reason why Pilgram Marpeck’s life and aspects of his thought were outlined. Marpeck did not write down specifics about his engineering practices. This is not
surprising, since it was in the year of Marpeck's death that the first modern document on mining and metallurgy, *De Re Metallica*, by Georgius Agricola, was printed, inaugurating a time of writing in engineering. It is evident, however, that many of his writings convey considerations and principles that are readily transferable to statements of value to the engineer. Marpeck took all of his teaching on personally, as made explicit in his Confession, presented to the Strasbourg city council, and in other aforementioned texts, which adds to his credibility. Furthermore, Marpeck in his approach and writings “unites the social and ethical dimension of the Christian life with the personal and spiritual, suggesting ways of creatively combining them.” [38] Thus, in this conclusion section, contents of the main sections, those on Marpeck's life and thought, are revisited with concluding remarks about their bearing on engineering activities.

Regarding practical life, Marpeck emphasized that gifts are given for the glory of the Creator and to serve others. Such understanding set a double perspective for all his activity, including his engineering work: the spiritual perspective of praise (directed towards God) and service to “the benefit of the neighbor” (directed towards men). An important nuance Marpeck gave to the second perspective is that serving itself should be taken as ground for joy, rather than the outcomes or successes attained by serving. Marpeck's considerations nicely fit into the general perspective of engineering as a serving profession explored by Van Antwerp [10].

With respect to empowerment of individual action, Marpeck emphasizes that a Christian's work is part of the manifestation of his/her faith. Deeds will express love, which is “faith in action; it edifies and improves.” [39] But the power of love does not stem from men: it is God given.

Although Marpeck for obvious reasons did not refer to 20th century concepts such as environment and sustainability, his emphasis is remarkable that “the life and deeds of all true believers serve all creatures.” [40] A concern for all creatures is most appropriate to inform and balance engineering activity, so often accused of lacking concern with creation at large.

Reason and will, two of engineer's most remarkable tools, are seen by Marpeck as admirable, but limited. In particular with respect to reason, he understands that humility is in place. Absolute trust in the power and the abilities of reason and free will, Marpeck critiques. Not surprisingly, elsewhere a correct blend of skepticism and optimism with respect to individual engineering problem solving capabilities is seen as the best possible posture (the so called “skeptical positive thinking” [41]), specially at the engineering project management level.

The solution of engineering problems requires means and material resources in addition to “imaginative faculties.” [8] For Marpeck, means and wealth are gifts to serve others; grasping after wealth is reprehensible. His successful enterprises and his concern for the socially weak or disadvantaged exemplified the practical consequences of his understanding. Typically, an understanding such as Marpeck's will entail socially responsible decisions with respect to the use of resources; those are demanded in many major engineering undertakings.

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4 A perspective linking engineering and doxology is discussed by Paul C. Heidebrecht in [2], chapter 5, without mentioning Pilgrm Marpeck.
On a more personal side, Marpeck’s comments on personal relationship and reaction to others – in particular on giving and taking scandal – are instrumental for life in community and teamwork, both highly valued in contemporary engineering, were multidisciplinary teamwork and the need to focus on customer demands and necessities has become commonplace.

Finally, the recognition of what drives us came to be of special concern to Marpeck in the later years of his life. He suggested four criteria related to the practical ethical life of the Christian, independently of her/his trade or profession. These criteria were chiefly formulated on spiritual grounds, envisioning a Christian's spirituality and practical life – including pragmatic professional concerns – as connected. The whole can also be taken as a warning and guide against unreflected behavior and “exerting oneself considerably” in the pursuance of what one may – personally and impulsively – consider worthy goals. Such concern presently is found in the engineering community. It underlies, for instance, the following promise, found in an engineering’s professional pledge commonly used in Brazil: “In fulfilling my duties as engineer, I will not permit to be carried by the glare of technology.” [42]

In this text Peachey's proposal of Marpeck as role model for the Christian professional was taken one step further. The consideration of Marpeck's thought from the perspective of his vocation laid open important insights of value to engineers concerned with aspirational ethics. In a broader sense it also serves as a call to reflection on relevant issues pertaining to Christian life, which – depending on the trade or profession – may or may not include engineering activity.

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References


[34] Gal 5:13


A Case Study of Integrally Christian Engineering

By Justin Vander Werff*

Abstract

Engineering programs at Christian colleges typically focus primarily on undergraduate education. Likewise, faculty members drawn to Christian engineering education tend to have a strong desire to disciple young men and women in what it means to be faithful Christ followers in engineering. Consequently, engineering faculty tend to work long and hard to provide a solid education experience, leaving little time for anything else. However, institutional demands on faculty typically extend far past teaching, and one area that inevitably pops up in growing Christian engineering programs is research and scholarship. What is the place of research in a Christian engineering program? Does it have a place at all? And what should Christian engineering research look like? These are big questions, and a simple paper like this one cannot provide an exhaustive answer. However, as a baby step, this paper will examine a Christian lens through which engineering scholarship can be viewed and critiqued. This lens consists of five guiding principles for engineering that were developed based on the Creation-Fall-Redemption paradigm and presented previously1. Using these guiding principles, engineering scholarship that was conducted in a typical university research format and published in a traditional engineering journal2 will be carefully examined and critiqued. In doing so, my hope is that a bit of light will be shed on what integrally Christian engineering scholarship looks like, and that this understanding might provide insight on answering other questions in regards to research and scholarship in Christian engineering programs.

Introduction

Dordt College’s “Founders’ Vision,” prominently displayed on our campus clock tower, states:

“An education that is Christian not merely in the sense that devotional exercises are appended to the ordinary work of the college, but in the larger and deeper sense that all the class work, all of the students’ intellectual, emotional, and imaginative activities shall be permeated with the spirit and teaching of Christianity.”1

From its inception, our engineering department has been passionate about articulating what this vision means in the engineering profession and then seeking to instill it in our students. In fact, on a personal level, my passion for this vision was one of the main reasons I decided to venture away from my several years of service in the engineering industry and instead enter the world of engineering academia. I had the strong desire to help more young Christian men and women understand this vision, particularly how it plays out in engineering. However, another reason I made that decision was out of a recognition that, despite my passion for this vision, I still didn’t have a complete grasp of the implications it had for engineering. I was eager for the opportunity

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to contemplate and study more carefully what engineering that is completely “permeated with the spirit and teaching of Christianity” looks like.

After several years, including several papers and presentations in the process, I have come to a couple of conclusions in this regard. First, on this side of eternity, I will never completely grasp what truly integral Christian engineering looks like. I certainly understand more particulars about what Christian faithfulness in engineering looks like, and I hope that in small ways I have contributed insights in this conversation, but I will not reach the pinnacle of this study. Second, although I will not attain the climax of this work in this life, I can joyfully continue in the confidence of Christ, knowing that He has already attained the ultimate victory and that He calls me to faithfully and responsibly serve as His hands and feet in His continuing work. In this paper, I pray that I can flesh out in a small way the beginning of what distinctively, integrally Christian engineering looks like by way of critiquing a bit of my engineering work over the past several years.

**Guiding Principles: A Framework for Critiquing Christianly**

In order to begin to recognize what distinctively, integrally Christian engineering looks like, we need to recognize that we do engineering, as we do all of life, in the metanarrative of Christ. Often this narrative is described as “Creation-Fall-Redemption,” recognizing that God created us and all things good, that human sin changed everything, and that Christ has paid the price for sin and continues to reconcile us and all of creation. To help recognize what implications the Creation-Fall-Redemption metanarrative has for engineering, five guiding principles have been developed:

1. God created us and all things for His glory.
2. Our two-fold (but singular) mandate is to develop and keep God’s creation.
3. We are creaturely and finite; we are not saviors.
4. As Christ hands and feet, we are involved in the alleviation of both human and non-human suffering.
5. We live in the already and not yet of Christ’s reconciling work.

These principles have been developed not as the only Christian approach to engineering but as one framework that can provide guidance in discerning how to engineer in a way that is integrally Christian. The principles were developed as an outworking of the Creation-Fall-Redemption narrative. Since their development, they have been used as a way to evaluate the content of our engineering curriculum and the effectiveness of our curriculum. As we have continued to exercise these principles in our curriculum, we continue to appreciate how this framework provides a usable means for Christian critique of engineering and technology.

**Integrally Christian Engineering Scholarship**

As those of us involved in academia know, there is far more involved in education than simply teaching and curriculum. Accordingly, if we want the engineering education we provide to be integrally Christian, we need to consider and critique far more than simply our teaching and curriculum. Given the usefulness of the guiding principles as a tool for critiquing curriculum, it
seems appropriate to try out their effectiveness as a mechanism for Christianly critiquing other aspects related to engineering.

One of the first areas that comes to mind is engineering scholarship. If done well, scholarship alongside quality undergraduate education can be a win-win, providing faculty an opportunity to dig in to their areas of expertise, giving them an opportunity to provide wise insight that can make a difference in others’ lives, and providing their students deeper and more authentic learning experiences. Of course, doing scholarship well, in a way that enhances our educational mission rather than detracts from it or dominates it, is much easier said than done. What is the place of research in a Christian engineering program? Does it have a place at all? And what should Christian engineering research look like? These questions have no easy answers, and a single simple paper will not provide a decisive conclusion. However, to provide a starting point for answering such questions, the following sections of this paper take a published piece of “traditional” engineering research and examine it through the lens of the five guiding principles.

Background: “Girder Load Distribution for Seismic Design of Integral Bridges”

The research work considered in this case study is presented in the paper “Girder Load Distribution for Seismic Design of Integral Bridges.” This paper was published in the ASCE Journal of Bridge Engineering in 2014. This journal is published by the American Society of Civil Engineers (ASCE), the professional society that is the gatekeeper of civil engineering infrastructure in the United States and around much of the world. The paper developed a comparison of how several different large scale experimental studies predicted that seismic load would travel through a particular type of bridge superstructure. It then went on to develop a simple analytical model that provided a relatively reliable technique of predicting this load distribution that was much simpler than the extensive experimental studies or even other fairly complex computer analysis techniques that had been used previously.

At first glance, this paper seems like any other technical research paper, so it may seem strange to try to critique this work from a Christian perspective. In fact, some might say that work like this paper is neutral, and it is silly or even misguided to Christianly critique it. However, if we are to take seriously the teaching of God’s Word that “[t]he earth is the Lord’s and the fullness thereof,” (Psalm 24:1) and that God cares about reconciling “to himself all things, whether on earth or in heaven,” (Colossians 1:20), I believe that we should be challenged to view every corner of the creation through a biblical lens. So, using the five principles as a framework for focusing that biblical lens, let’s dig into the ASCE paper a little deeper.

The Case Study: Walking through the Five Guiding Principles

The first principle states that God created all things for His glory. There are at least two possible approaches to critiquing a particular engineering work in light of this principle. One approach would be to critique whether the work specifically acknowledges being done for God’s glory. Unfortunately, most technical journals would quickly edit such motive-related material on the basis of the far-too-commonly-accepted dualistic separation of “faith” and “fact” (or perhaps we could say “motive” and “method”). There is no specific mention of God or His glory in the ASCE paper, so by this approach, this paper fails on this principle.
However, another approach for using the first principle would be to evaluate the underlying motive behind the work. For a neutral third party, this sort of critique would be difficult, if not impossible. However, if you are applying the principles to your own work, it is a little easier to self-critique in this area. For myself, I hope it is not too presumptuous or boastful to say that I truly do believe I have done all my engineering work, including the work related to this paper, to God’s glory. His Spirit continues to convict me that His glory is the only motive worth striving for.

Prior to moving onto the second principle, and as a brief aside, I think it is worth mentioning that the overall obedience and normativity of a particular engineering work does not necessarily hinge exclusively on whether it is done in accordance with the first principle. John Calvin, in Chapter 2 of his *Institutes of the Christian Religion*, drives this point home in the following quote:

“In the reading of profane authors, the admirable light of truth displayed in them should remind us that the human mind, however much fallen and perverted from its original integrity, is still adorned and invested with admirable gifts from its Creator. If we reflect that the Spirit of God is the only fountain of truth, we will be careful, as we would avoid offering insult to him, not to reject or condemn truth wherever it appears… If the Lord has been pleased to assist us by the work and ministry of the ungodly in physics, dialectics, mathematics, and other similar sciences, let us avail ourselves of it.”

We should not expect that someone operating from a non-Christian worldview can never produce an obedient idea or design, just as we should not expect that a Christian is guaranteed to produce a good, obedient design. However, that is why the five guiding principles are helpful, because all five principles help together to provide a framework, rather than simply a single criterion all by itself.

Let’s return to the ASCE paper, considering the second principle related to working and keeping God’s creation. Proper understanding of this principle may drastically affect the direction of a project. Do we approach a project from a humanist standpoint, where we are the dominator of the earth and its resources and they simply exist for us to exploit to our benefit? Or do we approach a project as a worshipper of the undeveloped creation, believing that it should be left untouched and unused? The proper posture realizes that either of the previous approaches are idolatrous, but that God’s mandate to us is to use His good creation in a stewardly way to His glory and our neighbors’ good, not worshipping either humankind or the undeveloped creation but recognizing that both are part of His creation and under the kingship of Christ. The book *Responsible Technology* provides valuable insight into how to approach engineering design normatively, so I will refrain from diving into that here. However, I do want to spend a bit of time looking at how the work in the ASCE paper recognized (or ignored) the single, two-fold mandate to develop and keep.

The meat of the work related to the development of an easier-to-use and analytically improved approach to predicting how seismic load travels through a bridge superstructure. The benefit of the improved model was two-fold. First, an analytical approach that was simpler than time-consuming, complex, and expensive computer models was more likely to be used by bridge engineers who might have otherwise might skipped the analysis. Second, an analytical approach that predicted
the load better made it more likely to design the superstructure more efficiently. Both benefits allowed a more stewardly use of resources (both time and material), fulfilling the “keep” portion of the mandate, and both benefits helped provide a safer design, fulfilling the “develop” portion of the mandate in a loving way that respects life but also provides usable infrastructure.

The third principle recognizes that as humans we are creaturely and finite. The work in the ASCE paper did well in this area, because a large part of it was devoted to recognizing that we would likely not find the perfect analytical model. Subsequently, it sought after a model that would be reasonably close to observed behavior and be able to provide a safe and stewardly design approach while recognizing that the model is simply a model and not a perfect predictor. An engineer coming from a humanist worldview might have a hard time accepting an imperfect model, even if the model is very well-suited to do what it is intended to do. However, a Christian who recognizes their fallibility and creaturely-ness can humbly use such a model carefully and appropriately to serve in particular circumstances.

The fourth principle recognizes that suffering happens both in the human and non-human creation. Working with earthquake loads seems to do well with this principle almost automatically, because there is a general acknowledgement of the uncertainty of time, place, and magnitude of earthquake loads, but then there is also an acknowledgement of the suffering people may go through because of an earthquake. At its heart, the work in the ASCE paper was devoted to developing safer structures that help prevent human suffering in the event of an earthquake, clearly recognizing the first part of this principle.

However, a critical critique could be made regarding how this work considered the suffering of the non-human creation. While this portion of this principle might be the most ambiguous of any of the five principles, at its heart it recognizes that Christ is reconciling everything to Himself, both us as His people but also the creation as it groans under the effects of sin. Perhaps another aspect of this principle that has not been fully fleshed out could be related to how we are called as humans to unfold the potential in creation, using language similar to what Leonard Kalsbeek introduced following in the intellectual tradition of Herman Dooyeweerd. The work in the ASCE paper is certainly involved with unfolding potential, as it helps use material resources to produce a safe bridge that provides a particular function. However, the work is at best ambivalent toward the harmony of the bridge with its surroundings; it does not address the aesthetic aspects of the bridge at all and it does not consider the interaction of the environment surrounding the bridge, other than during an earthquake event. The work could perhaps have been improved if a bit more time and effort could have been devoted to this line of thinking.

The fifth and final principle recognizes the “already and not yet” character of the era in which we currently live. This principle is similar to the first principle, in the sense that it is probably rarely specifically articulated, but yet likely lies at the heart of most engineering work that grows out of a Christian worldview. In this particular situation, the motivation for seeking to improve the seismic design of bridges is not to save the world or to create a humanistic utopia. The motivation is rather the recognition that, out of love for neighbor, we as engineers can do better at protecting people’s lives during earthquake events. Consequently, we strive to do such work out of grateful obedience for what Christ has already done for us. In addition, we do this work knowing that Christ
has purposes far greater than ours, and that He will use our work as He wills to build His kingdom. This knowledge can give us great hope and confidence. It takes the pressure of being a “savior” off our shoulders, which is a burden that many secular engineers bear. We also experience a great sense of fulfillment when we recognize that Christ uses us as His hands and feet in His work. He is, right now, reconciling His kingdom to Himself (cf. Colossians 1:20). This kingdom is not just an ethereal kingdom of a different realm but is a very tangible, physical, earthly kingdom that may very well look a lot more like our present world and life than we expect while at the same time looking far different than we could ever imagine.

**Possible Case Studies to Consider in Future Work**

The ASCE paper has been briefly considered in light of the guiding principles as an example of critiquing “traditional” engineering work through the lens of a biblical worldview. Prior to making specific conclusions related to this critique, brief consideration is given here of other possible case studies that could be helpful in future work.

“A cost-effective integral bridge system with precast concrete I-girders for seismic application”

One possible case study would be the work presented in “A cost-effective integral bridge system with precast concrete I-girders for seismic application,” published in the September-October 2015 issue of *PCI Journal*. This paper presents related work to the work in the ASCE paper discussed above; however, it focuses more on the experimental portion of the study. As such, a case study of this work could flesh out unique aspects of both the work and the principles, helping to provide an integrally Christian lens through which to view large-scale experimental research.

**Involvement in the ASCE Iowa Section**

Another interesting case study would be the work of our institution’s ASCE Student Chapter and the professional involvement of Christian engineering faculty in ASCE. The student chapter is a part of the same ASCE organization that produces the journal that published the paper considered for the case study in the preceding section. The student chapter operates under the oversight of the regional ASCE section, which has a membership of over 800 practicing engineers and also oversees the student chapters at two large state universities. The ASCE organization is, in many ways, the direction-setter for civil engineering infrastructure across the country. Our student chapter provides a unique connection for students to begin to see how they can be difference makers in the 21st century, and a careful study of this work through the lens of the five principles would likely bring new insights and help us to utilize this resource even more.

**Externships**

The past couple of summers, engineering students from our institution have participated in summer research “externships.” These externships would be fascinating and likely very helpful case studies. In these externships, the students provided local companies with structural engineering insight under the advisory capacity of engineering faculty members. At the surface, the externship experiences might seem like run-of-the-mill technical work; however, an examination of these opportunities in light of the five guiding principles might reveal unique ways that God has used...
them. Such consideration might shed light on how these opportunities did well in reflecting Christ and His work but also how future opportunities could be improved in doing so.

Conclusion

This brief work of considering the case study of the ASCE paper through the lens of the five guiding principles has been valuable. While the principles have been implemented and discussed already for a few years with students for big-picture thinking, this case study is the initial attempt at applying them to a particular engineering work. Doing so has increased my conviction that they can provide valuable insight into what it really means to do engineering in light of Christ’s Creation-Fall-Redemption story.

After walking through this case study, it seems that in their current form the first and fifth principles have a slightly different character from the other three principles. While the second, third, and fourth principles can be directly related to engineering decisions and particular forms of technological projects, the first and fifth principles seem to do better describing the posture of the Christian engineer who is engaging these projects. There is an appropriateness in the principles encouraging both direction and posture in considering whether work is integrally Christian. Direction is certainly important, in recognizing that responses that are obedient and faithful to Christ’s work and fall may indeed look different than disobedient, selfish responses, and these responses may have a direct impact on the work we do and the projects we create. However, posture is also very important, as we recognize in accordance with the insight from Calvin provided earlier that non-Christians may produce “good” work in the sense that it is true and productive, even though it was produced without a recognition of Christ and His ultimate truth. The five principles are helpful in providing guidance in both the posture and direction of engineering work.

This walk through the five principles has also shed light on possible limitations. In particular, the principles in their current form do not highlight our task as humans to unfold the potential of creation as Christ’s hands and feet in His ongoing creative work. The second principle hints at this important mandate, but it focuses more on the two-fold mandate to develop and conserve rather than highlighting our original creative mandate to unfold. The fourth principle focuses on alleviating suffering, which is certainly essential in our work but also does not get at the original “good” mandate to unfold the creation. Future work might be helpful in articulating the Scriptural call to unfold the creation, either by better fleshing out the second or fourth principle or perhaps by introducing a new principle related to this mandate.

Overall, the Spirit is using this work to continue to convict me of the importance of integrally Christian engineering. Whether through the framework of the guiding principles or some other method of biblical critique, we should daily be examining all aspects of our engineering and educational work in light of its faithfulness to Christ. I pray that He will continue to work in all of us to increase our conviction of His all-encompassing Kingship and that He may continue to reveal to us the practical applications of this Kingship.
References


Institutional Differences in the Education of Engineering and Computing Students about Ethics and Societal Impacts

Angela R. Bielefeldt¹, Madeline Polmear¹, Daniel Knight¹, Christopher Swan², Nathan Canney³

Abstract

This study explored the extent to which faculty report teaching engineering and computing students about ethics and societal impacts (ESI) in courses and via co-curricular activities. The research questions were to determine if there were differences in the topics, teaching methods, assessment methods, and satisfaction with ESI instruction between faculty from religiously-affiliated (RA) and non-religiously affiliated (NRA) institutions. A national survey was conducted, with about 1400 responses. This included 122 faculty from 60 RA institutions (across 17 denominations/faiths). Chi-square tests evaluated statistically significant differences (p<0.05). Among 18 ESI topics, six were taught more commonly in courses by faculty at RA institutions: risk and liabilities, engineering and poverty, social justice, ethical failures, safety, and societal impacts of technology. Within individual courses, faculty at RA institutions more commonly taught students about ESI using project based learning, reflections, and service-learning. More individuals from RA vs. NRA institutions assessed ESI instruction in courses (94% vs. 86%). More of the faculty at RA vs. NRA institutions felt that undergraduate students were sufficiently educated about ESI (48% vs. 30%). In co-curricular activities, the topics, teaching methods, and assessment of ESI education did not differ significantly between RA and NRA institutions. In interviews, seven faculty teaching at RA institutions noted that the institutional culture was supportive of ethics education. Overall the results provide interesting information into how faculty try to teach engineering and computing students about ESI issues. The differences noted may be indicative of a higher value being placed on ESI education by RA institutions over that of NRA institutions; however, the majority of faculty at both institution types feel that ESI education efforts could be improved.

Introduction

All higher education institutions generally have desires to educate students for ethical participation in society. These aspirations are widely endorsed; for example, the Associate of American College & Universities’ (AAC&U’s) “essential learning outcomes” includes personal and social responsibility encompassing ethical reasoning and action, intercultural knowledge and competence, and civic knowledge and engagement. More specifically, engineering and computing education globally have embraced the imperative to educate students for ethical conduct (ABET; Engineers Australia; IEA; IPENZ) and requirements for ethical behavior of licensed engineers (Engineering Council; NCEES; NSPE). This includes microethics, or individual responsibilities as outlined in various codes of ethical conduct (ASCE 2006; IEEE; etc.). As well, increasing attention is being devoted to macroethical issues (Barry and Herkert 2014), which encompass the broader responsibilities of the profession to society and the environment at large. Preparing engineers to consider macroethical issues is gaining attention.

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through issues of sustainability, social justice, and bioethics. In this paper, we will collectively refer to microethics and macroethics as “ethics and societal impacts” (ESI).

Despite the requirements for ethics education within accredited programs, the scope of the ethics education of engineering students varies widely. The American Society of Civil Engineers (ASCE) noted concern that the ABET requirements could be met via a few seminars or guest lectures (ASCE 2015). Thus, they chose to raise the bar for the ethics education of civil engineering students, adding a program-specific criterion to “analyze issues in ethics.” This language derives from Bloom’s cognitive taxonomy. However, what is truly desired is ethical behavior in practice. Data from Harding et al. (2006) on student cheating and professional activity is not particularly encouraging in that regard, where given example scenarios a similar percentage of the study participants decided to cheat in a college setting and behave unethically in a workplace setting (~36%). Further, ethics has affective attributes (ASCE 2008) that include values, which some argue are difficult to teach (Birbeck and Andre 2009). This research sought to develop a national picture of how engineering and computing students are educated about ethics, from the perspective of faculty.

Most studies have explored ethics education from the perspective of students. Finelli et al. (2012) proposed a conceptual framework for students’ ethical development in college. The model included elements of institutional culture from both an organizational context and the peer environment. Thus, one would suspect that different institutional environments could be impactful. Bielefeldt and Canney (2016) found that students attending five Christian-affiliated institutions on average had more positive social responsibility attitudes than students attending 12 secular institutions. But an individuals’ religious and spiritual beliefs were more important than institutional setting in predicting attitudes toward social responsibility. The large study by Finelli et al. (2012) encompassed about 4000 undergraduate students attending 18 institutions; it is unclear if any were religiously affiliated institutions. However, among the students, 29% reported occasionally or frequently participating in an on-campus religious organization. Comegys (2010) found that undergraduate students attending religiously affiliated institutions had attitudes about business that were more ethical than those attending non-religiously affiliated institutions.

How might religion interact with ethical beliefs and behaviors? Religion is often related to morals and values, which in turn impact ethical beliefs (Jun 2005; Flores and Vazquez-Parraga 2009). Tensions between religious views and ethics have also been acknowledged (Irwin 2017). Christian and religious perspectives have been linked with a number of macroethical issues, including environmental protection (Vesilind and Gunn 1999), sustainability / sustainable development (McKeown 2007; Olawale and Yemisi 2012; Rasmussen; Stuerzenhofecker et al. 2010; Vogt 2011), social justice (Todd and Rufa 2013), and bioethics (Foreman 1999). Some articulation of macroethical goals can be found in the mission and vision statements for religiously-affiliated institutions in the U.S. Examples include:

Mission: “educate the whole person… serving the communities of which we are a part in California and around the world; Vision: educate citizens and leaders of competence, conscience, and compassion and cultivate knowledge and faith to build a more humane, just, and sustainable world.” https://www.scu.edu/aboutscu/mission-vision-values/
Mission: “educate men and women for worldwide leadership and service by integrating academic excellence and Christian commitment within a caring community… the University provides advanced educational opportunities to develop ethical and capable scholars and practitioners who contribute to their academic disciplines, professional fields and society. Beyond the intellectual life, the University pursues the social, physical, ethical and spiritual development of each student.”

http://www.baylor.edu/about/index.php?id=88781

Other evidence of interactions between religious beliefs and/or spirituality and ethics have been published. HERI (2005) found that 29% of entering first-year college students with a high spirituality score also had high scores on the Ethic of Caring scale; by comparison, only 5% of those with low spirituality scores had high Ethic of Caring scores. Ethic of caring was defined as measuring “the degree of commitment to values such as helping others in difficulty, reducing pain and suffering in the world, and making the world a better place.” (p. 8) Glanzer & Alleman (2015) found that faculty teaching at institutions affiliated with the Council for Christian Colleges and Universities (CCCU) integrated their faith identity into their approach to ethics in courses in a number of ways. Lindholm & Astin (2008) found that higher faculty spirituality correlated with great use of student-centered pedagogy; however, this overall relationship failed to hold true among engineering faculty (the sole exception among 14 disciplines). The large HERI study in 2013-2014 (Eagan et al. 2014) found that faculty at religious institutions taught ethical issues more frequently and had more goals for developing students’ moral character; however these results may be due to the disciplines represented and cannot be used to infer that within engineering these differences would be found. Shahjahan (2010) found that for some faculty their spirituality was a key influence in shaping their teaching for social justice. While this study encompassed a range of spiritual traditions (inclusive and beyond Christianity), none of the faculty participants were from engineering disciplines.

Religious faculty and students exist at all types of institutions. Gross and Simmons (2007) reported that “about 50 percent of professors in non-religiously affiliated schools say either that they believe in God despite their doubts or that they have no doubts about God’s existence, this is true of 68.9 percent of professors in religiously-affiliated schools.” (p. 4) Differences were found among institution type (highest percentage of atheists or agnostics at elite doctoral schools, 36.6%) and by discipline (50% mechanical engineering professors atheists or agnostics). Sullins (2004) estimated that at 100 Catholic institutions, the percentage of Catholic faculty ranged from 14 to 87%, with a mean of 50%. The American Freshman study (Eagan et al. 2016) found that among entering college students the percentage who considered the objective of helping others who are in difficulty an essential or very important objective was 73.5% at public 4-year colleges, 74.3% at nonsectarian 4-year private institutions, and 79.9% at Catholic 4-year institutions; the percentage atheist, agnostic and “none” was 26.1% at public 4-year colleges, 33.9% at nonsectarian private 4-yr colleges, and 16.7% at Catholic 4-year colleges. In the study of engineering students by Bielefeldt and Canney (2016), students self-reporting as atheist or indifferent/not religious varied from 45% at three private doctoral institutions, to 26% at three Christian Master’s level institutions, down to 3% at a Christian Baccalaureate institution.

Recently, individuals have written of “secularization” of religiously-affiliated institutions (Arthur 2008; McKinley 2008), making it clear that a simple binary view of secular vs. religiously-affiliated institutions is a gross oversimplification. This idea is also supported by quantitative
data on differing attitudes toward social responsibility of engineering students at five different Christian-affiliated institutions (Bielefeldt and Canney 2016). Abelman and Dalessandro (2009) explored the composite vision statements of 210 different higher education institutions, and found vocabulary usage giving higher DICTION scores for “compelling” (based on usage of words including faith, honesty, and courage) for Catholic and Evangelical institutions (65.2 and 63.7, respectively) compared to secular public institutions (51.6) and “Christ-Centered”/CCCU institutions (48.3); individual institution scores ranged from 74.9 to 42.9. Thus differences among institution types and different religious groups is evident. However, the binary categorization into “religiously-affiliated” (RA) and “non-religiously affiliated” (NRA) or secular institutions is a place to start to explore ideas of intersectionality between religion and engineering ethics education.

Research Questions

RQ1. Determine if there are differences in the satisfaction with overall ethics/societal impacts instruction between faculty from religious-affiliated institutions (RA) and non-religiously affiliated institutions (NRA, including public institutions and nonsectarian private institutions), and if satisfaction correlates with the number of settings where individuals believe that their undergraduate students learn about ESI.

RQ2. Determine if there are differences in the topics, teaching methods, assessment methods for ethics/societal impacts instruction between faculty RA and NRA institutions, in both curricular and co-curricular settings

RQ3. Determine the perspectives of faculty from RA institutions on how the institutional culture relates to the ethics education of engineering/computing students

Methods

Survey. A survey was developed to explore how faculty members taught engineering and computing students about ESI. The survey began with an informed consent statement approved by the Institutional Review Board for Human Subjects Research. There were two versions of the survey: one asked questions about ESI instruction in courses first (curricular survey), followed by questions on potential integration of these topics into co-curricular/informal learning environments. The second survey (co-curricular survey) asked questions about co-curricular/informal settings first, followed by questions on ESI instruction in courses. The majority of the questions were multiple-select items related to ESI topics, course and co-curricular types, ESI teaching methods, and ESI assessment methods. Near the end of the survey individuals were asked to rate the extent to which they believed the ESI instruction of undergraduate and graduate students in their program was sufficient. The surveys also included an open-ended response question to share thoughts about the education of engineering students regarding ESI, and to optionally volunteer to participate in a follow-on interview. The survey concluded with a series of demographic items on the institution and individual. More details on the survey development and questions have been published (Bielefeldt et al. 2016).
Invitations to the online surveys were distributed via email. The curricular survey was distributed via list serves of the American Society for Engineering Education (ASEE), as well as direct invitations to individuals who authored papers and received NSF grants on engineering ethics education. The co-curricular survey was distributed via professional societies to their list serves and individuals who mentor campus chapters of various groups. Additional details on survey distribution strategies were previously described (Bielefeldt et al. 2016, 2016b). Individuals at RA institutions were not particularly included nor excluded from among the individuals invited to participate in the survey. Responses were collected from February to May, 2016. There were 1448 responses that were over 50% complete; individuals could skip any questions on the survey, resulting in varying numbers of respondents for particular items.

Interviews. A series of interviews were conducted. There were 230 individuals who indicated a willingness to participate in an interview on the survey; 11% from RA institutions (slightly over-represented compared to 8% overall survey respondents from RA institutions). Among this group, 52 were invited to participate in interviews in September 2016 to February 2017; including 9 (17%) from RA institutions and 5 from international institutions. Individuals were selected for interviews to encompass a diversity of ESI topics, teaching settings, disciplines, and institutional characteristics. Among this group, 35 interviews were completed prior to April 1, 2017; 7 from RA institutions. The interviews were conducted via phone or skype, with a typical duration of 30 to 60 minutes. The interviewees were assigned a pseudonym using a random name generator to maintain the confidentiality of the participants. The semi-structured interviews asked questions about the most effective way instructors taught students about ESI, as well as questions about institutional support for ESI. Analysis of the interview responses is on-going.

Data. Statistical comparisons were made between responses from those at RA and NRA institutions. Many of these were chi-square tests conducted in Excel. Other tests such as correlations and comparisons between counts used non-parametric statistical tests in IBM SPSS version 24 (Independent Samples Mann-Whitney U Test). Open-ended responses were coded for themes using emergent methods; inter-rater reliability among three coders was established based on a sub-set of the responses. Further details on the themes emergent from the survey open-ended responses are provided in Canney et al. (2017).

Respondents. An overview of the demographic characteristics of the survey respondents are summarized in Table 1. Individuals were not required to answer questions on the survey. Therefore, some individuals chose not to identify their institution. For those who did not identify their specific institution but noted they were at a public institution, the institutions were classified as NRA. Responses were excluded from the dataset for individuals who indicated that they taught at a private institution but did not note the name.

Among the 60 different religiously-affiliated institutions, 17 different denominations were represented. The majority of the 122 respondents were from Catholic-affiliated institutions (52%), including Roman Catholic and Jesuit institutions. Other denominational affiliations identified among the institutions were: Church of Jesus Christ of the Latter-Day Saints, United Methodist, Seventh-Day Adventist, Presbyterian, Church of Christ, evangelical, Lutheran, Christian Reformed, Church of the Brethren, Christian Brothers, Quaker, Mennonite, Church of God, Disciplines of Christ, and interdenominational. Some schools were initially founded or
historically tied with a religious group, but if the institution currently advertised itself as non-sectarian, this classification was used in our study (e.g. Duke University).

<table>
<thead>
<tr>
<th>Demographic Characteristic</th>
<th>RA, %</th>
<th>NRA, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest degree awarded at institution*</td>
<td>(n=122)</td>
<td>(n=1306)</td>
</tr>
<tr>
<td>- Associates (community college)</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>- Bachelor’s</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>- Master’s</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>- Doctoral</td>
<td>47</td>
<td>84</td>
</tr>
<tr>
<td>Institution Type*</td>
<td>(n=122)</td>
<td>(n=1306)</td>
</tr>
<tr>
<td>- Public</td>
<td>0</td>
<td>79</td>
</tr>
<tr>
<td>- Private</td>
<td>100</td>
<td>21</td>
</tr>
<tr>
<td>Respondent Rank</td>
<td>(n=122)</td>
<td>(n=1300)</td>
</tr>
<tr>
<td>- Full professor</td>
<td>35</td>
<td>34</td>
</tr>
<tr>
<td>- Associate professor</td>
<td>35</td>
<td>27</td>
</tr>
<tr>
<td>- Assistant professor</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>- Senior instructor other full time non-TT</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>- Others: Full time adjunct or research faculty, part time instructor, graduate student with teaching role, staff member</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Additional Roles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Dean</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>- Associate/assistant dean</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>- Department chair or head</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>- Director of program or center</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>- ABET assessment coordinator</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>- Honor council or similar</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>- Other</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Disciplines Taught</td>
<td>(n=122)</td>
<td>(n=1276)</td>
</tr>
<tr>
<td>- Mechanical Engineering</td>
<td>36*</td>
<td>20</td>
</tr>
<tr>
<td>- Civil Engineering</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>- First-year Engineering</td>
<td>23*</td>
<td>11</td>
</tr>
<tr>
<td>- Computer Engineering / Science</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>- Electrical Engineering</td>
<td>21*</td>
<td>12</td>
</tr>
<tr>
<td>- General Engineering</td>
<td>12*</td>
<td>5</td>
</tr>
<tr>
<td>- Chemical Engineering</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>- Biomedical Engineering</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>- Engineering Technology</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>- Humanities and/or social science for engineers</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>- Aerospace Engineering</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>- Other (Other, Environmental, Materials, Biological, Industrial, Engineering Management, Petroleum, Nuclear, Mining, Geological,….)</td>
<td>&lt;5% each</td>
<td></td>
</tr>
<tr>
<td>Gender*</td>
<td>(n=122)</td>
<td>(n=1306)</td>
</tr>
<tr>
<td>- Male</td>
<td>70</td>
<td>64</td>
</tr>
<tr>
<td>- Female</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>- Prefer not to say</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Race/Ethnicity (check all that apply)</td>
<td>(n=113)</td>
<td>(n=1260)</td>
</tr>
<tr>
<td>- White, non-Hispanic</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>- Hispanic, Latino</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>- Black or African American</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>- Asian</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>- Other</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>- Prefer not to say</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Hold a Professional Engineering license (P.E. or similar), yes</td>
<td>25</td>
<td>30</td>
</tr>
</tbody>
</table>

* Chi-square test RA vs. NRA p ≤ 0.05
Disciplines. On average, individuals from RA institutions noted 2.0 different disciplines where they taught engineering students, compared to an average of 1.7 different engineering disciplines for instructors at NRA institutions. The most common discipline among RA instructors was mechanical, a higher percentage compared to individuals at NRA institutions.

Results and Discussion

RQ1: Sufficiency of Ethics Education

Individuals were asked whether they believed undergraduate and graduate students in their program received sufficient education on ethics and/or broader impact issues; results are summarized in Table 2. A higher percentage of the individuals from RA institutions felt that their undergraduate students received sufficient education on these issues; 48% compared to only 30% at NRA institutions (p=0.0003). At RA institutions, there was a greater perceived deficiency in education on the broader impacts of technology (47%) compared to ethics (33%). This may indicate differences between microethics and macroethics education.

At RA institutions with a graduate program, fewer faculty felt that graduate students received sufficient education on ethical and broader impact issues than undergraduate students in their program (p=0.0006). Here, ethics education was perceived to be lacking by slightly more individuals (69%) compared to education on broader impacts (65%). There were not statistically significant differences in the perceived sufficiency of graduate student education on ethics between faculty at RA and NRA institutions (p=0.61).

<table>
<thead>
<tr>
<th>Response</th>
<th>Undergrad RA, % (n=102)</th>
<th>Undergrad NRA, % (n=1013)</th>
<th>Graduate RA, % (n=51)</th>
<th>Graduate NRA, % (n=840)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, but too much; the time could be better spent on other topics</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Yes, a sufficient amount</td>
<td>46</td>
<td>29</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>A sufficient amount of ethics, but insufficient on the broader impacts of technology</td>
<td>19</td>
<td>16</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>A sufficient amount on the broader impacts of technology, but not enough ethics</td>
<td>5</td>
<td>13</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>No, not enough</td>
<td>28</td>
<td>41</td>
<td>59</td>
<td>62</td>
</tr>
</tbody>
</table>

When the 37 open-ended responses from faculty at RA institutions were coded, six reinforced the importance of ESI topics (16%; 14% at NRA) and five indicated that ESI instruction should be improved (14%; 17% at NRA). The most common comments related to theory vs. practice (n=10 at RA, 27%; 7% at NRA). Examples of comments from faculty at RA institutions are:

“I believe in using a standard of a Biblical world view.”
“[our institution] in particular may prepare the students better than other universities in these areas because of the strong Liberal Education/Philosophy/Theology components of the engineering education.”

“I have found the key to teaching ethics in my courses is to emphasize not only that ethics is about avoiding evil, but also that ethics is about pursuing good. Engineers want to create products that help people. They need to know their profession is intrinsically ethical, and that being a good engineer means being not only technically, but also morally good.”

“Engineering programs are too tightly scheduled to permit much introduction of this material; it is a struggle to do this even at a university with a values/ethics/social justice mission, elsewhere it is nearly impossible to get support for adding anything other than the bare minimum required by ABET. Realistically, to get this to be effective, the culture of engineering would have to be motivated to make room and provide resources for an effective and well-integrated ethics curriculum for engineers, not just a single engineering ethics course that never gets referenced by other engineering faculty, or used by the students in any other part of their engineering education.”

Individuals were asked to indicate where they believed undergraduate students in their program learned about ethics and/or societal impact issues, with 11 choice options presented and unsure. Among faculty at RA institutions, two noted unsure and their responses were not included in the analysis. Among those with an opinion from RA institutions, an average (and median) of 4 settings were noted (with a range of 1 to 9). There was not a statistically significant correlation between the perceived sufficiency of ESI education and number of educational settings where undergraduate students in the program learned about ESI at RA institutions (Spearman’s rho - 0.012, sig. 0.908). Individuals at NRA institutions noted an average of 3.3 settings where they believed undergraduate students learned about ESI (median 3, range 1-11; excluding 148 unsure responses); this was lower than RA institutional responses (Mann-Whitney U Test sig. 0.001). The lower average number of settings where individuals at NRA institutions believed that undergraduate students learned about ESI topics is congruent with the larger percentage feeling that undergraduate student education on these issues was insufficient. Among individuals from NRA institutions there was a significant correlation among perceived ESI education sufficiency and number of educational settings (Spearman’s rho -0.177, sig. 0.000, n=975).

The percentage of respondents noting each setting where they believed undergraduate students in their program learned about ESI are shown in Table 3. The majority of instructors at RA institutions believed that their students learned about ESI in their senior capstone design course and a first-year introductory course; many also indicated humanities and/or social science courses and sophomore or junior level engineering science and/or engineering courses. Among the 27 individuals from RA institutions who believed that undergraduate students in their program learned about ESI via a full course on engineering ethics, 55% also believed that the ESI instruction of their students was sufficient (the highest sufficiency among all course types). The “other” courses written in by respondents from RA institutions included:

- university core curriculum
- ethics course from philosophy department (which was intended to be included under humanities and/or social science courses)
• senior management course (which some might classify as a professional issues course)
• appropriate technology course
• completion of 4-year design sequence
• software engineering project
• senior laboratory

TABLE 3. Where respondents thought undergraduate students in their program learn about the societal impacts of technology and/or ethics

<table>
<thead>
<tr>
<th>Setting instructors perceived that students learn about societal impacts and/or ethics</th>
<th>RA instructors, % (n=108)</th>
<th>NRA instructors, % (n=1074)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior capstone design</td>
<td>72*</td>
<td>61</td>
</tr>
<tr>
<td>First year introductory course</td>
<td>50</td>
<td>44</td>
</tr>
<tr>
<td>Humanities and/or social science courses</td>
<td>46*</td>
<td>31</td>
</tr>
<tr>
<td>Sophomore or junior level engineering science and/or engineering course</td>
<td>43</td>
<td>37</td>
</tr>
<tr>
<td>Co-curricular engineering service society (e.g. EWB)</td>
<td>36*</td>
<td>24</td>
</tr>
<tr>
<td>Design-focused course in the sophomore, junior, or senior year</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>Co-curricular engineering professional society (e.g. AIAA, AIChe, ASCE, ASME, IEEE)</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Full course on engineering ethics (any level)</td>
<td>25*</td>
<td>17</td>
</tr>
<tr>
<td>First-year design-focused course</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Professional issues course (at any level)</td>
<td>22</td>
<td>28</td>
</tr>
<tr>
<td>Other courses and/or co-curricular activities</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Average total number of settings</td>
<td>4.0**</td>
<td>3.3</td>
</tr>
</tbody>
</table>

* p ≤ 0.05, ** p≤0.001

Higher percentages of faculty at RA vs. NRA institutions believed that students in their program learned about ethical and societal issues in senior capstone design, humanities/social science courses, co-curricular engineering service groups, and a full course on engineering ethics.

Some form of co-curricular experience was also indicated as contributing to student learning about ethics and/or societal impacts by 47% of respondents from RA institutions. This included engineering service groups like EWB (36%) and/or professional societies (28%). Other co-curricular activities listed included: mission trips to other countries; enrichment seminar in computing; required professional development activities.

RQ2. Ethics and Societal Impacts Instruction

Course topics. Instructors at RA institutions typically taught more ESI topics in their courses to engineering students than instructors at NRA institutions; median of 6 vs. 5, respectively (p=0.006). The specific ESI topics taught in their courses for engineering students are summarized in Table 4. At RA institutions, the most common ESI topics were the societal impacts of engineering & technology and professional practice issues. Seven ESI topics were taught more commonly by faculty at RA vs. NRA institutions.
### TABLE 4. Ethics and societal impact topics taught to engineering and computing students

<table>
<thead>
<tr>
<th>Topics taught in one or more courses (undergraduate or graduate)</th>
<th>RA, % (n=108)</th>
<th>NRA, % (n=1092)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Societal impacts of engineering and technology</td>
<td>69*</td>
<td>56</td>
</tr>
<tr>
<td>Professional practice issues</td>
<td>67</td>
<td>62</td>
</tr>
<tr>
<td>Safety</td>
<td>61*</td>
<td>49</td>
</tr>
<tr>
<td>Engineering decisions in the face of uncertainty</td>
<td>57</td>
<td>51</td>
</tr>
<tr>
<td>Sustainability and/or sustainable development</td>
<td>56+</td>
<td>47</td>
</tr>
<tr>
<td>Ethical failures</td>
<td>56*</td>
<td>45</td>
</tr>
<tr>
<td>Engineering code of ethics (e.g. NSPE)</td>
<td>54</td>
<td>48</td>
</tr>
<tr>
<td>Risk and liabilities</td>
<td>54*</td>
<td>36</td>
</tr>
<tr>
<td>Ethics in design projects</td>
<td>46</td>
<td>41</td>
</tr>
<tr>
<td>Environmental protection issues</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Responsible conduct of research</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>Social justice</td>
<td>28*</td>
<td>18</td>
</tr>
<tr>
<td>Ethical theories</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Engineering and poverty</td>
<td>26*</td>
<td>16</td>
</tr>
<tr>
<td>Privacy and civil liberties</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>War, peace, and/or military applications of engineering</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Other topics related to social and ethical issues</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Bioethics</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Nanotechnology ethics</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>No topics related to the societal impacts of technology or ethics</td>
<td>0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Chi-square test: * p < 0.05, * 0.05 < p < 0.10

Some topics may differ in the extent of inclusion at RA institutions affiliated with different types of faiths; however, the number of respondents from institutions of different denominational types was too low to evaluate these differences statistically. For example, social justice appeared to vary between institutional denominational affiliations: 40% of Jesuit, 38% Roman Catholic, 23% Catholic (not Jesuit or Roman Catholic), 17% Baptist, 0% United Methodist, and 0% Church of Jesus Christ of Latter-Day Saints.

**Course Types.** Instructors were asked to indicate all of the types of courses where they taught ESI; results are summarized in Table 5. Instructors at both RA and NRA institutions indicated a median of two course types (range 1 to 8). Given that typical teaching loads often range from 3 courses (at highly research active institutions) to 8 courses (for full time instructors), some of the respondents may have infused ESI issues into all of their courses. ESI topics were included most commonly in senior capstone design and sophomore/junior level engineering science and engineering courses. Examples of the sophomore/junior engineering/engineering science courses are: statics, material and energy balances, mechanics of materials, heat transfer, software engineering. Two course types were more commonly reported among RA vs. NRA instructors, first-year introductory courses and first-year design focused courses. It is unclear if simply more of the respondents from RA institutions taught these course types, or if more of the individuals who taught these course types infused ESI issues into them.
TABLE 5. Types of courses where instructors teach engineering students about ESI

<table>
<thead>
<tr>
<th>Course Types</th>
<th>RA, % (n=108)</th>
<th>NRA, % (n=1096)</th>
<th>RA most effective course taught, % (n=100)</th>
<th>RA most effective/teach, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior capstone design</td>
<td>48</td>
<td>39</td>
<td>18</td>
<td>38</td>
</tr>
<tr>
<td>Sophomore/junior engineering science or engineering course</td>
<td>48</td>
<td>38</td>
<td>22</td>
<td>39</td>
</tr>
<tr>
<td>First-year introductory course</td>
<td>44*</td>
<td>29</td>
<td>13</td>
<td>30</td>
</tr>
<tr>
<td>Design-focused course in sophomore, junior, or senior year</td>
<td>38</td>
<td>32</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>Graduate level course^</td>
<td>24</td>
<td>33</td>
<td>14</td>
<td>58</td>
</tr>
<tr>
<td>First-year design-focused course</td>
<td>23*</td>
<td>11</td>
<td>9</td>
<td>39</td>
</tr>
<tr>
<td>Professional issues course (at any level)</td>
<td>16</td>
<td>17</td>
<td>6</td>
<td>38</td>
</tr>
<tr>
<td>Humanities and/or social science course</td>
<td>14</td>
<td>8</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>Full course on engrg ethics (any level)</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>56</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
<td>13</td>
<td>9</td>
<td>113</td>
</tr>
</tbody>
</table>

Chi-square test: * p < 0.05; italics = some of these were also UG courses
^ as a percentage of instructors at institutions with graduate degrees

There were 100 instructors from RA institutions who described one course where they believed they most effectively taught engineering/computing students about ESI. The majority of the most effective courses were undergraduate (96%), with only 10 describing a graduate level course (6 of these were cross-listed as undergraduate courses). Among the 96 undergraduate courses described, 77% were required for students in one or more engineering/computing majors, 24% were electives for students in one or more engineering/computing majors (1 was both). Looking at the types of courses described as most effective, it appears that graduate level courses and full courses on engineering ethics were perceived as more effective at teaching ethics/social issues; this is because 56-58% of the instructors who reported teaching ESI topics in these courses also selected the course as where they most effectively taught these issues (final column in Table 5). Less effective courses include design-focused courses in sophomore-senior year, humanities & social science courses, and first-year introductory courses. There were also 18 individuals who described a second course where they taught ESI topics.

Teaching Methods in Courses. There were 100 instructors at RA institutions who described one or two courses where they taught ethics/societal impact issues (a total of 118 courses described). Given a list of 16 potential teaching methods used to teach ESI, an average of 5.4 methods were used in the most effective courses (n=100) and 4.0 methods were used in the additional course described (n=18). Table 6 shows the percentage of courses where the teaching methods were used. Across all courses, a similar number of teaching methods for ESI were used by instructors at RA and NRA institutions; average 5.3 and 5.1, respectively. Overall, the most popular methods used to teach ethics and societal impact issues at RA institutions were examples of professional scenarios, case studies, and in-class discussions. In general, similar methods were used to teach ESI by instructors at NRA institutions, with the exception of greater use of project based learning, reflections, and service-learning at RA institutions, and more lectures at NRA institutions. The greater use of active/student centered teaching methods for ESI at RA institutions is congruent with findings from Lindholm & Astin (2008) that faculty with greater
spirituality were more likely to use student-centered teaching methods in undergraduate courses (presuming that more spiritual faculty are likely to be found at religiously-affiliated institutions).

TABLE 6. Methods used to teach students about ethics and/or societal impact issues

<table>
<thead>
<tr>
<th>Teaching Methods ((^{ASC}) = typically active/student centered)</th>
<th>RA, % (n=118)</th>
<th>NRA, % (n=1187)</th>
<th>RA soph/jr eng sci/eng, % (n=27)</th>
<th>RA capstone design, % (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples of professional scenarios</td>
<td>64</td>
<td>58</td>
<td>78</td>
<td>57</td>
</tr>
<tr>
<td>Case studies (^{ASC})</td>
<td>61</td>
<td>66</td>
<td>52</td>
<td>57</td>
</tr>
<tr>
<td>In-class discussions (^{ASC})</td>
<td>60</td>
<td>68</td>
<td>67</td>
<td>62</td>
</tr>
<tr>
<td>Lectures</td>
<td>53</td>
<td>66*</td>
<td>52</td>
<td>43</td>
</tr>
<tr>
<td>Project based learning (^{ASC})</td>
<td>47*</td>
<td>37</td>
<td>44</td>
<td>52</td>
</tr>
<tr>
<td>Engineering design (^{ASC})</td>
<td>46</td>
<td>42</td>
<td>41</td>
<td>57</td>
</tr>
<tr>
<td>Reflections (^{ASC})</td>
<td>41*</td>
<td>25</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>Guest lectures</td>
<td>26</td>
<td>30</td>
<td>26</td>
<td>48</td>
</tr>
<tr>
<td>Videos, movie clips</td>
<td>25</td>
<td>28</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Service-learning, community engagement (^{ASC})</td>
<td>25*</td>
<td>12</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>In-class debates and/or role plays (^{ASC})</td>
<td>17</td>
<td>22</td>
<td>22*</td>
<td>0</td>
</tr>
<tr>
<td>Problem solving heuristics (^{ASC})</td>
<td>17</td>
<td>14</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Think-pair-share (^{ASC})</td>
<td>14</td>
<td>14</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Humanist readings</td>
<td>13</td>
<td>10</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Moral exemplars</td>
<td>10</td>
<td>9</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Others, fill in</td>
<td>8</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Chi-square test: * p < 0.05, * 0.05 < p < 0.10

It is likely that different teaching methods are used to teach ESI topics in different types of courses. However, given the small number of responses from RA institutions, statistically significant differences were only found for one method (in-class debates). Apparent differences (>15%) were greater use of engineering design and guest lectures in the capstone design courses, compared to greater use of professional scenarios and service-learning (SL) in sophomore/junior engineering/engineering science courses.

The “other” teaching methods written-in by instructors at RA institutions included:

- readings of essays that explore biblical implications on engineering perspectives
- final Pechakucha talk developing and describing own morale theory
- students write an ethical dilemma short story, play a board game on environmental ethics
- students create a work of fiction involving an ethical grey area
- board game dilemma
- ethics papers and design/safety considerations
- participation in a professional meeting or conference, volunteering there
- CITI training
- creative writing

Assessment Methods in Courses. Instructors were asked what methods were used to assess student learning of ethical/societal issues. Instructors at RA institutions used an average of 2.4 methods to assess ethics/societal impact learning in their courses (range 1 to 6). The most commonly used methods in courses at RA institutions were individual reflections (57%) and group-based assignments (47%); these assessment methods were less commonly used at NRA
institutions (38% and 33%, respectively). Other assessment methods for ESI instruction used by instructors at RA institutions included: individual homework graded with a rubric (42%), test/quiz questions (31%), team ratings (18%), individual assignments with right/wrong answers (12%), surveys (8%), individual standardized assessment (e.g. DIT2; 3%), and other methods (14%). In addition, a larger percentage of instructors at NRA institutions did not assess ESI outcomes in any manner (14% compared to 6% at RA institutions).

Co-curricular Learning. The survey also explored co-curricular activities where students may learn about ethical and/or social issues; results are summarized in Table 7. Eighty-five individuals from RA institutions described the topics included in 128 different co-curricular activities that they mentored. These responses were compared to those from 931 individuals from NRA institutions describing 1265 co-curricular activities. For co-curricular activities that included some education on ESI, an average of about four different topics were included. The topics that were most common across all co-curricular activities were professional issues, safety, and the societal impacts of engineering and technology. Only one topic, environmental protection issues, differed in prevalence between institution types, being more prevalent at NRA institutions.

<table>
<thead>
<tr>
<th>Topic</th>
<th>NRA % All (n=1265)</th>
<th>RA % All (n=128)</th>
<th>RA % Prof. society (n=57)</th>
<th>RA % Design group (n=21)</th>
<th>RA % Eng service group (n=17)</th>
<th>RA % REU (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional issues</td>
<td>62</td>
<td>58</td>
<td>61</td>
<td>57</td>
<td>65</td>
<td>58</td>
</tr>
<tr>
<td>Safety</td>
<td>45</td>
<td>44*</td>
<td>35</td>
<td>67</td>
<td>88</td>
<td>33</td>
</tr>
<tr>
<td>Societal impacts of engrg &amp; technol.</td>
<td>45</td>
<td>43</td>
<td>46</td>
<td>24</td>
<td>71</td>
<td>42</td>
</tr>
<tr>
<td>Engrg. decisions under uncertainty</td>
<td>36</td>
<td>37*</td>
<td>23</td>
<td>67</td>
<td>53</td>
<td>67</td>
</tr>
<tr>
<td>Sustainability / sust. development</td>
<td>37</td>
<td>34**</td>
<td>26</td>
<td>29</td>
<td>94</td>
<td>42</td>
</tr>
<tr>
<td>Responsible conduct of research</td>
<td>27</td>
<td>26*</td>
<td>19</td>
<td>24</td>
<td>24</td>
<td>67</td>
</tr>
<tr>
<td>Engineering code of ethics</td>
<td>29</td>
<td>25</td>
<td>30</td>
<td>14</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Ethics in design</td>
<td>22</td>
<td>24*</td>
<td>21</td>
<td>33</td>
<td>53</td>
<td>17</td>
</tr>
<tr>
<td>Risk and liability</td>
<td>19</td>
<td>23*</td>
<td>16</td>
<td>38</td>
<td>59</td>
<td>8</td>
</tr>
<tr>
<td>Engineering and poverty</td>
<td>17</td>
<td>17**</td>
<td>9</td>
<td>0</td>
<td>82</td>
<td>0</td>
</tr>
<tr>
<td>Environmental protection issues</td>
<td>28*</td>
<td>17*</td>
<td>14</td>
<td>10</td>
<td>53</td>
<td>25</td>
</tr>
<tr>
<td>Social Justice</td>
<td>13</td>
<td>16**</td>
<td>9</td>
<td>0</td>
<td>53</td>
<td>8</td>
</tr>
<tr>
<td>War, peace, and/or military</td>
<td>11</td>
<td>16</td>
<td>11</td>
<td>22</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Ethical failures</td>
<td>17</td>
<td>14</td>
<td>19</td>
<td>5</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>No topics</td>
<td>9</td>
<td>11*</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Privacy and civil liberties</td>
<td>19</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Ethical theories</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Nanotechnology</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Other topics</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bioethics</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average # topics</td>
<td>4.5</td>
<td>4.2</td>
<td>3.7</td>
<td>4.0</td>
<td>7.6</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Chi-square test NRA vs. RA, * p < 0.05
Chi-square test different types of co-curricular activities at RA institutions, *p<0.05, **p<0.001,

Four different types of co-curricular activities were described by the majority of individuals from RA institutions. Nine topics differed in the extent that they were included in these different types of co-curricular activities. For example, safety was highly prevalent in engineering service groups (Engineers Without Borders, Engineers for a Sustainable World, and Engineering World
Health, and others), but much less commonly discussed in professional societies or research experiences for undergraduates (REU). The most widely represented groups within the professional societies category were: American Society of Mechanical Engineers (ASME), American Society of Civil Engineers (ASCE), Institute of Electrical and Electronics Engineers (IEEE), Society of Women Engineers (SWE), and Association of Computing Machinery (ACM). The types of design activities included SAE Baja, ASCE Concrete Canoe, Human Powered Vehicles, EcoMarathon, VEX Robotics, and ChemE Car team. Overall, more ethical/societal impact topics were included in activities with engineering service groups (average 7.6), than other types of co-curricular activities. This indicates that engineering service groups may provide particularly rich opportunities for students to learn about ESI issues in an authentic context.

In the co-curricular activities at RA institutions, the most commonly reported methods used to teach students about ESI were: design projects (59%); lectures, presentations, guest speakers (59%) discussions (56%); working with communities (45%); and other (13%). Some of the other methods written in were: attending conferences (n=3), reflection, international travel, field trip, and formal competition. The teaching methods for ESI were similar in frequency compared to co-curricular activities at NRA institutions, with the exception of design projects (only 45% of NRA; chi-test p= 0.002). Only 14% of the co-curricular mentors at RA institutions reported that they assess ESI instruction in these settings; methods included surveys, observations of discussions, evaluations of projects/reports.

RQ3. Institutional Culture

Seven individuals teaching engineering/computing students at RA institutions agreed to participate in interviews. The institutions represented different Christian affiliations (Baptist, Catholic, Jesuit, Church of Brethren, Church of Christ, Church of the Nazarene, and Lutheran). From Carnegie Basic Classifications the institutions included two doctoral research universities with high research activity, three Master’s institutions (large and medium), and two Baccalaureate with Arts & Sciences focus. The faculty represented mechanical engineering (n=3), electrical engineering (n=2), and humanities/social sciences (ethics, psychology). The individuals spanned multiple ranks (3 professors, 2 associate professors, 1 assistant professor, 1 full time adjunct or research faculty), and included one female and six males.

The interviews touched on a number of themes connected to the relationship between institutional culture and ethics education. All seven of the interviewees commented on their respective institution’s culture in relation to the value placed on teaching ESI to engineering and computing students. Six of the interviewees directly discussed the religious affiliation of their university in this context. Three of the interviewees mentioned that the religious foundation of their institution motivated an ethics across the curriculum approach to educating engineering students. One interviewee commented that ethics are woven throughout the curriculum because it is “part of who we are, we are a Catholic Marianas university… that religious foundation and the fact that it is part of our common academic program.” The university incorporated practical ethical action as a learning outcome, which translated to an emphasis on ethics throughout the undergraduate experience. Another interviewee, who teaches graduate courses at a Jesuit institution, noted the university is “trying to get ethics across the curriculum, ethics into everything” and that the engineering school “is always trying to figure out new ways to get ethics
A professor with a psychology background who teaches a required course on ethical issues in software design noted that the success of his course has resulted from its integration into the computer science program. Ethics has been recognized as a “crucial piece of the curriculum” with ESI spread throughout the curriculum at the Lutheran institution. Students gain exposure to sociotechnical systems and ethical considerations in two courses before taking his course and thus already have a foundation to build on. Students are then required to conduct an ethical analysis on their senior projects to complete the loop. The ethics across the curriculum approach helps students gain an understanding of how ESI topics are embedded in a range of engineering contexts.

Another theme that emerged in the interviews with instructors from RA institutions was the requirement of an ethics course. All of the interviewees explicitly discussed this curricular requirement at their school and five mentioned offerings within and outside of their engineering programs. An instructor at the Catholic institution noted, “ethics courses don’t have to come from philosophy or religion” and that any department can propose a course to fulfill the requirement. The educator at the Baptist university expressed a similar approach to providing a range of course options for the ethics requirement with engineering students taking classes in business, philosophy, mechanical engineering, and humanitarian engineering. The interviewee from the Lutheran school noted that the ethics requirement was part of the fabric of the liberal arts institution and a reflection of its “emphasis on ethics”. Similarly, any department including philosophy, psychology, computer science, and dance can develop and offer courses to fill the mandate. The requirement for stand-alone ethics courses serves as a curricular manifestation of the emphasis on ethics and provides an educational deep dive into ESI for engineering students.

Two of the interviewees also discussed the explicit role that Christianity plays in ethics education at their institutions. The educator at the institution affiliated with the Church of Christ noted he “works from a personal ethics approach through the gospel of Christ.” All of the lectures included in his ethics and professionalism course, which is taken in conjunction with senior design, tie directly to the Bible. He takes a “broad view of ethics” to teach topics “in the sense of things that are very real” to the students. The class begins with students sharing ethics-related situations that they might face in engineering and the course content is then structured around those concerns. By incorporating case studies, discussions, and the Scripture, the interviewee aims to apply the faith that students develop in their community, family, and church contexts to the domain of engineering. The institution requires 16 credits of Bible and ministry courses and he connects the ethics education and critical thinking offered in those courses to engineering content. The interviewee from the institution founded by the Church of the Nazarene noted that the textbook used in his course on technology and social responsibility is from the Christian perspective. At both of these schools, Christianity imbues all aspects of student life, institutional culture, and ethics education.

The interviews also explored how the institution’s denomination impacted its approach to ESI instruction. The professor at the Lutheran institution noted that although the school was religiously founded, it does not require daily chapel and does not have a faith statement and these are important “caveats” to understanding its academic culture. The interviewee who teaches at the institution affiliated with the Church of the Nazarene commented that the Christian foundation underscores its approach to ethics education. He articulated that the affiliation
motivated “learning by serving.” The institution focused on teaching ethics to engineering students through service learning and community outreach. He previously taught at a Presbyterian school and discerned a difference between the two denominations in their ways of teaching ethics. He noted the Presbyterian institution emphasized thinking rather than doing with the integration of theory, reflection, and philosophy. These comments help parse out the influence that different Christian denominations have on the institutions’ approach to the ethics education of engineering and computing students. The analysis of the findings from the qualitative interviews is on-going, and additional themes might emerge in future.

Limitations and Future Work

The primary limitation of the findings is based on the sample – individuals who chose to respond to the survey. It is likely that individuals choosing to take their time to respond to a survey on engineering ethics care about ethics education more than an average faculty member. The second limitation is the relatively small number of individuals from religiously-affiliated institutions that responded to the survey. Not all religiously-affiliated institutions with engineering and computing degrees were represented, nor are the varying opinions within institutions and across disciplines likely to be fully represented. Further, it is expected that findings might differ among institutions affiliated with different types of Christian faiths; however, the sample size was too small to evaluate such differences. It was also not possible to explore non-Christian religiously-affiliated institutions.

At present, the religious beliefs of individual instructors and the extent to which this impacts their ESI teaching practices in educational settings for engineering and computing students are not known. Highly religious individuals may teach at NRA institutions, and similarly atheists may teach at RA institutions. Individuals at all institutional types are expected to have a range of personal religious beliefs and personal attitudes regarding the importance and relevance of ESI topics. The extent to which institutional culture encourages or discourages faculty from bringing these personal perspectives to their teaching practices could vary. More research is needed to understand these nuanced ideas.

Summary and Conclusions

Nearly half of the faculty at religiously-affiliated institutions (48%) believed that undergraduate engineering and/or computing students in their programs received sufficient education on ethics and societal impact issues; far fewer faculty (30%) at NRA institutions believed that undergraduate education on ESI was sufficient. On average, faculty at RA institutions believed that undergraduate students learned about ESI in four types of courses and/or co-curricular activities, higher than the average of 3.3 settings among faculty at NRA institutions. The educational settings most widely believed to include ESI at RA institutions include senior capstone design (72%), first year introductory courses (50%), and humanities and/or social science courses (46%). Instructors at RA institutions taught a median of six different ESI topics in their courses; societal impacts of engineering and technology, safety, ethical failures, risk and liabilities, social justice, and engineering and poverty were taught more commonly by faculty at RA institutions compared to NRA institutions. An average of 5.3 methods were used by faculty at RA institutions to teach ESI topics in courses for engineering and/or computing students; the
most common methods were examples of professional scenarios, case studies, and in-class discussions. These same instructors used an average of 2.4 methods to assess ESI instruction, most commonly individual reflections. Co-curricular activities with professional societies, design groups, engineering service groups, and undergraduate research also included ESI education. Interviews with faculty at RA institutions revealed that the institutional cultures were important in supporting the ethics education of engineering and computing students. However, the extent that Biblical grounding and Christian values were included in the ethics education varied. The results provide ideas for infusing ESI into any type of course, focused on various topics using a range of teaching and assessment methods. It appears that on average faculty at RA institutions teach ESI topics more widely across various course types, using a range of rich teaching and assessment methods, than peers at NRA institutions. Further research is needed to explore the reasons behind these differences.

Acknowledgement
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References


IEEE, Institute for Electrical and Electronics Engineers. IEEE Code of Ethics.


“Philosophy of Teaching and Student and Peer Mentorship:
A Christian Perspective”

Scott Anson, Ph.D., P.E
Department Chair and Professor, Mechanical Engineering

Abstract

As Professors our students have the multifaceted status of being 1) our customers, 2) our product and 3) our future colleagues. In addition as Christians, they are our brothers and sisters in Christ or those we influence for His glory. As customers they have a choice where to pursue their education and have expectations. Some expectations are reasonable, some we need to recalibrate for them. As our product, their professional growth and abilities are to varying degrees a result of, and to a very large degree, a reflection of us and our institutions. As graduates employed in an industry we participate in and serve, they will become colleagues who will recall our relationship when they were students.

As fellow Christians, and those whose souls we are concerned for, we need to demonstrate and teach how to live the faith in their profession, and seek their spiritual growth and welfare as they grow academically and transition to their professional lives. We find ourselves rapidly switching roles from salesman, to customer service agent, to concierge, to manufacturing process optimizer, to trainer, to quality inspector, to warden or judge, to mentor, to friend, to career/life coach, to make shift pre-marital counselor, to poorly prepared emergency Pastor, to collaborator, to friend, and to brother or sister in Christ. In the mist of this chaos we are committed to teach classes to meet the requisite needs for career success and accreditation. How we teach; quality, demeanor, and life example is as relationally important as what we teach. A contemplated and written Philosophy of Teaching makes executing these diverse responsibilities easier and beyond that, a Philosophy of Student Mentorship can uniquely help us as Christian faculty. A sample of each philosophy will be presented and discussed as a starting point for subsequent individual creative thoughts and document generation. As a conversation starter, a fledgling philosophy of peer mentoring will be introduced for subsequent refinement.

Introduction

As engineering Professors we are called upon by our discipline to teach, serve, research and publish such that the next generation of engineers is prepared to face the challenges of today and able to figure out solutions to the challenges of tomorrow. All Professors share these individual challenges and the unsettling challenge of balancing between them in such a way that legitimate needs are met and tenure is granted. (Boyer) As Christian faculty we have, or should have, a tendency to be more likely to seek the best for others, while not neglecting our own concerns, such as tenure and promotion. In a Christian University context (largely undergrad, higher cost structure than a state university) the pressure to research and publish is often reduced, but not to zero. The new additional imperative is to answer the often unspoken question “What value does

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a student derive from this Christian University experience?” which is at the forefront in the mind of both students and parents. The answer often involves a philosophy of science as understanding how God has created the world and an examination of thoughts and findings for Biblical consistency, as well as community covenants for standards of living and behavior. However, feedback from parents has indicated that the key differentiating expectation is the way Christian faculty interact with and invest in their students. As teaching and learning is largely a human interaction, shouldn’t the human interaction also be affected by a Christian worldview such that teaching could be done differently by a Christian or in a Christian university context? While drastic deviation of tested and proven methods of teaching and human relating would be perilous at best and self-destructive at worst, perhaps a further refining of standard approaches from a Christian perspective would be wise and effective.

**Biblical Overview on Human Relating**

While this overview is cursory at best, it will provide a backdrop for consideration of a teaching philosophy. There are many verses and principles in verses that could be extracted to apply to the human interaction of teaching and learning. Some of them are highlight below:

Matthew 7:12 “So in everything, do to others what you would have them do to you, for this sums up the Law and the Prophets.”

I Peter 4:10 “Each of you should use whatever gift you have received to serve others, as faithful stewards of God’s grace in its various forms.”

Philippians 2:3-4 “Do nothing out of selfish ambition or vain conceit. Rather, in humility value others above yourselves, not looking to your own interests but each of you to the interests of the others.”

I Peter 5:5b” All of you, clothe yourselves with humility toward one another, because, “God opposes the proud but shows favor to the humble.””

Galatians 5:22-23 “But the fruit of the Spirit is love, joy, peace, patience, kindness, goodness, faithfulness, gentleness, and self-control. Against such things there is no Law.”

A Biblical word search on “teaching” or “one another” would surely provide additional insight for developing a philosophy of teaching.

**Questions for Reflection Before Developing a Teaching Philosophy**

A list of questions is put forth for consideration as the reader warms up to developing a teaching philosophy. The list does not include what must be taught, as that is covered by ABET requirements or when should it be taught, as that is covered by the course sequence.

1. How do I like to learn?
2. What distracts me from learning?
3. What makes learning boring for me?
4. Do I like a structure or outline up front, so I can see where a lecture or topic is going before I get there?
5. How does God get me to respond – force, kindness, winsomeness, patience?
6. What makes a topic seem scary to me?
7. What makes a scary topic seem doable to me?
8. What did I like about my favorite Professors?
9. What did I dislike about some Professors?
10. How is this generation known, or perceived, to be different from when I was an engineering student?
11. What helped me most when I was stuck on homework?
12. What as a student nearly broke my will to try?

What is A Philosophy of Teaching?
A philosophy of teaching is not overly pedantic or technical, but is broad and quite personal to the writer. There are numerous discussions and examples to draw from in the higher education community. (Chism) (University of Minnesota: Center for Educational Innovation) (The Ohio State University)

Common attributes of a philosophy of teaching are:

- 1-2 pages
- Personal statement and in first person
- Generally write in present tense unless reflecting on a past experience.
- Includes general (not course specific) goals for students
- Includes what is done to make teaching effective and why it is done – gives the rationale.
- While our students will not likely be invited to read it, it should be written at a level that our typical student could largely comprehend.

A Christian’s philosophy of teaching should have the same attributes that make a typical philosophy of teaching effective, but also have a sense of deeper human concern and desire for whole person prospering.

Below is an example for consideration.

Example Philosophy of Teaching

Given that a large part of my profession as a Professor is teaching, I have developed the following Teaching Philosophy as a set of guiding principles in teaching my courses. I would like to add that beyond teaching course material I am constantly modeling professionalism, responsible citizenship and people skills. Candidly, I find this realization simultaneously exciting and an awesome responsibility.

Major Goals for my Students

1) Learn the course material
2) Understand the industry relevance of the course material
3) Learn to think critically – question logical inconsistencies
4) Embrace lifelong learning
5) Learn to communicate effectively (groups, writing, presentations)
6) Learn to take personal responsibility (timeliness, quality of work)

The fundamental principle in my teaching philosophy is to teach a class the way I would want it taught to me. Out of this principle flow the following outcomes:

1. I provide clear communication of my grading criteria and expectations of students.
2. I provide multiple opportunities for grade assessment and consider that anyone can have a bad day on one exam day.
3. I engage students in class discussions by asking questions and encouraging students to share experiences on course topics.
4. I explain to students why we are studying an entire course or a specific topic.
5. I assign homework that emphasizes the important topics for the exams and professional practice and weight it as approximately 20% of the course grade. This weighting ensures that students do the assigned work and learn the material so we can move on to subsequent topics.
6. In calculation intensive courses, I provide solutions before most homework is due in order to allow students who are struggling with a problem to refer to the solution and learn the material the correct way efficiently. By me providing solutions before the homework is due, my students can avoid the frustration of wasting extensive time on a relatively simple mistake. I plainly warn students that if they blindly copy the homework solutions they will ‘earn’ the homework portion of the course grade, but I will catch them on the exams. The main objective behind this is effective use of their time and effort. The secondary benefit of this is effective use of my time in that the students have fewer questions and clearer questions when they come for help. This not only saves me time but, more importantly, allows me to spend time contributing higher value in students learning.
7. I encourage students to ask questions if something is unclear or if it seems contradictory to some other established course concept. I openly tell them that the contradiction could be 1) I misspoke, 2) they misunderstood, 3) some other possibility that we need to figure out.
8. I require students to maintain a professional atmosphere in the classroom, including no foul language or disrespectful attitudes. On one problematic occasion I told students something like, “I don’t know what happens in your other classes, but in this class we need to have mutual respect, between you, me and each other (fellow classmates). If you don’t have mutual respect, fake it. If you can’t fake it, find another class to take.”
9. When I don’t know an answer to a student question I openly tell them, “I don’t know”. I often follow up “I don’t know” with possible answers and candid uncertainty. Students have commented on course evaluations that they appreciate my openness.
10. I make great efforts to relate the course material to professional practice based on my own 8 years of industry experience and when applicable I incorporate my own scholarly publications in course material.

11. When students are losing interest in lecture, I try to engage them with questions and entertaining stories. My primary goal is to teach them, not to entertain them. However, if I make them laugh they will ‘wake up’ (become more engaged in class discussions) and if they are awake (engaged) they have a chance to learn.

12. I treat students with the respect that I would want to be treated with.

When dealing with struggling students I strive to apply the following principles:

1. “Warn the idle” – make students aware of the implications of non-performance
2. “Encourage the timid” – teach students who lack confidence that they can succeed
3. “Help the weak” – assist struggling students to help them develop the skills to succeed
4. “Be patient with everyone” – this principle applies to all categories above (“Idle”, “timid”, “weak”) and anyone else who I cannot ‘fit’ into one of these categories. Candidly, this is the toughest of these principles to practice consistently.

Surely other examples of philosophies of teaching can be searched and reviewed to gain broader insight in preparation for writing your own philosophy of teaching.

**Philosophy of Student Mentoring**

This document could be a continuation of the Philosophy of Teaching, but is likely more personal as the relationship between mentor and mentee is deeper than teacher and student. It deals with deeper interpersonal interactions that occur through the natural growth of some human relationships, a Senior Design Team, or a student who was “encouraged” (read - required) by Student Life personnel to find a mentor in response to a behavior problem. This document will also include general ministry and Christian living concerns. Below is an example.

**Example Philosophy of Student Mentoring**

1. I have a scary responsibility and will be utterly ineffective without God’s blessing and empowerment.
2. While student ministry is very important, neglecting my own wife and children would be sacrificing the essential for the important. I must be vigilant.
3. Not every student will connect with me or relate to my personality, but I do hope they know I care about them personally.
4. I can help people in things that I have not yet mastered as it is God’s word and Holy Spirit that give power, not my arrival at an ideal position.
5. In the closeness of Christian living, professional and personal boundaries must be kindly enforced and if needed, fiercely guarded. I am their brother in Christ, but I am still their Professor. They may be invited to my home but must respect my family. Alumni who become friends can call me Scott, students call me Dr. Anson. It reminds them and other students of the invisible boundary.
6. Not all students are Christians yet. I should deliberately look for opportunities/openness.

7. Christian young men need a model – kindness, boldness, tenderness, willingness to fight for what is important, grace, enthusiasm, leadership.

8. Christian young women need the same things as young men, but also need to be simply respected as people and treated as students. Focus on the commonalities (students, people who God loves, Christians, professionals forming) not the difference (gender).

9. Students want to be understood before they will take life advice.

10. Students want to discuss life problems and options, not be given answers.

11. Devotionals can be topical but often the daily life lessons that God teaches me resonate with students.

There are many fine examples of student mentoring philosophies, but they are largely for graduate student mentoring, and no examples were found that specifically included a Christian perspective. (Sollenberger) (Toke) (Barger)

**What About Practicing Engineers Mentoring New Engineers at Work?**

Mentoring in the workplace can be formal or informal. The risk of formal mentoring is that someone is asked by upper management to be a mentor and does it out of obligation or to get some sort of corporate “mentoring merit badge”. These obligatory mentors don’t necessary have the skills to care for people or even a desire for the welfare of the mentee. Mandatory mentoring is like mandatory kindness; it does not mean as much unless it is sincere. In general but especially in formal/mandatory mentoring scenarios it is very helpful to have a defined period for a mentoring relationship to continue such as 6 months or 1 year. It is much easier to renew a mentoring relationship than it is to fire a mentor. The prearranged timeline becomes a natural breaking point for a mentoring relationship to end if it is not bearing sufficient fruit or to be renewed if it is sufficiently beneficial.

**Guiding Principles**

It is essential to match expectations for mentoring colleagues. Some want a formal structured program with a curriculum and others want something less formal and more personal. A couple of years ago, a colleague and friend, asked if I would mentor him. I replied “probably, but let’s discuss what you want from me and the experience”. He replied, “I just want to ask you questions when I have them”. Well, we are in a mentoring relationship! I suggested a year period but it has been so informal that we lost track of the year and there have been some key times where I have been the one on the receiving end of the mentoring. As our friendship has grown, mentoring is not really a topic but trusted friendship and seeking each other’s wellbeing is.

You don’t need to have it all figured out to be a mentor and the mentee can be stronger than the mentor in some areas. Proverbs 27:17 states “As iron sharpens iron, so one person sharpens another.” This passage says nothing about one person having it all figured out or being somehow “better” than someone else. The key requirement is that the mentor care for the mentee and have some things to offer. Frankly, people who have most things figured out would either intimidate me or be unreachable from my position in the organization.
Questions for Reflection Before Developing a Work Mentoring Philosophy

1. What do I wish someone told me when I was a new Engineer?
2. What was I embarrassed to find out too late?
3. What “tribal knowledge” (unwritten but everybody knows it) exists in this company?
4. How could someone respect me as capable while guiding me as not knowing corporate culture?
5. How did I feel the first day with no desk or computer?
6. Who told me about using the group refrigerator and microwave?
7. How can I show appropriate care and respect before I give advice?
8. How can I give advice while allowing the mentee to act on it or not, without feeling like I think they are wrong?
9. How would I feel if someone referred to me as their protégé?

Example Working Engineer Mentoring Philosophy

Goals for my mentee:
1) Produce for the company
2) Grow in capability and confidence
3) They feel respected and cared for by me
4) Remain eligible for career advancement
5) They value other people (colleagues, management, customers)

1. I strive to make new people feel welcome in the workplace. This is done through a welcome greeting, checking if they are settling in alright and helping when they need something.
2. It costs very little time to stop in someone’s doorway and greet them. Read their body language and determine if it is best to connect for a moment, move on quickly that day, or most days.
3. I share tribal knowledge (unwritten norms) that would be difficult to figure out unless someone in the tribe shared them with you.
4. Coffee is not always about caffeine; it can be about connection. I often spontaneously invite a colleague or mentee for coffee as it allows us to catch up and possibly help with any concerns. It is important to reassure an invitee that we can have coffee another time if the time of my spontaneous suggestion is not best.
5. I think of things I wish had been told instead of floundering my way through and figuring them out. Examples are:
   a. Work is very unproductive between Christmas and New Years as many people are out of the office and those that are in the office are not fully engaged in work. You might want to take time off or plan some very independent work.
   b. On the Friday before a holiday weekend, nearly everybody leaves in the mid-afternoon.
   c. Bonus checks come out in May and November, if they are issued.
   d. Drive separately if taking customers to dinner with that colleague. He sometimes drinks excessively and you will not want to ride with him.
6. I provide my perspective on what works for me while realizing the mentee has a different set of skills, style and perspective. It is essential that the mentee feel free to not take my advice in that they can consider it and freely decide to take a different course of action.

A Biblical Model of Mentoring
I Thessalonians Chapters 1 and 2 are a demonstration of biblical mentoring. Paul, Silas and Timothy greet the church of the Thessalonians in this letter. Paul had mentored both Silas and Timothy and now the three of them are mentoring the Thessalonians. The highlights of this mentoring are:

*I Thessalonians 1:5b-6 “You know how we lived among you for your sake. You became imitators of us and of the Lord, for you welcomed the message in the midst of severe suffering with the joy given by the Holy Spirit.” (Emphasis added)*

Paul, Silas and Timothy modeled the Lord so the Thessalonians could see it an imitate service, faithfulness and Godly suffering.

*I Thessalonians 2: 7b-12 “Just as a nursing mother cares for her children, so we cared for you. Because we loved you so much, we were delighted to share with you not only the gospel of God but our lives as well. Surely you remember, brothers and sisters, our toil and hardship; we worked night and day in order not to be a burden to anyone while we preached the gospel of God to you. You are witnesses, and so is God, of how holy, righteous and blameless we were among you who believed. For you know that we dealt with each of you as a father deals with his own children, encouraging, comforting and urging you to live lives worthy of God, who calls you into his kingdom and glory.” (Emphasis added)*

As Paul, Silas and Timothy lived their lives in service to the Lord; they modeled and urged/exhorted the Thessalonian church (mentees) to do the same. They lived well among them so others could model after them, and in so become more like Christ. At times it is unclear whether Paul is mentoring Silas and Timothy, or whether they are mentoring the church at Thessalonica. While it could be an interesting topic to discuss over good coffee, the important point is that mentoring was occurring, and people were growing in work ethic and in service to Christ.

Conclusion
In the conduct of our profession as Christian faculty, we find ourselves rapidly switching roles from salesman, to customer service agent, to concierge, to manufacturing process optimizer, to trainer, to quality inspector, to warden or judge, to mentor, to friend, to career/life coach, to make shift pre-marital counselor, to poorly prepared emergency Pastor, to collaborator, to friend, and to brother or sister in Christ. On the surface this is impossible, or at least unreasonable! Upon reflection this is no more than what our Lord and Savior Jesus Christ offered us in that He is our brother, Creator, teacher, judge, substitutional atonement, companion and friend. It is our call as Christian faculty to imitate Christ as we fulfill these diverse and manifold roles. May the reader

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2 Thanks to “Abstract Reviewer 1” for calling out this thinking.
find comfort and inspiration in His words in Matthew 11:29 “Take my yoke upon you and learn from me, for I am gentle and humble in heart, and you will find rest for your souls.” What has been put forth is a lofty goal, but should be considered in the fuller context of scripture such as Proverbs 21:31 “The horse is made ready for the day of battle, but victory rests with the Lord.” This verse concisely states the duality that we must work and exert effort in life but that we cannot guarantee outcomes in that God is ultimately responsible for the outcome (“victory”). Our role is to do what we can to honor Him and lead a balanced life; not overworking as some misguided sense of duty. As Professors and former/current practitioners of engineering, we have the opportunity to inspire our students, who are becoming engineers, to first seek a mentor in the workplace and to eventually become a mentor as an act of service to others.

Bibliography


Beyond Voluntourism: Examining the Motivations and Roles of Engineering Student Groups in International Development

Thomas S. Soerens

Abstract

Each year, nearly 300,000 US college students study abroad and many more go on short-term service trips. The ethic of using engineering skills to serve developing communities abroad is strong in the engineering field. For Christian students and Christian colleges, this service can also integrate with their mission to serve God by serving and evangelizing others, whether motivated by charity, philanthropy, or scriptural mandate. These service programs have impacted students profoundly, often changing the life course of a student. But do they positively impact the targeted communities? Is it efficient to spend $30,000 in travel money to send an unskilled student team to drill a well that could be constructed better by a local well driller for $2000? Certainly it’s a great experience for the students, but what about the community? Does it in fact engender passiveness, cynicism, and dependency by the local partners? If we conclude that it’s inefficient, that we should just send money so a local business or an experienced NGO to drill the well, then do we deny the students a potentially life-changing opportunity?

What is the role of student groups and engineering in academia in serving the poor? How might the approach at a Christian college be different from a state university? This paper discusses the motivations and practicalities of student projects for development and how they integrate with faith, scholarship, and education. Experiences and lessons learned from implementing international community development into the engineering curriculum at The University of Arkansas and at Messiah College are presented.

Introduction

“Dear children, let us not love with word or with tongue but in deed and truth” 1 John 3:18

As John reminds us, Christian believers are called to demonstrate their love. We have a scriptural mandate to walk in the anointing of Jesus who said:

"The spirit of the Lord is upon me, because he anointed me to preach the gospel to the poor. He has sent me to proclaim release to the captives, and recovery of sight to the blind, to set free those who are oppressed, to proclaim the favorable year of the Lord” Luke 4:18-19.

All believers are called to serve others and to proclaim the gospel in word and in deed. Many of the ways we serve we have in common, but starting with the third generation on earth (Genesis 4), people’s contributions were organized into different occupations. College students are looking to find their calling, their vocation, and their area of service.

In pursuit of answers to these questions of life, some students participate in short-term service opportunities in developing communities. These trips have multiple goals – 1. specific education of the student in their major, 2. clarifying of the student’s passions, goals, and priorities of their
Christian calling, 3. having a good time and experiencing a different place and culture, and 4. benefiting the partner community. Of these goals, it is the first and last that are the most difficult to accomplish. Service trips often turn into “voluntourism”, where the students have a good time, are inspired and impassioned for service, but do not have lasting benefits to the partner community. In addition, the work students do during their service trip often does not fulfill specific outcomes and objectives of their major curriculum.

This paper discusses the motivations and practicalities of student projects for development and describes a model that is appropriate for a college or university, provides great experience for students, and serves communities. The aspects of this model are 1. Long-term partnerships with specific communities, 2. Students working on innovative technical improvements to systems that can be used to serve developing communities, and 3. Site visits by students with specific objectives to investigate the specific community situation and/or to install pilot systems.

I believe that short-term student service trips can be valuable in the positive transformation of students and the target community while integrating into a student’s scholarship and Christian calling. And I believe that an exemplary model of integrating service into a student’s education is the approach taken by Messiah College, which incorporates the three aspects suggested above.

Motivations to Serve Developing Communities

“I pray that the eyes of your heart may be enlightened, so that you will know what is the hope of His calling, what are the riches of the glory of His inheritance in the saints” (Ephesians 1:18).

I believe God’s glory among the poor is seen in them getting out of poverty, both physical poverty and the poverty of spirit that Myers calls their “marred identity”. The glory of God is best displayed among the poor by them rising out of their poverty and knowing the infinite grace available to them in the kingdom of God. Our job as believers is to glorify God among the poor by fighting poverty of spirit and body and to not “separate gospel-as-word from the gospel-as-deed”.

Christian engineering students often wrestle with combining their zeal to serve God and their heart to serve others with their inclination and aptitude toward a technical career. I know I faced this as a college student. I and other students decided that we could combine all three – serving God, serving others, developing technology - by engaging in technical work that serves the poor in international development and supports Christian mission work. We believe this is our calling and vocation and that engineers are specially equipped to help meet the physical needs of the poor, which is an essential role of believers. Jordan points out that vocational calling is more easily understood in the context of liberal arts education than in engineering and questions whether this call can be taught to engineering students, but concludes that engineers working on international projects is a good fit for Christian engineers and for engineering programs at Christian universities.

The calling or motivation to serve the poor in international development can come from several origins. Peppard, writing from a Catholic theological context, sees the right to water as a theological and ethical mandate, a justice-based motivation similar to liberation theology. Slim writes from a Christian viewpoint but talks of the “ethical origins of humanitarian instincts”. He points out that aid is motivated by philosophical and ethical motives and not exclusively
theological motives. Many Christian leaders take the more traditional straight-forward approach that serving the poor is simply what we as Christians are called to do. Beer makes a distinction between philanthropy and charity. Charity, in his description, is “an inescapably personalist and remarkably nonconsequentialist ethic” and is motivated by personal connections and desires. Philanthropy, on the other hand, is more strategic and is concerned with results. The tension between the two approaches is an ongoing issue in large scale development and is an especially pertinent debate when assessing small group projects. As discussed later, there are calls for more evaluation of results in student projects. And Myers emphasizes that “what works” is an important part of “gospel-as-deed”.

A student project team will almost always be charity motivated. It would almost always be more efficient to give the team’s funds to an experienced non-government organization (NGO), and projects are almost always selected through personal connections rather than strategic targeting. If we only make choices on “what works”, aren’t we denying students a possibly life-changing experience? Is it selfish to want to be involved ourselves? Is it selfish to pray “here am I, send me?” (Isaiah 6:8). Shouldn’t we rather pray “here am I, but send whoever can do the job most effectively and efficiently”? I would argue that charity-motivated projects are still valuable, valuable to the students involved, and valuable to the community served. A well conducted project may not make a huge difference in solving the problems of the whole world, but like the boy in the starfish story, we can say “it made a difference to that one”.

As Christians, we are also motivated to engage in projects that advance the preaching of the gospel. For example, at The University of Arkansas (UA) I worked with a student senior design team to develop a small community scale rainwater filtration system using biosand filters. I then traveled to Colombia to install filters in previously unreached indigenous villages along an Amazon tributary as a part of an evangelistic effort by Pastor Jaime Useche with YWAM Colombia. So the clean water systems were an opening to bring in the spoken gospel. Jaime even allowed me to preach in one of the villages. I preached the gospel and he translated, although I would speak one sentence and then he would “translate” for about five minutes. Often a mission group is motivated to work with a student team because it will help them with the service part of their ministry and the team’s visit can coincide with a special evangelistic effort. For a Christian believer, it is the eternal impact of their work that is the most valuable and working in a missionary effort makes this explicit. Myers cautions, however, that when we only do the physical because it leads to the spiritual, we deny the holistic nature of the gospel.

Whether motivated by charity, philanthropy, justice, ethics, scriptural mandate, or opportunity to preach the gospel, we see a strong desire among students and others young and old to travel overseas and help the poor. That desire is almost universally seen as a good thing, but it needs to be done correctly. We have made a lot of mistakes on every scale from large intergovernmental efforts to small groups and individuals. And the idea that we’re doing good can mask or justify pride and hubris and can lead to us hurting those we’re trying to help or even hurting us and our families. The remainder of this paper discusses how to apply the lessons from the past to help us design student project experiences that are positive for the students and the communities served.
The Problem with Voluntourism

Each year, about two to three million people from the United States go on short-term mission trips internationally at an average cost of around $1400 per person. If you travel to Central America in May, odds are that there will be several mission or school groups on your plane in matching t-shirts ambitiously proclaiming their mission to save Belize or Honduras or Nicaragua. The group will likely work with a local mission group to do a service project and will then spend a day or two visiting tourist attractions. Voluntoursim is not exclusively a Christian phenomenon, but the 2009 book, *When Helping Hurts*, by Steve Corbett and Brian Fikkert, awakened many in the Christian community to the concept that short-term, paternalistic mission trips can do more harm than good. The authors point out that spending tens of thousands of dollars to send short-term, untrained young people to “save” poor people in developing communities makes no economic sense and can disturb rather than assist the local partner organization and the community they are trying to help. These observations have been echoed by other recent Christian authors as well.

Although *When Helping Hurts* was a needed wake-up call, it should not have been necessary. Many of the revelations in the 2009 book were recognized in the development community decades earlier. The Peace Corps began in 1961 and thousands of volunteers were sent out. By 1964, Peace Corps volunteers and administrators recognized that a project was only successful “if the people are well-organized and can carry on projects after you leave”. In the 1970s there began to be scholarship and textbooks laying out methods for involving community participation in development. At the same time, there began to be some critical reevaluation of appropriate technology assumptions. Also in the 1970s, The World Bank, the Peace Corps, and other aid agencies began using anthropologists in their water and sanitation programs to assure that the programs fit with the community. Chambers emphasizes the need to spend time in rural areas personally interacting with the poor and to understand their vulnerability and powerlessness, but he warned against “rural development tourism” in 1983 and continued to warn against it in the following decades.

Short-term mission and service trips can be justified by the educational and life experience value to those who are traveling. Kollman and Tomas-Morgan observed that international service-learning trips “showed significant changes in the worldviews of student participants” and that these trips in faith-based contexts have “important potential to help students connect their deepest convictions … to their broader education”. The authors go on to state “It thus behooves religiously affiliated universities to utilize their distinctive religious foundations as they integrate international service learning into their broader educational goals”.

To realize the value of these trips to the student travelers, it is important that the travelers consider themselves learners and not saviors to the poor people they’re visiting. The international NGO that facilitates UA community development study abroad program outlaws the use of the word “help”. The idea is that we partner with the community, not “help” them. In *When Helping Hurts* and the follow-up workbook *Helping Without Hurting in Short-Term Missions*, Corbett and Fikkert suggest that short-term trips adopt a learner approach and not think of themselves as “sacrificing” to go on these trips. The authors also suggest that the travelers not engage in the tourist activities. I believe the travelers should embrace the fact that they are tourists. Too often I have heard students on these trips ridicule the measly tourists or expect some special treatment or prices because they are there not as tourists but rather as
saviors. Embracing the tourist part of their trip would help the travelers understand their role better. Those who go on these trips should recognize what a tremendous privilege they have to travel and meet and interact with people far away. This opportunity is possible because of the wealth of them, their parents, their church, or someone. Traveling on a short-term mission trip is a wonderful, expensive luxury, not a sacrifice.

Short-term service trips can also be a blessing to the target community. If done correctly, the trip can be a big boost to the local partner organization, can bring new ideas in, can produce a project that would not have happened otherwise, and can be inspirational to individuals in the community. However, hard questions on the effectiveness of the project should probably be asked. Easterly\textsuperscript{23} emphasizes that quantitative assessment of development projects has historically been lacking and that all new programs should include quantitative assessment of their results and should be adaptable to the assessment results. Peace Corps partners were calling for more research and assessment of program and project outcomes as far back as 1965\textsuperscript{24}, but such work is still lacking. Measurement and assessments must also get at the fundamental questions of whether people’s lives are improved. Bartram\textsuperscript{25} argues that current all-or-nothing measurement of water and sanitation, e.g., has or does not have improved water, do not adequately describe the water and sanitation situation and needs. More descriptive and adaptive measurements and assessments are needed\textsuperscript{26,27}. Ongoing projects also require management methods that respond to the community. In addition, asking tough questions up front about the outcomes of a project may impact the project selection process\textsuperscript{28}. Amadei\textsuperscript{29} has recommended a systems approach to modeling community development projects and has also compiled a guide to planning and evaluating the types of projects undertaken by student teams\textsuperscript{30}. Lupton\textsuperscript{12} advocates using business world measurements to assess development including short-term service trips.

For student group projects, a university works with an NGO or mission organization that works with the partner community. A university group can initiate assessment and measurement and follow up over time, but the community participation and ongoing management of the project goes through the partner organization. In some cases, the missionary organization is “old fashioned” in how they involve the community. The students, who have recently been enlightened and are idealistic about community participation and local control, sometimes chafe at how the missionary does things. However, the missionary has a history of working in the community, knows the specific situation much better than the students do, and the students should be instructed to go along with the decisions of the local partner. Discussions between the missionary and the faculty and students about how and why the missionary makes their decisions can be educational to both sides.

A Better Model

So what is the appropriate role of student groups and service trips in international development? I believe that trips that sync with longer term community development, that are part of valid technical, educational, or economic advancement, and have specific objectives can be valuable to the students traveling, to the partner community, and to the scientific and engineering community.
The three important aspects of effective international service projects are:

1. Long-term partnerships with specific communities
2. Innovative technical improvements
3. International trips with specific objectives related to the students’ project

Messiah is working toward fulfilling these aspects in their projects. I will describe how Messiah fulfills these aspects and contrast this with other programs including the community development summer study abroad program I helped initiate at UA.

In Messiah program, projects are performed for real clients. We make an effort to work with clients over the long term on multiyear projects and to initiate new projects with the client and the partner community. For example, an alum in Burkina Faso has worked with Messiah on the mobility trike project for over a decade. Other multi-year projects with this alum have included biodiesel, solar power, and well drilling. Another example is Friends In Action working among the Rama people in Nicaragua. Our partner first approached us about improving the design of a block-press machine for construction blocks. In addition, we are also initiated a latrine project and a footbridge project. The hope is to work with the partner over several years in several improvements in the Rama community.

The longer-term projects facilitate deeper engagement and partnership with the community, allow us to observe the sustainability and appropriateness of the project over a period of time, and give feedback for technical and non-technical improvements. Multiyear project continuity also has value in the education of the students.

The service-learning summer study-abroad program at UA also values long-term partnership and multiyear projects. When we decided to partner with a community, we made a commitment to come every summer for at least five years. The program is currently in its 11th year working in the same community. However, there is not as much continuity in the projects as there is at Messiah. The students are involved for only one summer each and the projects are not integrated into the academic year. Some of the projects, most notably the micro-finance projects, are sustained year-to-year, but each summer has a different group of students and many of the projects turn out to be one-off construction or implementation projects rather than ongoing projects that can be sustained and iterated year to year.

Because we were working with the same community for three to five weeks each summer plus another one week trip during the academic year, I made some very close relationships with local people in Belize through UA of Arkansas program. I spent many hours with several individuals and became good friends. The students, however, were only there one summer each. At Messiah College, the students worked with partners at a distance for two to four years and connected in person a few short periods over those years. The Messiah students often formed bonds with the missionary partner and several of our students joined the mission groups upon graduation. So the relationship dynamics are different in the two programs and they both have their advantages and disadvantages.

The second aspect of a better model for student service teams is technical innovation. Engineering projects in developing countries are a good fit as senior design experiences. It is
more difficult to incorporate such projects into other courses. At Messiah, the projects are integrated into a required five-semester project sequence and students can choose to be involved from their first semester. Projects performed through the engineering curriculum at Messiah are focused on technical innovation. Messiah is not an NGO that implements established technologies and not a research institution that advances pure research. Our role is to make innovations that solve specific problems for our clients and lead to technical advancements that can be applied more broadly. For example, the Village Water Ozonation System (VWOS) project took an existing technology, ozonation, which had been used for disinfection of hot tubs, pools, as well as for larger scale water disinfection and applied and adapted it to an in-between scale of a girls’ home in Nicaragua. Ongoing iterations lead to exploring its application to a community center in Mexico and possibly to truck-mounted mobile systems that can be used to start small businesses of pure water provision. Branching off of what was learned though applying ozonation, the VWOS team is now looking to adapt existing UV disinfection and biosand filtration to in-between scales. This is all made possible by the project being ongoing, the student team actively working on the project during the academic year, and having underclassmen working with seniors and then getting their opportunity to lead. Technical innovation is the focus of the project and Messiah programs support innovation.

At UA, we worked with a national park and the adjoining village every year during our summer program. We built a small gravity fed water filtration for the village in 2007, greatly expanded it in 2009 based on a senior design project, and made major adjustments to it in 2010. Integrating the water system into a senior design project in 2009 allowed us to make iterative improvement on the system. However, because we did not have an ongoing team working on it over the years, much of the design work fell to the faculty (me) and we did not have the knowledge transfer and integration that we have at Messiah. Nor did we have time dedicated during the academic year to do research, go back and forth with our client, and make technical improvements before the implementation. I believe we could have made a better design more quickly had we integrated the project into our curriculum as we do at Messiah. The year-by-year approach hindered technical innovation.

The third aspect of an improved model for student service projects is to have specific student project objectives for the service trips. This is in contrast to mission trips or service trips that merely have the students participate in an outreach or service effort chosen by the host mission agency or have the students engage in a cross-cultural experience. Those experiences can be valuable to the student and to the host mission and have their place, but are not specific to the student’s academic objectives. Trips made for specific project objectives will drive the students to achieve more academically and, in my opinion, are more justifiable. For example, the Block Press team at Messiah is planning an implementation trip in June 2017 for their block press design. The client has a specific goal to have a working block press in June. This urgent request has pushed the team to design a press, get it manufactured, and have it ready to go for the summer. The project is driving the trip and the students have individual ownership in seeing the project completed. As part of the trip, the students will also support the partner’s service and evangelistic efforts, and will have a valuable cross-cultural experience.

Our program at UA also had specific project objectives, but the students signed up for the program before knowing what the projects were and did not have ownership of the project in the same way they do at Messiah. At UA, it was the trip that was driving the projects. We had a
group of students showing up in the summer and needed to have something for them to do. The
UA program had longer time for the students on the ground than the Messiah site trips, but a
shorter-term project life over all. The different time scales have their advantages and
disadvantages.

I believe Messiah model, which integrates projects and scriptural disciplesships is an excellent
model. There are of course improvements to be made and we fail to perfectly live up to our
ideals. For example, we are not always as client-driven as I presented. I contrasted the two
programs, but I believe we did a lot right at UA and I am very proud of the program we built
there. Although we did not work with Christian mission groups in that program, many of our
students were Christian believers who wanted to serve God in missions and saw the program as a
step in their calling and vocation. At UA, the trip abroad is credit-bearing while the academic
year is not and this is reversed at Messiah. I believe Messiah model is better, but it would
improve Messiah model and we could get more student and faculty involvement for the trips if
we could make them credit-bearing without losing the credit for the academic year project work.

Summary
As Christians, we are called to serve the poor, preach the gospel in word and deed, and do our
part to restore the wholeness that Jesus paid for in each person’s life. Service projects in
developing communities can play a part in this mission and can be a stepping-stone and
clarifying experience in the life of a student. Unfortunately, short-term service trips are often not
much more than “voluntourism” that is inspirational to participants but does not accomplish
much for development. By integrating short-term service trips into a student’s curriculum, by
having specific project objectives for these trips, and by working with a developing community
partner over a period of years, these service trips can be more effective and efficient.

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A Brief Survey of the Biblical Integration of Engineering and Missions
with Emphasis on Appropriate Technologies

Frederick G. Harmon

Abstract

A Biblical foundation for the integration of engineering and missions, an overview of appropriate technology in a Christian context, a survey of projects at other Christian engineering programs, and proposed engineering projects are discussed for remote areas and developing countries. At the core of the Biblical integration of engineering and missions is the desire to use engineering skills and resources to assist others, especially those in the Christian family, improve their lives, help them obtain Biblical information, and encourage personal responsibility. Engineering topics are proposed that will help people gain access to information, improve agricultural methods, improve their health, and grow in the Word. Through engineering efforts, Godly relationships between engineers and others in developing countries can be fostered to help spread the Gospel. The specific categories of topics that are considered are electrical engineering focused and are in the areas of electrical power, instrumentation and data logging, telecommunications, remote sensing, radio, agriculture, medical equipment, and security systems. Emphasis is placed on appropriate technologies that are small-scale, can be fabricated with local inexpensive materials, and can be maintained locally by the people.

Introduction

Numerous opportunities exist, inspired by Scripture, to apply engineering skills and talents to improve the lives of others in our nation and around the world, which can result in relationships where the Gospel can be shared. Inspiration for the integration of Biblical principles, engineering, and missions can be found in Matthew 25:35-36 where Jesus says “For I was hungry and you gave me food, I was thirsty and you gave me drink, I was a stranger and you welcomed me, I was naked and you clothed me, I was sick and you visited me, I was in prison and you came to me.” [1] Engineering talents and resources can be applied to help people improve their methods for growing and harvesting food, obtain water, and develop medical equipment. Inspiration for technologies such as radio equipment and smart phone apps that can be used to spread the Gospel can be obtained from Romans 10:14 that says, “How then will they call on him in whom they have not believed? And how are they to believe in him of whom they have never heard? And how are they to hear without someone preaching?” [1] Numerous opportunities are available for engineers to meet the needs of others, improve their lives, and in the process build relationships to share the Gospel and spread God’s Word.

This brief survey paper includes material obtained from a literature search, insight into efforts at other Christian engineering programs, and feedback from discussions with missionaries and engineers working in the field. It discusses the Biblical foundation of missions-focused engineering and a concept, appropriate technology, from a Christian worldview. Emphasis is placed on surveying appropriate technologies (AT) that have been and could be developed to improve the lives of people and be used as a means to build relationships to share the

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Gospel. Missions-focused engineering projects that have been completed at several Christian university engineering programs will be summarized. Then technologies and topics are proposed that could be developed or taught in senior design projects, engineering electives, and other courses. Interdisciplinary technologies could also be developed with collaboration between departments such as engineering, biology, and business. In addition, possible collaboration opportunities with other Christian universities with engineering programs are proposed. The suggested topics emphasize that the development of the technology is to improve the lives of others, to develop God-honoring relationships, and not just to develop what could be considered a new “cheap” technology.

**Biblical Integration of Engineering and Missions**

The importance of missions-focused engineering will be highlighted with a few key Biblical concepts such as transformation (Romans 12:2), doing good to others (Galatians 6:9-10, Philippians 2:3-4), personal responsibility for a project (Leviticus 23:22), and the Great Commission (Matthew 28:16-20). These key concepts provide direction and insight into the importance of using our engineering skills and resources to help others and improve their lives.

Engineering conducted in the context of serving others and meeting their needs is one area where the engineering field can glorify God and reflect His transformative work in this world. Romans 12:2 declares “Do not be conformed to this world, but be transformed by the renewal of your mind, that by testing you may discern what is the will of God, what is good and acceptable and perfect.” [1] Christ is the creator and redeemer of all Creation and is transforming us to be more like Him. Ashford, in his article about the relationship between Christianity and culture, says, “God’s redemption and restoration transforms us in the totality of our being, across the entire fabric of our lives.” [2] As Christian engineers, God can use us to transform our culture and He can utilize our creative abilities to help others flourish. We desire to glorify Him and be used as His light in the workplace and in the mission field. Christian engineers want to apply their engineering talents and skills to participate in His transformative work. We want to be transformed to be more like Christ allowing God to use us to reach others with His Word.

Another important aspect of the integration of engineering and missions is that we are encouraged to do good to everyone. Galatians 6:9-10 commands “And let us not grow weary of doing good, for in due season we will reap, if we do not give up. So then, as we have opportunity, let us do good to everyone, and especially to those who are of the household of faith.” [1] Philippians 2:3-4 complements this Scripture by commanding us to “Do nothing from selfish ambition or conceit, but in humility count others more significant than yourselves. Let each of you look not only to his own interests, but also to the interests of others.” [1] Excellent statistics are available for topics where people can be helped: “Of the 5 billion people living in the developing world, one billion are illiterate, one billion lack access to safe drinking water, and 2.5 billion lack access to basic sanitation.” [3] Fellow Christian brothers and sisters around the world can be assisted with our engineering skills in many ways. Ideally, we want to teach them about designing and building devices that will help meet their basic needs, but also show that as fellow Christians, we are serving them as members of the body of Christ.
As we help fellow believers in other countries, we also want to help build their confidence, responsibility, and independence. One important concept related to these character traits is found in Leviticus 23:22, “And when you reap the harvest of your land, you shall not reap your field right up to its edge, nor shall you gather the gleanings after your harvest. You shall leave them for the poor and for the sojourner: I am the Lord your God.” [1] Based on this Scripture, the poor had to walk to a field to gather some of the gleanings, which illustrates that resources should not necessarily be given directly to the poor but the poor need to participate and supply labor and time to obtain the resources. Their participation gives them a sense of ownership and responsibility. Dale Harlan, from the organization Serving in Mission (SIM), and Gonzalo Fiorilo, from the BOL-CAN Foundation, emphasize three related concepts in their water supply ministries as they help those near Cochabamba, Bolivia. They refer to the concepts as self-led, self-financed, and self-propagating in the context of a Christian worldview, recognizing that God is providing for them [4]. With assistance from engineers and missionaries, the participants are expected to learn how to make the wells and hand-operated pumps, provide half of the funds, and supply labor toward the construction. In the process, they build confidence that they can construct a device and learn how to maintain and repair it. The water ministry based on Scriptural principles has resulted in a very successful outreach to help people obtain clean water and build their confidence, but also has developed numerous Godly relationships between engineers, missionaries, and local people.

Using our engineering abilities to serve others, help them learn new skills, and build their confidence are very important. However, the greatest reason for committing time and resources is the Great Commission (Matthew 28:16-20). The Great Commission commands Christians to witness to others near home but also in lands further away. Relationships with others and building bridges to share the Gospel should be a top priority as we engage in various engineering projects. Engineers and missionaries from SIM have been involved in water supply ministry. A hand-operated water pump has been developed by SIM and tested in rural areas in Bolivia. Cedarville University (CU) engineering teams have participated in some of the efforts. The successful trips that CU teams have taken to Bolivia to assist with water ministry and church encouragement have proven that God uses engineering efforts to help build Godly relationships and spread His Word. For example, a 2016 Bolivia engineering team helped install a water pump for a woman named Aurelia. The team decided to buy her a Bible and then many of her friends asked if the team could help them get Bibles. The local missionary has arranged for the team to help purchase approximately 75 Bibles for her friends, family, and other church members. The recipients of the Bibles each pay half of the cost and the team assists with the purchase of the rest. God used an engineering project to open up an opportunity to spread His Word. The proposed projects described later in this paper are intended to provide opportunities to build relationships to help spread God’s Word in addition to improving people’s lives and meeting basic needs.

Appropriate Technology

Scripture clearly emphasizes that efforts be taken to use our skills and talents to meet the needs of others and help build independence and responsibility. One concept found in the literature that has several Biblical principles is “Appropriate Technology.” Although not derived from Scripture, aspects of appropriate technology (AT) are beneficial from a Christian perspective to
assist others with their technological needs. Appropriate technology (AT) is characterized and defined by technologies that are “small-scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community.” [5] Advantages of AT are summarized by Hazeltine and include the following: provides goods, services, and jobs that can’t be provided otherwise, benefits a lot of people not just a few, is less disruptive to the social structure, can be adapted to local requirements, fosters self-reliance and responsibility, and encourages cooperation and frugality [5]. Developing these types of technologies have Biblical underpinnings since they help others as God commands, encourage participation by the people due to the small scale, use locally available resources that God has provided, and encourage self-reliance and responsibility as discussed in Leviticus 23.

The aspects of AT that have Biblical parallels will be emphasized in the rest of the paper. AT concepts can help guide ideas for engineering projects that can improve the lives of people in rural or remote areas. If the technology is small-scale and decentralized, then local residents can participate in the development, fabrication, and maintenance of the technologies and devices. If the materials are obtained locally, then the equipment will more likely be affordable to those in-country. The owners can pay for some of the costs and contribute labor to the assembly and maintenance following the principles of Leviticus 23:22. Long term, families could develop small businesses to manufacture and assemble devices or teach others to do the same.

Another objective of AT is to involve more members of an area in the economic activity. Biblically, this could be thought of as doing good to others. One critical aspect of AT is that instead of a large industry controlled by a few people, many people are involved in the productivity of items. Akubue stresses, “It goes without saying that using AT to stimulate productivity and employment in sectors outside the modern sector is such an important objective that it ought to be seen as a national imperative.” [6] Evidence shows that getting more of the society involved in more of the production stimulates the economy. Helping more of the people in a country participate in manufacturing and developing beneficial technologies is doing good to others.

A few Biblical reasons for the support of developing AT have been given. If an engineer or missionary helps many people in a society be more productive and helps them develop self-reliance and responsibility, then this encourages more relationships to be developed and opens up the door for the Gospel and Christian discipleship. These are Biblical reasons for considering AT but criteria can also be specified to determine the possible success of a particular technology.

From the perspective of a Christian organization with limited resources, it is important that resources be used prudently. Therefore, the proposed AT projects must be judged using criteria. Some of the possible criteria to judge the appropriateness of technology is given by Wicklein and are listed below [7]:

1. Systems Independence: relates to the ability of a technology to stand alone or does it need supporting facilities, materials, and equipment. If it does need supporting materials and equipment, are they available locally?
2. Image of Modernity: people want to be perceived that they are modern and progressing in their society so the technology has to provide a positive image from the perspective of the local people.

3. Individual vs. Collective Technology: this criterion is related to the culture where the technology will be implemented and the type of culture will determine how well it will be successful.

4. Cost of Technology: a very important consideration and what may seem cheap to us may still be too expensive for another society so it must be determined if the people are willing to pay for the technology.

5. Single-Purpose vs Multi-Purpose Technology: certain technologies may be more successful if they can serve more than one purpose.

This is intended to be a brief overview of criteria to consider for any new technology. The proposed technologies listed later in the paper should be evaluated using criteria such as these depending on the location, materials available, and the culture that will use the technology.

The book by Bunch entitled “Two Ears of Corn” also lists some very relevant questions and some are summarized here. Many of the questions are similar to the criteria already provided [8]. The type of culture, intended application of the technology, cost, and other areas addressed below will also determine the success of the technology.

- Perception: Is the technology recognized as being successful?
- Usefulness/Benefits: Does the technology meet a felt need? Will the technology benefit the user? Does it arouse enthusiasm with the potential users?
- Cost: Is the technology financially advantageous? This was mentioned in the criteria and the local people do not necessarily have to pay for all of a new technology but enough so that they have a sense of ownership and responsibility.
- Uses Local Resources: How does the technology use the resources that are locally available? This topic is related to the systems independence criteria described by Wicklein. A technology is more likely to have success if the users have local supplies to fabricate and repair the technology.
- Culture: Is the technology culturally acceptable? The type of culture being either collective or individual will help determine if the technology will be successful.
- Simplicity: Is the technology simple to understand? Can the technology be communicated efficiently? Does the technology require minimal on-site supervision?
- Education: Is it simple to teach? Missionaries involved in the water ministry of SIM teach the local people how to assemble the concrete rings for the well and PVC pipes for the pumps. The technology is simple enough to teach to make it successful in the culture.
- Number of Applications: Is the technology widely applicable? Just as Wicklein suggested multiple uses, if the technology can apply to multiple uses then that will encourage the success of the technology.

These criteria and questions need to be considered and are important for the success of a technology in a new society or culture. Organizations such as Practical Action, National Center for Appropriate Technology (United States), and Centre for Appropriate Technology (Australia) have many more resources where a Christian engineer could obtain ideas and judge them against
the appropriate criteria. Potential topics should be evaluated in light of the Scriptural topics listed above and also the cultural considerations, cost, and other criteria described.

**Christian Engineering University Projects**

Engineering teams from Cedarville University (CU) have worked on a number of missions-related projects in Romania, Liberia, and Bolivia. The teams that have traveled to Bolivia during the last three years have focused on clean water ministry supporting SIM and the BOL-CAN Foundation. A hand-operated PVC water pump has been developed by SIM, modified and tested during senior design projects, and tested in the field near Cochabamba, Bolivia. Prior to the involvement in Bolivia, CU took several missionary teams to Liberia. Teams worked with SIM in Liberia on a number of projects related to solar-powered lights, clean water ministry, and well-drilling machines. The projects in Liberia and Bolivia have been guided by Biblical principles and some of the AT concepts.

Other Christian engineering programs have also participated in several integrated engineering and missions projects. As a fellow Christian engineering program, much can be learned from them and a few of the projects are summarized in this section (the list is by no means all-inclusive). Other universities also have efforts in these areas but there is not sufficient room to include them all. In this survey paper, information from three other universities are included: Messiah College, Letourneau University, and Dordt College.

David Vader at Messiah College has established a well-run and financed collaboration center called “The Collaboratory for Strategic Partnerships and Applied Research” that supports a number of missions-related engineering projects [9]. Some of their work is in collaboration with SIM at Burkina Faso, Africa. Various groups in the Collaboratory focus on different technical areas. One group in the Collaboratory Center focuses on communications technology. One research topic related to the internet and telecommunications involves using VSATs for internet connectivity. Increased internet connectivity in a region can improve education and support local businesses. Another group at Messiah College assists disabled persons. They have developed a hand-operated tricycle that can be used by disabled people to travel around the terrain at Burkina Faso. A trike such as this can be maintained by the local people and can help people in their own community. In a letter from the Collaboratory to an SIM missionary, an engineering professor has the following goal in mind for the manufacturing of the wheel chair:

> “Our goal is to develop the manufacturing processes, supply chains, and local fabricators needed to make the 3-wheeled off-road wheel chair that we developed to become widely available. This technology brings new freedom and dignity to people who have previously lived much of their life on the ground. With mobility comes the ability to go to school, hold down a job, and have a family.” [10]

In addition, students at Messiah in the Energy Group of the Collaboratory have installed solar electricity systems for clinics, mission stations, and rehabilitation centers in Africa.” CU also has experience in this area and there is a possibility for collaboration on these types of solar electricity projects that are feasible for these developing areas.
In addition, water ministry is an important focus at Messiah:

Clean, abundant water is one of the most pressing needs in the world today. Messiah Engineering students are working to develop and expand many water-related technologies, including well drilling, irrigation, water pumping, water purification, and sustainable agriculture. Several senior design projects have developed key water technologies, such as a low-cost, portable water filtration system, a percussion well drilling rig, and a redesigned hand pump for disabled persons. Work on these projects and more continues within the Water Group of the Collaboratory. [9]

LeTourneau University also has a number of senior design projects related to missions-focused engineering for developing nations and remote areas. The list on their website includes frontier wheelchairs, prosthetics, disaster relief solutions, and water relief solutions in sub-Saharan Africa (will be tested in Senegal in the summer of 2017) [11].

Dordt College is one of the few Christian colleges with degrees in agriculture and engineering, which opens up opportunities in agricultural missions. For example, Dordt College has collaborated with the ECHO organization on a solar power project: “The goal of this project is to design an off-grid solar power generation system for the Educational Concerns for Hunger Organization (ECHO) in North Fort Myers, Florida. The system will generate electricity for an office on the ECHO campus, and it will also be used as a demonstration to educate development workers and missionaries on solar power and its benefits for developing countries.” [12] As discussed later in the paper, many opportunities exist at the intersection of engineering and agriculture and collaboration with Dordt College could be very beneficial.

Technologies

With a Biblical background, overview of appropriate technology and leveraging it in a Christian context, and survey of efforts at other Christian engineering colleges, an overview of possible future engineering topics will now be discussed. The emphasis will be on electrical engineering technologies that can help improve people’s access to information, agricultural methods, health, and growth in the Word. Increasing cellular coverage and developing smart phone apps will increase education and knowledge of the Word. The following topics are intended to help build people’s sense of ownership and responsibility as they participate in the design, development, assembly, and maintenance of devices. The categories of topics considered include electrical power, instrumentation and data logging, telecommunications, remote sensing, radio, agriculture, medical equipment, and security systems. Although emphasis is on appropriate technologies, some of the projects and devices may require assistance from engineers in more developed countries due to the electronics or training required.

Power

For many of the electrical-engineering focused projects that will be discussed, power is a critical factor and is not readily available in remote or rural areas of the U.S. or in developing nations. In many areas, distributed power generation can be the most feasible solution to power various
devices. In many parts of the world, including in Africa and Australia, there is a boom with cell phones but landlines are much less common due to the required infrastructure. The same trend appears to be occurring with off-the-grid power generation with possibilities such as solar, wind, and small hydro-electric plants. If sufficient fuel supplies are available, small generators that run on petroleum-based products such as gas, diesel, natural gas, or propane would also be feasible. For example, natural gas is used in many vehicles in Bolivia due to the abundant supply so small natural-gas powered generators could be feasible. The distributed nature of these solutions minimizes the amount of infrastructure needed. When the U.S. was being settled, the windmill was a very common way to generate mechanical power to obtain water. Leveraging technologies such as the windmill could be very beneficial in certain countries. Any topic related to distributed power generation to make it more efficient or which uses local supplies would be a worthwhile endeavor.

One potential project, suggested by Ray Hutchison of SIM who has spent many years on the mission field in Africa, is to develop solar-powered cell phone chargers [13]. Cell phones are becoming much more popular in areas such as in Africa and South America. There is a strong need for more effective and efficient ways of charging the phones. Based on the solar-powered lights developed and assembled by students at CU, possibly a solar-powered charger could be designed and fabricated for cellular phones. Experience and knowledge gained by Messiah College on their solar projects would also be of value and collaboration on this project is possible.

Other potential projects are small power generation or electrical storage devices for data loggers for instrumented water pumps, agricultural equipment, or medical devices. As technologies are developed to help in these areas, power generation and electrical storage solutions could be designed and assembled by local people. Resident people could be trained to maintain and repair the devices.

Another power generation option with potential is micro hydro-electric power. An excellent survey on this topic and the innovative technologies being considered for rural Africa is given by Kusakana [14]. Micro hydro-electric power is considered a very viable option in Africa and other areas such as Canada that has many rural residents. Designing a micro hydro-power system for a specific area needs to consider the penstock, turbine, generator, and electrical storage options [14]. One creative solution that includes hydro-electric power is hydro-aero power, which includes a windmill, water storage, and power generation as shown in Figure 1. The windmill powers a pump to draw water up to the storage tank where it can be used for drinking water or drains through a pipe to operate an electricity generator. This solution is finding success in Africa since many of the farmers already have a windmill. Various designs

![Figure 1: Hydro-Aero Power](image)
of the hydro-aero power system could be evaluated for other areas taking into consideration available wind, resources available, and power requirements for a household.

**Instrumentation/Data Logging**

Small microcontroller-based systems for data logging have been investigated and partially developed for several applications. One system includes instrumentation, analog circuitry, a microcontroller, an SD card, and a Bluetooth module [15]. A version of the system was designed and tested by a CU senior design team to log data for a SonSet Solutions radio transmitter. Similar systems could permit data for a radio transmitter, water pumps, agricultural equipment, or medical devices to be logged and uploaded to a smart phone or the internet. For areas without internet, data can be sent via SMS or satellite connectivity to analysts in another location. Other design details could be leveraged from another data monitoring system that was briefly tested to monitor and analyze AC circuits [16]. Due to the electronics and software programming required, this technology may not completely satisfy the AT principles. However, as local people receive more education and training, this type of technology could be very beneficial to the people. Missionaries and engineers can collaborate with the local people to develop these types of systems to monitor various devices.

**Telecommunications**

Many areas in the world such as in Australia, Africa, and South America have a telecommunications network available to them but not infrastructure to access the internet. Via cell phones, residents are able to download and listen to Bible podcasts, download educational material, and data concerning their areas (for example, imagery for fields). One 2015 Centre for Appropriate Technology (CAT) report states that the focus of the report is on “a particular area of interest to our constituents, namely the adequacy of cellular mobile services for communities of remote indigenous residents, noting that mobile services are their telecommunications medium of choice.” [17]. The CAT organization is developing mobile phone hotspots for parts of Australia that amplify the signal so that users who are more than 10-15 km from the base station still have access to cell phone signals. The mobile phone hotspots developed by CAT use unpowered passive parabolic dish antennas to focus and amplify the received and transmitted signals.

The CAT mobile phone hotspot was designed for Australia (see Figure 2) but a potential project could be to investigate types of antennas and hardware configurations that could be used in remote areas of South America and other locations to amplify cell phone signals. In the Vacas area in Bolivia, there can be limited cell phone

![Figure 2: Mobile Phone Hotspot (photo from [17])](image)
coverage. A possible study would be to determine the size and types of antennas that would be appropriate to assist rural communities to be able to have cell phone coverage to receive Biblical educational material and other important information. Possible additional information could be field information such as the health of crops. Any project related to telecommunications that would assist small business operations would be of significant value.

Re-purposed satellite dishes or other pieces of equipment can help improve the coverage of cellular mobile service. Possibly some types of very small aperture terminals (VSATs) could be used for internet connectivity. Local residents could use them for receiving educational material and improving sales channels for small businesses. Depending on the area, it would need to be determined when a VSAT solution would be beneficial over an increase in cell phone coverage.

**Remote Sensing**

Remote sensing (RS) technology has found hundreds of applications as discussed in the online article by GISGeography [18]. The question then becomes how the technology could be leveraged for the developing world to help them improve access to information and data or improve small operations such as crop production [19]. As telecomm infrastructure increases and access to data becomes more feasible for many areas, then application of RS technologies will become more feasible. Different sensors use different wavelengths (infrared, radar, etc.) and data can be collected and utilized for different purposes.

In the agricultural area, infrared systems, synthetic aperture radar (SAR) systems and other RS systems can be used to detect the health of crops, amount of moisture in the soil, and amount of fertilizer required. As this data becomes more available, appropriate smart phone apps could be developed for farmers. Applications could help compare the trade-off between increases in yield versus the cost. Using remote sensing in agriculture is a component of precision farming:

“Precision farming is like a hidden goldmine in agricultural production. Savings estimate 10% in fertilizer. On top of that, crop yields are also improved. Precision farming uses different wavelengths of light to see how healthy crops are. Variable amounts of fertilizer are worked out keeping money in farmer’s pockets.” [18]

The Normalized Difference Vegetation Index (NDVI) is one way to use RS in crop production. In addition, near-infrared radiation can be used to detect healthy vegetation since healthy crops reflect green light and absorb red and blue light and this can be detected in the light and near infrared regions. Therefore, near infrared radiation in combination with NDVI is a primary remote sensing application in agriculture. Developing simple smart phone apps and developing procedures to request the correct data be available in other countries could help with crop production and yield.

One very beneficial use of RS data is to assist local fisherman with the current location of fish. GISGeography states, “There are plenty of fish in the sea from a satellites viewpoint. Satellites monitor sea surface temperature and ocean colors because they are indicative of specific fish species. The top-down view of remotely sensed data can be communicated with local fisherman. Fishermen use this information to save time and fuel in real-time.” [18] Computer scientists and
engineers can work together with local fisherman and agencies to provide the data and image viewing tools that will benefit the fisherman.

Radio

A foundational Scripture for this paper is Romans 10:14 in which technologies are used to spread God’s Word. In some areas such as in South America, short-wave radio is still used to transmit educational material. Inexpensive AM/FM and slightly out-of-band short-wave radios are available and solutions need to be investigated to include attachments or modifications to the radios to allow the small inexpensive radios to receive the appropriate short-wave frequencies. SIM has requested that options be investigated to convert AM/FM radios or modify inexpensive out-of-band short-wave radios [20]. Critical questions for this would be to determine which AM/FM radios are currently available, which ones would allow an add-on to convert the frequency, and the cost of the materials. For an inexpensive solution, the local people would likely be willing to pay for them, which would help more people receive His Word. The local residents could also be trained to make the modifications. A collaboration opportunity could be to work with a South American university that offers an electronics degree to see if their students could help design and build these add-ons or modifications to the radios.

Agriculture

Agriculture is one area that AT could prove to be very beneficial. Several applications of RS and information logging have already been mentioned in the area of agriculture. Efforts such as aquaculture and aquaponics could benefit greatly from a data logging and telecommunications capability. Facilities such as greenhouses to raise vegetables or aquaponics systems in which fish could be raised in addition to vegetables could be monitored with simple instrumentation or data logging systems. If cellular mobile service is available, then data can be transferred to engineers or other people in other locations to help monitor the system. This data could be used to help improve the systems and train the local residents on the critical information to be monitored.

In some areas such as in the Vacas region of Bolivia, the diet of many people are short in protein. Adding meat such as fish would greatly improve their diet. The BOL-CAN Foundation, in Bolivia, is currently collaborating with other organizations to investigate the types of fish that could be raised in Bolivia to help improve the diets of the residents. Fish could potentially be grown in an aquaponics system. A data logger could be used along with a small electrical power system to help monitor the system.

The duration of the life of fruits and vegetables can be improved if they are dehydrated. If the products can be shipped further, then additional markets would be available to the sellers. A number of technologies are available to dehydrate or measure the water content of fruits and vegetables. These technologies may be too expensive for some areas and research projects to analyze which dehydration technologies would be appropriate for different crops or areas could benefit many people.
Topics related to the intersection of engineering, agriculture, and missions have unlimited potential. Any project to help reduce the costs of fertilizer, decrease time planting and harvesting, decrease labor, decrease shipping and storage costs, and improve processes is worth investigating. Greenhouses are becoming more useful and methods to monitor the health of plants and vegetables would be beneficial. Any advances in the data logging and system monitoring capabilities would also contribute to the agricultural area.

Medical Equipment

Developing low-cost technical solutions for medical applications for remote areas is an enormous area of opportunity. A couple of ideas proposed here include developing medical data monitoring capabilities, producing medical supplies, and designing location monitors for disabled people or small children.

Some previously mentioned projects involve collecting, processing and logging signals, and then sending the data through a cell phone to another location to be analyzed. In the medical area, a similar project has resulted in a small tablet to monitor heart information and passing it to cardiologists at a central location as described below:

Himore Medical in Cameroon has designed CardioPad, a wireless solution that enables the efficient monitoring of cardiovascular diseases (CVDs). While the majority of cardiovascular specialists practice in the capital city of Cameroon, Yaoundé, 80% of the country’s population lives in rural areas. The CardioPad, therefore, provides improved access to cardiovascular healthcare for patients living in remote areas. It is a touchscreen tablet smaller than most conventional tablets, making it easier to operate. The device includes a set of four wireless electrodes and a sensor that is attached to the patient’s chest; this generates a signal, which is then transmitted via Bluetooth to the tablet. A digitised electrocardiogram (ECG) of the patient’s heart function is then taken and transmitted through a mobile network to a second CardioPad device – situated in a city hospital – where a registered cardiologist can make a diagnosis. [21]

The solution developed is designed to monitor cardiological data (see Fig. 3) but other types of medical data could be monitored depending on common medical problems in the area of interest. Medical professionals at centralized locations can analyze the data that is sent from remote locations. Some of the experience gained with other data monitoring and logging solutions could be leveraged to begin looking at these types of medical applications.

Inexpensive solutions for items used in surgeries or medical procedures would be useful. Technology such as 3-D printing could be used to produce small medical items and supplies. Educating and training local people to produce the medical items appears to be a huge
growth opportunity. Other topics which result in inexpensive replacements would be advantageous such as cheaper LED lights used in place of blue lights that can provide a huge cost savings [22].

Other universities such as Letournea are designing wheelchairs as previously mentioned. One possible idea is to put GPS or other tracking device on the wheelchair or person where safety is a concern so staff members, family, or friends can monitor the location of the person. The location of disabled people or small children at schools or orphanages could be monitored.

Developing effective, inexpensive medical equipment and supplies is a great area of opportunity. Many countries have orphanages with children with various medical conditions that could be helped tremendously with appropriate technologies. God commands us to help the orphans and this is one area that Christian engineers can carry out this command. However, there are challenges using the technologies in new areas such as the availability of appropriate power, spare parts, and consumables [3]. These challenges need to be considered as the technologies are designed, developed, and implemented.

Security

One topic that continued to be mentioned by missionaries interviewed for this project is the security of small technology solutions. Theft can be a common problem even for small electrical devices. Solutions that provide security or alarm signals to the user or owner of the technology would be an important topic.

Summary of Topics

A list of the proposed engineering projects is provided below in Table 1 that could be researched by students and faculty in Christian engineering programs. Other topics in other engineering disciplines such as mechanical, biomedical, and civil could also be investigated.

Table 1: Summary of Proposed Engineering Projects for Developing Countries

<table>
<thead>
<tr>
<th>Area/Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td></td>
</tr>
<tr>
<td>Solar-powered Cell Phone Charger</td>
<td>Small solar-powered cell phone chargers are needed for people in remote areas in Africa and other areas to listen to educational material, especially Biblical programs. The experience gained designing and assembling solar-powered lights or radios can be leveraged.</td>
</tr>
<tr>
<td>Natural Gas Generator</td>
<td>Natural gas and other petroleum-based resources in a nation that has been blessed with these resources can be used for small power generators.</td>
</tr>
<tr>
<td>Distributed Power or Energy Storage for Data Loggers</td>
<td>Inexpensive batteries, solar power, or other types of distributed power generation or energy storage are required for data loggers or monitors. A data logging capability could improve the monitoring of equipment such as water pumps, agricultural devices, or medical equipment.</td>
</tr>
<tr>
<td>Micro Hydropower</td>
<td>Small hydro-electric power units for distributed power in remote areas could be very beneficial. This topic includes hydro-aero power that combines windmills with hydro-electric power generation.</td>
</tr>
<tr>
<td><strong>Instrumentation/Data Logging</strong></td>
<td></td>
</tr>
<tr>
<td>Data Logger for Water Pumps</td>
<td>Instrumentation and a data logger are needed for hand-operated water pumps. A system is needed that can be used to collect data such as the long-term cycles of a pump.</td>
</tr>
</tbody>
</table>
Conclusions and Recommendations

Based on a Biblical foundation and a brief introduction to appropriate technology, various technologies have been considered after discussions with missionaries and conducting literature searches. Future activities could include interdisciplinary teams and collaboration with other Christian engineering programs. Interdisciplinary teams could be formed to investigate different
technologies involving multiple fields such as engineering, biology (agriculture), chemistry (energy storage), and business (local businesses). Possible collaboration with the nursing school to design and prototype medical supplies or devices is a possibility. Even an interdisciplinary research center could be established if the organization would benefit the researchers and potential receivers of the technologies. The business school or international studies areas could potentially analyze the potential for the technologies to be the foundation of small businesses for local peoples. Investigating the manufacturing capability in an area to get more local people involved could be advantageous to the acceptance of the technology. Additional relationships with missionaries in other countries who are onsite would provide beneficial feedback and suggestions. Connections and networking with people in remote areas, either on the mission field or in the states, could also drive excellent ideas for needs. In addition, possible collaboration opportunities with other Christian universities would be highly encouraged based on overlapping interests as discussed in this paper.

The paper focused on specific technologies, but education and training is very important. For example, SIM in Bolivia educates the people on the fabrication and assembly of the wells and water pumps. This helps the people build confidence. With any of the engineering topics discussed, education and training of the local people should be a high priority.

This survey on missions-related engineering projects with emphasis on appropriate technology will help faculty and students gain insight into possible future undertakings. It is critical for faculty and students to understand the time and effort that they should dedicate toward these types of projects in the future. The engineering teams will be able to make wise decisions about the use of future resources. The most promising efforts will be incorporated into senior design projects or technical electives and will help students understand other cultures as they learn how to apply their skills to help others. The education and experiences gained by the faculty and students will be grounded in Biblical truth such as Matthew 25:35-36 and Romans 10:14.

Acknowledgments

The author would like to thank those who contributed to this research. First, several missionaries were interviewed who gave invaluable feedback. Ray Hutchinson from SIM provided great insight and suggestions related to cell phone chargers and security. Excellent discussions and e-mail communication with Ann Wheeler and Dale Harlan from SIM were very beneficial. Input from SonSet Solutions provided ideas in several areas. Finally, I want to thank the VPA office at Cedarville University who provided the release time and grant to complete this paper.

Works Cited


How Developing Electrical Technologies Can Meet Human Needs with Christian Compassion

Harold Underwood

Having students work on service-oriented projects that meet basic human needs has become a popular strategy in engineering education; such active learning motivates students and prepares them for professional practice. While conventional engineering service project teams often implement a solution that meets human needs on the spot, exploratory technology development service projects, such as I address here, take time to reach proof of concept maturity, before wider application may occur. Whether implementing or developing, a Christian Engineer following Jesus finds solid ground by establishing links between objectives of a service-oriented project and the counsel of Scripture. Hebrews (13:3) calls Christian to identify with prisoners, and those who are mistreated; Romans (8:19-21) suggests that the creation waits with anticipation for children of God to be revealed, and to be free from its bondage; James (2:14-17) explains that good works reveal the faith of a compassionate heart. While interpretations may vary, I argue these passages support the value of Christian compassion as expressed in engineering projects focused on needs of people restricted in some way (e.g., physically or socially), that they may gain more independence. Such scriptural support provides a foundation, but the Christian gospel presents God as an active agent in Jesus Christ, caring and participating with his image bearers in creative works of service, to fine tune both workers and the work, just as he did in the creation itself. Thus, the gospel compels a Christian to prayerfully seek the Lord, search the scriptures and consult with others beyond mere project justification to ongoing guidance, so those served as well as the servants are mutually blessed. Specifically, I suggest that despite inherent risks and limitations, developing electrical technologies conveys Christian compassion to the needs of certain people otherwise overlooked. Two examples of ongoing projects hosted by the Collaboratory for Strategic Partnerships and Applied Research at Messiah College will illustrate: 1) flight tracking and messaging systems (FTMS) to follow small planes in remote locations, as a safety risk management service to the pilot and family; and 2) an assistive communication system known as wireless enabled remote co-presence (WERCware) intended for those with cognitive and behavioral disabilities to foster sustained employment and more independent living. After identifying scriptural and social support for these projects, this paper will describe our strategy for ongoing guidance, and comment on the challenges of maintaining responsible balance in our most recent work. Transferable principles will be suggested for the reader who wishes to extrapolate from our experience to another institution.

1. Introduction

The benefits of experiential learning such as service-oriented projects in engineering education have become well known, inside the Christian community and without, as indicated in the literature including a companion paper by this author. While experiential learning can include a variety of activities, I focus here on service-oriented engineering projects, that address basic

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human needs otherwise overlooked by the commercial world, and serve those that cannot or do not initially provide monetary compensation for benefits received. On the other hand, I also intend the descriptor service-oriented in a broad sense to include a wide range of engineering project activities from A) the conventional service project involving a site-team\textsuperscript{iv} implementation trip, to B) an exploratory\textsuperscript{v} technology development project requiring applied research to meet objectives; in each case, the project should be guided by a client familiar with the target community being served. Category A examples might include construction or installation of 1) a clean water facility to improve health, 2) a solar photovoltaic panel for electrification to raise standards of education, or 3) foot-bridge over wetland to promote access to resources, targeted to the poor in a developing country. Such implementation projects represent a few of those deployed over the years by the Collaboratory for Strategic Partnerships and Applied Research (Collaboratory) at Messiah College. I describe two category B examples in section 4 of this paper: Wireless Enabled Remote Co-presence (WERCware) and Flight Tracking and Messaging Systems (FTMS). For quality and integrity, even category A examples require preliminary (exploratory) site-survey, design, testing, redesign and follow-up phases of engineering activity to ensure the work meets the need effectively, and in a sustained way. So, longer-term category B projects where applied research and testing is required to develop a “proof of concept” prototype must not be automatically dismissed; exploratory technology development should be eligible for service-oriented status, even if the application is not so immediate. To keep them on track, one further criterion for both project categories serves as a safeguard: a knowledgeable client together with the project manager (e.g., faculty member) through frequent meetings with students to guide the work, critiquing progress on the objectives, and arranging field studies when real consumers can test the prototype to provide feedback for future improvements.

2. Scriptural directives

In his sermon on the mount, Jesus compares those who hear his words and put them into action to a wise person who builds a house on the rock. Building on a solid foundation, to a Christian engineer, has meaning on multiple levels: the direct physical application, rational worldview implications and spiritual consequences. Coming at the end of his sermon, Jesus surely meant at least that if we as his followers act like salt and light on the earth, give to the needy, and treat others as we wish to be treated (to recap just a few main points), we live more worthwhile God-pleasing lives in general. But further extending Jesus’ words to the engineering context provides impetus for projects that focus outward, fitting for salt and light, directing attention towards the needy, and treating those served as we would wish if we were in their place. While these ideas offer solid ground for service-oriented projects, heeding Jesus admonition to avoid pitfalls in the foundation also requires examining the scriptures broadly. Any divine counsel found applicable to engineering project initiatives helps set worthier objectives and direct healthier work.

In Romans, the Apostle Paul offers more basic principles to guide the Christian life in thought and in practice. Following up on the Christian believer’s continued struggle with sin, Romans 8 reveals the glorious truth of no condemnation in Christ. We learn that with the freedom of spiritually enlightened minds, believers may live as children of God. Sharing in his suffering, we are told, enables us to share in his glory. In the suffering versus glory context, Paul says
I consider that our present sufferings are not worth comparing with the glory that will be revealed in us. For the creation waits in eager expectation for the children of God to be revealed. For the creation was subjected to frustration, not by its own choice, but by the will of the one who subjected it, in hope that the creation itself will be liberated from its bondage to decay and brought into the freedom and glory of the children of God. (Romans 8:19-21, NIV)

Which prophecy refers to future event(s) (e.g. “will be revealed”), and which has already occurred has been a matter of ongoing debate among Bible scholars and commentators. Advocates of “realized eschatology” claim the end has already come, while proponents of “future eschatology” say the end lies ahead. Could the truth lie in between? Though “we now see in a mirror dimly” (1 Cor. 13:12, ESV), while the “kingdom of God has come near” (Luke 10:9, NIV), glimmers of God’s glory that now seem evident may “foreshadow” the fullness of the His glory yet to appear in the final redemption. The creation “waits” as Romans 8 describes, even anticipates the appearance of God’s children. This revelatory appearance of His offspring may not necessarily be so obvious; as Tim Keller explains, it is likely to be accompanied by the glory of God’s holiness, incomplete until later.vi Yet all Christians saved by God’s grace have Jesus’ mandate to make their presence known as the Lord’s elect children, in the form of “salt and light.” Next, the Romans 8 passage indicates that the Lord of creation cast his work into a temporary state of “frustration” (just as he expelled Adam and Eve from Eden), planning all along to free it again by “glory of the children of God.” While final perfection of this redeemed state must be future eschatology, as the Lord does not yet reign supreme on this earth, will not the grace and Spirit of God alive in Christian believers today reveal a few faint glimmers of light, when Jesus’ followers including engineers make progress toward his desired end? Here, brokenness of creation goes beyond consequences of the Fall, offering children of God a present redemptive opportunity, as agents of God’s glory. Thus, a partial display of God’s glorious grace may occur by good works, creatively applied via gifts of his image bearers, even today.

Many forms of brokenness in this world can be identified, such as the destitution of poverty, injustice that results in the suffering of innocent who have committed no crime, and the struggle of those with disabilities in situations that require certain social or physical skills. The author of Hebrews, just after addressing the kingdom that cannot be shaken, identifies a few practical acts and attitudes toward others, including the broken, that represent sacrifices pleasing to God. Remembering prisoners “as if you were together with them in prison, and those who are mistreated as if you yourselves were suffering” (Hebrews 13:3, NIV) make this list. Christian prison ministry certainly has a valuable place for offering hope of forgiveness, redemption and reformation to those incarcerated for crimes committed, and encouragement for those wrongly punished (mistreated). I suggest here, though, that the “prison” many people face may involve less obvious “bars” of involuntary restriction: disadvantage, lack of freedom due to poverty, criminality of others, and disabilities over which the bearers have little control. For those who experience this sort of captivation and mistreatment, the injunction of Hebrews must also apply. People in these situations live not just in developing countries, but throughout the world, even perhaps in our own communities or families. Some engineering projects should certainly be devoted to ameliorating difficulties for them. I describe two examples of this sort in section 4.
Finally, here, on scriptural directives, consider James, a stalwart advocate of demonstrating Christian faith by one’s good deeds. In chapter 2, we have his inspired words:

What good is it, my brothers and sisters, if someone claims to have faith but has no deeds? Can such faith save them? Suppose a brother or a sister is without clothes and daily food. If one of you says to them, “Go in peace; keep warm and well fed,” but does nothing about their physical needs, what good is it? In the same way, faith by itself is, if it is not accompanied by action, is dead. (James 2:14-17, NIV)

Restated in a positive sense, James says that actively meeting basic needs of someone close (i.e., doing good works), offers evidence of a faith that is alive. While interpretations may vary, the Bible also teaches that saving faith (i.e., salvation) must be worked out “with fear and trembling, for it is God who works in you, both to will and work for his good pleasure” (Phil. 2:12,13 ESV). The sanctifying power of God’s grace puts good works required by James in better perspective. To the point of this paper, while feelings of compassion alone towards the needs of others do not necessarily help anyone, Christian compassion accompanied by a real deliverable can effectively meet a felt need. Thus, a real deliverable should certainly be the goal of what is produced by service-oriented engineering projects, whether it be the short-term implementation result, or the one ultimately achieved by the long-term technology development approach.

3. Project guidance

Credible authorities now view the origin of the universe, and its subsequent development, as a supremely powerful yet carefully planned, sustained and guided process. In *Case for a Creator*, the journalist turned author and pastor Lee Strobel presents arguments for Intelligent Design and fine tuning supported by several prominent scientists and philosophers who enumerate such precisely balanced conditions. Besides serving as convincing clues about God’s character imbedded in his creation, what if such fine tuning also suggests how the Lord involves himself in our personal and workplace endeavors, sovereignly guiding us (e.g., through finely tuned circumstances, personal relationships, etc.) to produce more godly character as we grow in maturity? By extension to engineering project management, we need a Christian model for guidance that provides checks and balances on the project work, and the teams that pursue it. Teams should make satisfactory progress toward service-oriented project objectives, and ensure that expressed needs of those served are ultimately and adequately being met. Timely feedback by a knowledgeable client, and technical consultants, during periods of development can help project teams make necessary corrections and/or reinforce good work being accomplished.

A previous publication details the agile project management strategy we follow, in the Collaboratory at Messiah College, to help guide our students in service-oriented engineering project work, as they prayerfully proceed. Weekly discipleship meetings offer all project team members voluntary opportunities for worship, inspiration, reflection and practical application of spiritual matters. As for time management, our student project teams commit to 6 to 9-week blocks of time—called Minimum Viable Progress (MVP) periods—during which they address the next critical objectives necessary to move the work forward. At the beginning of each MVP, student teams formulate and submit their objectives for review to the project manager, a faculty member or professional engineer. The project manager either approves these new objectives, or
recommends revisions. Upon approval, student teams proceed to brainstorm individual tasks, and time-estimate them by a bidding process, during the MVP planning stage. These estimated project task hours together with hours per week committed by each project team member determine the predicted length of an MVP period. If the predicted MVP period does not fit the specified 6 to 9-week time frame, the team must adjust it by putting some tasks in the “ice box”, or adding additional tasks. MVP periods deliberately framed in this way, apart from the typical 12 to 15-week semester, free project teams from artificial boundaries of the academic calendar (i.e., to help students realize that real-world projects do not necessarily begin or end in sync with an academic semester). In coordination with the Collaboratory, each MVP ends with a review, much like a design review. Those who attend the design review include 1) the student project team providing an informal Q&A presentation, 2) a student administrator moderating the time and discussion, and 3) a panel that includes project managers, voluntary technical consultants, and the client, if available. The panel makes comments, asks questions and ultimately assesses the team. During the MVP, the client typically communicates regularly with the project team (e.g., via email, Skype or face-to-face meetings); the panel assesses quality of the evident client communication as one of several rubric items.

At the end of the MVP review, the student project team leaves the room while the panel discusses, deliberates and evaluates a range of rubric items as prompted by the student administrator. Rubric items assessed include the following:

- attributes of the presentation and receptivity to comments and questions by the panel
- professional quality of documented work pre-submitted by the team
- progress against stated objectives for that MVP period
- alignment with key project indicators overall (as stated in the Project Charter required of each project team initially and updated annually, which speaks to its mission fit within that of the Collaboratory)
- team composition (whether the right kind of engineering specializations and/or other major disciplines seem to be represented on the team including advisors and consultants)

After reentry by the student project team, panel representatives briefly report highlights of the MVP review assessment, offering both positive feedback and constructive criticism, followed by more detailed written comments. Notably, the MVP review serves as a key guidance tool, affirming good work, and identifying any deficiencies with recommendations for improvement. The review also helps the project team identify new objectives, technical and otherwise, for the next MVP period, toward producing for the client and end users being served a deliverable of the highest possible quality, which they deserve.

4. Service-oriented Exploratory Engineering Technology Development Projects

This section presents two service-oriented exploratory technology development projects, currently ongoing at Messiah College, that satisfy mission fit of the Collaboratory. They also require applied research to meet objectives as in the category B distinction above, and follow the project guidance policies as described in the previous section. The following subsections present
further motivation and objectives for these projects by including some additional rationale and context from which they originated.

4.a. Redesign of an Automatic Flight Following System

One of the most dedicated and well-trained yet vulnerable servants among those who give their talents for relief, development and missionary organizations, a pilot will fly small planes into remote locations delivering supplies and personnel to their destinations. Often, the pilot leaves his or her family behind to hope and pray for a safe journey and timely return. A pilot and passengers face potential risks including technical problems with the plane, unexpected severe weather, and criminal intent of a bandit or drug runner at intermediate stops. These risks can and have resulted in scenarios such as the landing of a plane in a place outside of its flight plan, or worse, a high-jacking, a kidnapping or even a crash. The result may range anywhere from mere inconvenience to serious emotional and physical trauma—temporary or long term—or even untimely death. In the most serious of these scenarios, authorities can only decide whether to launch a costly search and rescue operation, for recovering the pilot and/or passengers, by locating the plane when the event (e.g., deviation from the flight plan) occurred. Without a precise enough GPS coordinate location, search and rescue may not be justifiable. Thus, in the worst case, the pilot, any passengers, and family members left behind could remain separated and without hope of reunion in this life. Is this a kind of human tragedy that Jesus would leave unaddressed? No, Jesus compares himself to a shepherd who goes from the ninety-nine sheep in the protected fold to recover one lost. Likewise, missionary aviation has done whatever possible to rescue a lost pilot, whenever that might become necessary.

The conventional missionary aviation problem of tracking small planes outside of radar control has been historically solved by the pilot periodically reporting flight status by two-way radio to a family member acting as a ‘flight shepherd’, monitoring progress on the ground. A notable innovation to this convention was designed and developed in the field by JAARS missionary aviators in the 1990s. With the Automatic Flight Following System (AFFS), JAARS introduced the concept of shepherding a flight using an electronic ‘protected fold’. In 2005, after experiencing a short-term trip with PACTEC in Afghanistan, and talking with one of the pilots hoping to benefit from more of the latest flight tracking technology, this author was introduced to one of our main stakeholders, Cary Cupka, an avionics and safety philosophy consultant; this long-term relationship ultimately resulted in our taking on the upgrade of AFFS with one of the original developers, Carman Frith, as a Collaboratory engineering project. While our organizational client and objective focus has shifted over time, a project team at our institution has been working to upgrade and improve flight monitoring and communications technology ever since. In recent years, aging AFFS technology, limitations of its High Frequency (HF) radio band mode, and emerging communications alternatives, have led most JAARS flight programs to outsource flight tracking. Yet, our consultant, Cary Cupka and others believe the legacy AFFS scheme with its field-tested value is a strategically positioned platform for radically improving the electronic ‘protected fold’ by voluntarily integrating new concepts developed by civil aviation after the disappearance of Malaysian Airlines flight MH370 in 2014. Our goal is to redesign AFFS with the latest electronic component upgrades, and introduce interoperable
communication (including satellite) modes, so that the well-tested user interface of its aircraft control unit (ACU), with a form factor known to fit safely in the typical aircraft cockpit, can meet modern safety needs of small aircraft, and offer more.

Thus, the Flight Tracking and Messaging Systems (FTMS) project team, as it is presently known at Messiah College, continues to consult with Cary Cupka and others to redesign AFFS toward a field-upgradable pilot and aircraft-tailored version of the electronic ‘protected fold’ system. Our latest technical progress involves the choice of an industrial grade microcontroller paired with a UDOO ‘maker’ board capable of emulating AFFS 1.0 functionality, with potential for further expansion in the redesigned version. Careful study of the existing AFFS ACU pilot-interface display (circuit) board has enabled the student team to improve its layout, upgrade components, and propose a more compact manufacturable version. To test the overall system during development, serial communication has been established as a hardwired link between the ACU and AFFSWin\textsuperscript{xii} to simulate sending messages from the ACU to a ground station monitoring the flight. This project presents considerable technical challenge to our student team, typically made up of engineering students with an electrical and/or computer concentration. While significant work remains to reach the “proof of concept” prototype stage, it offers these students excellent pre-professional experience on an exploratory service-oriented project. By this project, the FTMS team has been moving the electronic ‘protected fold’ technology forward toward the worthy goal of reducing the risk pilot families face in flying planes in remote locations to accomplish missions typical of most relief, development and mission organizations.

4.b. Developing a Remote Coaching System for the Cognitively and Behaviorally Challenged

The rise of the internet and electronic media technology has been accompanied in recent years with increased awareness of socially disadvantaged and disenfranchised people. Renowned media theorist, Marshall McLuhan, who foresaw the emerging “global village” once observed,

\begin{quote}
Minority groups can no longer be contained—ignored. Too many people know too much about each other. Our new environment compels commitment and participation. We have become irrevocably involved with, and responsible for, each other.”\textsuperscript{xiii}
\end{quote}

Those with needs overlooked by cost-effective marketplace product developments include people with various cognitive and behavioral challenges. Lack of effective helpful intervention for people with these disabilities often means forfeiting gainful employment or independent living opportunities, despite their potential. Such disadvantages represent another less visible form of barrier holding its “captives” who are waiting to be unlocked. At Messiah College, Wireless Enabled Remote Co-presence (WERCware) is another service-oriented Collaboratory project under development for the last nine years to assist those with those with challenges ranging from high functioning Autism to Post Traumatic Stress Disorder (PTSD). WERCware delivers social services to a participant from a remote coach, by means of wireless technology. The history of this project, including key lessons learned, has been previously documented.\textsuperscript{viii}

WERCware has matured since its inception as a service-oriented student engineering project thanks to grant funding, three field studies, and multiple consultants. The WERCware system presently consists of an Android smartphone platform interfaced with stress-detecting bio-
sensors. Sensor testing, signal analysis via software code, and system integration development represent the latest focus of the student team. Human stress detected by a WERCware bio-sensor will automatically trigger a video conference call between the participant’s smartphone and the remote coach. While a manually initiated call can also do the same, as a backup, the automatic call allows the remote coach to check in, amid stress, and if needed, give social intervention from a participant-specific database, using scripts or other supports. When connected to the remote coach, to safeguard employer or participant confidentiality in defined areas (e.g., restroom), an automatic audiovisual shutoff occurs, by design, as triggered by proximity to Bluetooth beacons.

Like FTMS, WERCware also represents a decidedly service-oriented engineering project, under the guidance of a client representative who is a knowledge expert about the target community. WERCware uniquely involves technology development related to social issues that have never been fully addressed, and includes methods (e.g., human stress detection via bio-sensors and automatic neural networks) that are on the cutting edge. This offers excellent challenging interdisciplinary pre-professional experience for engineering students especially those with electrical or computer concentrations, while developing technology that conveys compassion by better meeting the need of many who are waiting to be freed from socially confining dependence.

5. Achieving Responsible Balance

Beyond effectively meeting the needs of an end user, a good design should carefully balance quality factors, to optimize overall value. As a classic work on Christian values applicable to engineering, Monsma and his group\textsuperscript{xiv} identify normative principles (NPs) involving human choice, to responsibly guide the activities of doing technology. Their seven NPs include appropriateness of culture formation, information or openness of communication, stewardship of economic aspects, a delightful harmony of aesthetic aspects, justice & caring for all of creation, and finally trust, meaning dependability without dishonor to God. While all seven NPs deserve full consideration in a thorough approach, to achieve the delightful harmony (Shalom) advocated by Monsma, this section considers how selected normative principles relate to each of the two projects highlighted in this paper, and the challenge of achieving the right balance.

Achieving cultural appropriateness, per Monsma, means balancing sets of opposing factors. One pair of opposites, continuity versus discontinuity, has been an issue during FTMS development. During the early years, before the Integrated Project Curriculum (IPC) at Messiah College, students completing the traditional senior capstone project felt compelled to design projects from scratch. With the pendulum at the discontinuity end of the spectrum, the field-tested value of AFFS did not receive enough attention; students designed an ACU prototype which though innovative, would not fit in the cockpit of the plane, or retain the safety-tested pilot interface. Stakeholders were not so pleased about this development. In more recent years, with the advent of IPC, multiyear projects and Collaboratory oversight, students began to grasp the value of ongoing project work. Such realization convinced FTMS student teams to “buy into” the value of retaining the pilot interface as a project starting point. FTMS design then more realistically focused on internal contents of the ACU and initially replicating the original AFFS functionality, rather than striving for something completely new. The pendulum had reached a midpoint between continuity and discontinuity, where a better balance between innovative design and
field-tested aspects of the ACU met. This balance of culturally appropriate opposites not only better satisfies our stakeholders, it most likely will lead to a higher quality product in the end.

To explore how the NPs relate to WERCware development, consider the balance that must exist between openness of communication, caring and justice. The openness desired in WERCware, an assistive communication technology, should be self-evident: to allow quality audiovisual interaction remotely between a participant and remote coach. If electronic openness were all that was needed, a smart phone at each end might be fine, by itself. However, combining the value of openness with caring and justice, we find that product with unique features is needed. Caring for those with disabilities means giving them as much independence as possible. Thus, we do not want the connection open continuously, only as needed. Hence, the development of biosensors to detect human stress, as an automatic call trigger, in case “heat of the moment” catches the participant unaware. After interaction with the coach, the connection may be closed manually, and remain “off” to promote a healthy “fading” of intervention. We now bring justice into the mix. The participant must use good judgment to determine when to open or close the connection with the coach. As a backup to ensure confidentiality in defined locations (e.g., personally private restrooms or employer secured private document areas) the automatic shut-off feature comes into play. The automatic beacon-triggered shutoff in confidential areas guarantees the connection between parties will be closed to protect the ethical and legal rights of each participant, preventing unnecessary harm from coming to those involved. Thus, openness must be balanced with caring and justice to convey Christian compassion with quality and integrity.

6. Conclusions

As a focus for experiential learning, in this paper I recognize that service-oriented engineering projects intended to meet human needs can fit into two legitimate categories: short term conventional site-team implementation efforts and longer term exploratory technology development efforts requiring applied research. Both kinds of projects can convey Christian compassion, and have value from an educational, engineering and biblical point of view; exploratory projects should not be overlooked. Scriptural directives support a wide range of service-oriented opportunities. These include Jesus’ priorities of being salt and light, attending to the needy and treating them as we would wish to be treated if we were in their place. Other scriptural directives provide further guidance such as the concept of working as redeemer of a broken creation, offering a tangible deliverable to meet the need, and specifically remembering prisoners of various kinds. These directives support both exploratory technology development projects highlighted here. Further rationale and context has been provided for the redesign of AFFS, and developing WERCware, ongoing service-oriented projects in the Collaboratory at Messiah College. The teams working on each of these projects hopes to convey Christian compassion by working with qualified clients to meet unique human needs often overlooked. Striking a responsible balance of normative values in the work represents an ongoing challenge.

Transferable principles from this work include the scriptural directives suggested here in section 2, strategies for engineering project management we have employed for guidance in section 3, and methods of finding service-oriented projects for which I have found networking and travel to be most fruitful. Networking can help match the need or vision to the resources and expertise
faculty and students happen to have at a specific school. Traveling to the neediest places to meet
and visit people where they live and work can expose opportunities that others have overlooked.

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Abstract

The engineering analysis discussed here considers the minimum estimated energy and power that would have been required for the fire miracle on Mount Carmel in 1 Kings 18 that destroyed an altar made of stones, a sacrificial bull, and twelve containers of water poured onto the sacrifice. The purpose is not to determine precise values but rather to calculate order of magnitude estimates. The analysis shows the fire was unnaturally hot, the vast majority of the energy would have been used to destroy the stones used to make the altar, and the amount of power would have been comparable to a modern power plant. The results show the unmatched power and sovereignty of God.

Introduction

1 Kings 18 has been called “one of the most dramatic chapters in the Bible” (Olley 34). “Fire from heaven on Mount Carmel is among the most stunning and impressive miracles in the Old Testament” (Baukal, Pyrotechnics 289). The encounter on Mt. Carmel was “perhaps Elijah’s central episode” according to Levine (34). Keller (91) describes this event in his own inimitable style:

A flash of fire fell upon the evening sacrifice. The flames blazed and burned with fury. The temperatures were so intense the water was instantly turned to steam. The great joints of beef and piles of wet wood were consumed in moments. Even the twelve large boulders and the damp soil all around were oxidized and obliterated by the holocaust.

This event might be viewed as a court case where the prophets of Baal act as the prosecuting (persecuting?) attorneys trying to protect Baal’s honor and sovereignty. Elijah acts as the defense attorney protecting Yahweh’s honor and sovereignty. The jury in this case is the people (Tonstad

1. Oral Roberts University, Tulsa, OK.
253-66) who will have to decide which god to ultimately follow, as Elijah has called them to make a choice as to which god they should worship. This summit contest pitted a present god YHWH against an absent god Baal (Glover 451).

Altar

Elijah had to rebuild an existing but abandoned altar.\(^2\) Israelites were not normally supposed to make sacrifices outside the Temple, but there are some possible explanations for the existence of this broken-down altar outside Jerusalem. The unusual circumstances of having a Jewish monarchy (Ahab) dedicated to serving Baal\(^3\) may have dictated having an altar far away from the king (Slotki 133). Another possibility is this altar\(^4\) was built before the Temple was constructed (Hammond 424). These worship sites were a fundamental element of Israelite life up until the construction of the Temple (Nakhai 21). For example, in the time of Solomon “The people were still sacrificing on the high places, because there was no house built for the name of the Lord” (1 Kings 3).

The altar may have fallen into disrepair because of the persecution of Yahweh’s prophets by Jezebel (Konkel 300). Elijah rebuilt the altar himself (1 Ki. 18:30) even though he at least had one servant with him (v. 43) as well as numerous bystanders who could have helped rebuild it. This should not have been a problem since Elijah was apparently in excellent shape because he later outran Ahab’s chariot to Jezreel some distance away. He did not have to build a new altar

\(^2\) It is ironic that Elijah rebuilt an altar he was planning for Yahweh to destroy with fire shortly after it was rebuilt.

\(^3\) 1 Kings 16:33 notes “Ahab did more to provoke the LORD God of Israel than all the kings of Israel who were before him.”

\(^4\) There are some similarities between the description of the site on Mount Carmel and what was believed to be a cultic site that was found on Mount Ebal (Zertal, “Early Iron Age” 105-165). Large quantities of ash, coals, burnt wood and animal bones, including many cattle bones, were found at the site (111, 115). The site was elevated (105) and appeared to be designed for a relatively large crowd (157).
from scratch, but rather chose a location with an existing, albeit broken down, altar. This altar should have been a strong reminder to the Israelite spectators of what was once done at that location. Israelites sometimes had their own legitimate high places for worship but often kept Canaanite traditions alive by having illegitimate worship centers at the same location (De Vaux 288). That was likely the case on Mount Carmel. Whitney (125) called such places “the chief crucible for the conflict between the faith of Israel and the religion of Canaan.” The existence of altars for both gods made this location ideal for the showdown.

Elijah rebuilt an existing altar that had either fallen into disrepair, or more likely had been torn down (1 Kings 19:10, 14). Rebuilding this altar symbolically demonstrated Elijah was reclaiming the cultic site for Yahweh (Zannoni 269). Elijah added twelve stones representative of the twelve tribes of Israel (v. 31) and reminiscent of Moses’ and Joshua’s erection of twelve stones at Sinai (Ex. 24:4) and in the middle of the Jordan River (Josh. 4), respectfully. The symbolism of putting twelve stones representing the twelve tribes of Israel (v. 31) would not have been missed by the spectators. The twelve stones were a symbol of the unity of the people (Heger 119). The stone altar on Mount Carmel is not the only stone altar mentioned in the Old Testament.

In addition to arranging the twelve stones for the altar, Elijah also made a trench around the altar which was filled with water. The trench may have been made to create a barrier to keep the heavenly fire contained (Cogan 443). While the trench could have been dug to increase the

5. This symbolism was also used in an earlier miracle when the Jordan river was parted for the Israelites to go into the Promised Land and a memorial was erected using twelve stones from the riverbed (Josh. 4:1-7).

6. Yahweh gave instructions for Moses for making an altar of uncut stone (Ex. 20:22-25); Moses gave instructions on setting up an altar of uncut stones on Mount Ebal after the Israelites crossed over the Jordan (Deut. 27:4-8); the people of Beth Shemesh offered the cows who brought back the Ark on an altar consisting of a large stone (1 Sam. 6:13-14).
amount of water to be evaporated to further heighten the miracle, it could also have been the usual way of preparing a place of sacrifice to catch the blood running from the sacrifices (Heger 80). The trench may be an indicator of the width of the flame as the heat from the fire evaporated the water.

A high place is situated on a natural or manmade elevated location (Barrick 566). First and Second Kings both warn about high places used to sacrifice to other gods. However, the altar here is referred to specifically as an “altar of the LORD” (1 Ki. 18:30) which indicates this particular offering site was sanctioned by Yahweh (Van’t Veer 242). The altar on Mount Carmel could have been recently used in Israel based on Elijah’s later comments about the people of Israel having torn down Yahweh’s altars (1 Kings 19:10) (Van’t Veer 243). The altar most likely was torn down as part of Jezebel’s religious persecution (Monson 79). The irony of Elijah rebuilding the altar on Mount Carmel is that no altar had been built in Israel for years, nor had any sacrifices been offered to God for many years. Another possible reason for the selection of Mount Carmel for this contest may have been the availability of an altar of Yahweh, albeit in need of repair (Patterson and Austel 146).

Heavenly Pyrotechnics

The fire used on an altar of Yahweh in the Old Testament was very special, “this fire upon the altar was sacred, possessing positive purifying and sanctifying power” (Morgenstern 6). God sent fire from heaven at the dedication of the altars at: the tabernacle in the desert (Lev. 9:22-24), David’s altar built on the threshing floor of Ornan (1 Chron. 21:26), Solomon’s Temple (2 Chron. 7:1), and Elijah’s rebuilt altar on Mount Carmel (1 Kings 18:30-38) (Morgenstern 6-26).

Fuel

Elijah instructed the prophets of Baal to place their sacrifice on an altar with wood (1 Ki. 18:23). This wood likely came from the dwarf-oaks and olive trees that are common on Mount Carmel (Cook 204). However, this wood was not the main fuel used to consume Elijah’s sacrifice. Some have suggested Elijah used some trickery by pouring fuel such as naphtha, which is naturally-occurring and clear, instead of water on the sacrifice or by using flammable stones made out of bitumen, but that is unlikely (Ibid.).

Although God could have performed this miracle any way He chose, an attempt will be made here to describe the minimum aspects of the miracle using our current understanding of combustion. For the fire to have come literally from the sky, the fuel would have to have been heavier than air so that, for example, it probably would not have been natural gas or hydrogen which are both lighter than air and tend to rise rather than fall. Gaseous fires tend to be extremely buoyant and therefore do not normally burn downwardly unless there is a high momentum fuel jet oriented directed downward. Gaseous fuels such as natural gas and hydrogen tend to burn with relatively little luminosity and therefore would not have been as easily seen from a distance as other fuels. If the fuel was a gas, it would probably have been something like propane or butane which are both heavier than air, would naturally have fallen down, and would have burned with considerable luminosity to be easily seen from a long distance (Baukal, *Heat Transfer* 103). The advantage of a gaseous fuel is that it is easier to ignite and more easily mixes with air to combust compared to liquid and solid fuels.

The fuel could have been a liquid, like oil, since liquid fuels are much heavier than air and naturally fall downward. God could certainly have used other liquid fuels like gasoline and diesel that do not occur naturally, did not exist at that time, and are produced through complex
processing of crude oil. If a liquid fuel was used, it could have been “poured” from the sky onto the altar, somehow ignited, and burned in a streaming column. One of the problems when using a liquid fuel is that it must be sufficiently atomized (broken up into fine particles) to produce a stable flame so the streaming liquid fuel would also have had to have been continuously atomized as it fell to earth. If it was all atomized in the sky and then fell to earth, the vaporized liquid fuel could have become too light to fall to earth and the fire would then have been uncontrolled.

It is possible that even a solid fuel, such as bitumen, could have been used because solids are also much heavier than air and naturally fall downward. However, this is less likely (on a natural basis) because solid fuels are even more difficult to ignite and burn than liquids (Ragland and Bryden 24).

Thermal spallation is a technology using flames to “drill” through rocks (Rauenzahn and Tester 381-99). These flames typically use pure oxygen, instead of air, to oxidize the fuel because the resulting flames are much hotter. Air contains mostly nitrogen (N$_2$) which acts as a ballast to reduce the temperature of a flame compared to using pure oxygen. For example, the maximum possible or adiabatic flame temperature (AFT) of an air-methane flame where both the air and methane are initially at ambient temperatures is approximately 1980°C (3600°F), while the AFT of an oxygen-methane flame is over 2760°C (5000°F) (Baukal, Oxygen-Enhanced Combustion 17). These high temperature flames are used, for example, to melt sand in the production of glass (Eleazer and Hoke 215-36). Therefore, pure oxygen may have been used to combust the fuel raining from heaven to produce a flame hot enough to consume stones. There is no natural explanation for the source of this pure oxygen, which is produced today by various air

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8. Rich deposits of bitumen have been found in the region of Palestine (Forbes 27).
separation techniques (Kerry 77-87; McGuinness and Kleinberg 43-75).

The combustion process was at least efficient enough that apparently no significant smoke was produced as there is no mention of smoke in the narrative. Smoke is mentioned many times elsewhere in the Old Testament,\(^9\) so it would likely have been mentioned if it were present on Mount Carmel. It is also possible that smoke could have been generated but was not as visible because of the time of the day since the miracle was at dusk where the darker sky could have masked any smoke. Another reason it is unlikely any significant smoke was produced is that would have reduced the visibility and therefore the impact of the fire from heaven. The lack of smoke suggests the most likely fuel would have been a gas, which normally produces less smoke than liquid or solid fuels (Baukal, *Industrial Combustion Pollution* 529).

**Fire**

Elijah arranged the wood and cut the ox into pieces and laid them on the wood (1 Ki. 18:33), just as the priests had been commanded to do by God (Lev. 1:7-8). Proverbs 26:20 emphasizes the need for fuel to keep a fire going, “For lack of wood the fire goes out.” Wood was the source of fuel used for an altar fire (Lev. 3:5).

The combination of fire and a sacrifice is significant (Ryken 507):

Elijah prayed for fire because before the people could receive any other blessing from God, they needed to receive atonement for their sins. They needed to get right with God before they could get any rain from God. Remember that the reason there had been no rain in the land was that the people had sinned against God. Drought was God’s particular punishment for idolatry: “Take care lest your heart be deceived, and you turn aside and serve other gods and worship them; then the anger of the LORD will be kindled against you, and he will shut up the heavens, so that there will be no rain, and the land will yield no fruit, and you will perish quickly off the good land that the LORD is giving you” (Deut. 11:16-17).

Many commentators (e.g., Allen 199; Ap-Thomas 153; Auld 120; Bronner 63; Monson 80; 9. E.g., Exod. 19:18, 20:18; Lev. 16:13; Josh. 8:20-21; Judg. 20:38-40; Isaiah 9:18.)
Matheney and Honeycutt (211; Van’t Veer 281; Walsh 253; Wood 91) have suggested lightning, instead of fire, was used to consume the offering. However, this misses an important part of the miracle which is the simulation of an evening sacrifice on a grand scale. Lightning was not used for a normal evening sacrifice – fire was, which is why real fire is the more likely source of energy to consume the sacrifice on Mount Carmel, simulating an evening sacrifice on steroids.

Besides fire and lightning, a volcanic eruption has been offered as a possible source of the “fire” from heaven, although this is summarily dismissed as Mt. Carmel is a limestone spur which makes volcanic activity highly unlikely (Ap-Thomas 150-1; Skipwith 690).

Energy Analysis

High intensity flames consumed the water-soaked sacrifice, evaporated a large quantity of water around the altar, and even consumed the stones used to make the altar. The minimum amount of energy needed for this miracle can be estimated. There are several components of the heat load: the stones used to make the altar, the water poured on the altar that soaked the bull and altar, and the bull sacrificed on the altar. Each of these is considered next.

Altar

The exact shape of the altar is unknown, although altars built during this period in Israel’s history were probably simple and low in stature (Heger 170). Two general types of altars have been discovered in Palestine dating back to the Old Testament: Type I which is taller and more circular and Type II which is shorter and more oblong (Vaughn 40-55). Some of the former have been as large as 14 m (46 ft) in diameter and some of the latter as long as 18 m (59 ft). An example is the altar found on Mt. Ebal which was an earth and stone structure approximately 7 m
x 9 m x 3 m high (23 ft x 30 ft and 10 ft high) (Zertal, “Has Joshua’s altar been found” 40). An Old Testament altar had to be substantial in size to hold a sacrifice as large as an ox and the wood necessary to burn a large animal (Gadegaard 35-45).

While it is impossible to know how big Elijah was, a reasonable estimate can be made to determine how large the stones used to build the altar may have been. The average height and weight of an Israelite man from this time period was approximately 5’0” (152 cm) (Matthews 3) and 65 kg (143 lb), respectively. It is assumed Elijah was of average size as the Bible often notes when a person was exceptionally large such as king Saul (1 Sam. 10:21-23) and Goliath (1 Sam. 17:4). It is also assumed Elijah was of average strength as the Bible also notes when a person is exceptionally strong such as Samson (Judges 16:5). Elijah was likely to have been in excellent physical condition as he outran king Ahab who was in a chariot from Mount Carmel to Jezreel (1 Kings 18:44-46) which is roughly a distance of 16 km (10 miles). Strength Level (www.strengthlevel.com) has sampled thousands of people to determine standards for weightlifting in five categories ranging from beginner to elite in a variety of lift types. The one-repetition maximum performance for a front squat for a 65 kg (143 lb) male ranges from 45 to 140 kg (99 to 309 lb). More weight can be lifted for a normal squat over the shoulder and even more for a deadlift. Because of the bulky nature of a large stone, the weight for a front squat for a novice will be assumed here as a minimum instead of the larger weights for a normal squat and deadlift. The front squat lift weight for a novice weightlifter is 63 kg (139 lb) will be used here.

While Elijah was likely in excellent condition and there is some evidence to suggest people were generally in better condition in ancient times due to diet and more physical lifestyles, he may

10. This is comparable in size to Solomon’s Temple Altar and Ezekiel’s Visionary Temple Altar, although considerably bigger than the Tabernacle Altar.
have had to carry the stones some distance and he carried twelve of them which would reduce the amount of weight for each stone he could carry compared to a single lift.

Elijah repaired an altar of the LORD using twelve stones (1 Ki. 18:30-32). These stones most likely came from Mt. Carmel, i.e., they were probably not brought up to the mountain by Elijah or his assistant. The stones used by Elijah were likely made of limestone because Mount Carmel is in a limestone ridge (Hallner and Rosenau 61-80). The stones were likely of a size that could be handled by Elijah himself. Although Elijah had a servant with him, Elijah carried the twelve stones to make the altar (1 Kings 18:31-32). In Joshua 4:5, Joshua told each representative of the twelve tribes to take up a stone on his shoulder which indicates the size and weight of each stone could be handled by a single man. It is likely that was the case for the stones used by Elijah.

The density of typical limestone made primarily of calcite (CaCO₃) is 2.72 g/cm³ (170 lb/ft³) (Oates 18). Then, a 63 kg (139 lb) stone would have a volume of 0.023 m³ (0.081 ft³). If the stones were spherical, they would have a diameter of 35 cm (14 in.) which is not too bulky to carry. Then the total mass of twelve stones weighing 63 kg (139 lb) each is 756 kg (1670 lb).

The total cross-sectional area of these spherical stones with no gaps between them would be 1.2 m² (13 ft²). If the stones were aligned instead of staggered with their edges touching to make a single layer, then the cross-sectional area would be 1.5 m² (16 ft²). With mortar between the stones, the cross-sectional area would be at least 2 m² (22 ft²). That would be barely enough to hold a bull by itself. The stones were probably not perfectly spherical and were probably somewhat flatter which means they could have been laid in such a way to cover even a larger total area than if they were spherical. It will be assumed here that Elijah’s stones provided a second layer over an existing base layer remaining from the broken-down altar. Given the size of the altar found on Mt. Ebal, it is likely the altar on Mt. Carmel was much larger than assumed
Then for two layers of limestone rock as assumed here, the total mass would be approximately 1,500 kg (3300 lb). The average specific heat of calcite (Oates 20) between 0 and 800°C (32 and 1500°F) is 1.1 kJ/kg-K (0.26 Btu/lb-°F). Calcite dissociates into quicklime (CaO) and carbon dioxide (CO₂) at 900°C (1700°F). The sensible energy to heat the limestone from 20 to 900°C (70 and 1700°F) then is approximately 1.5 x 10⁶ kJ (1.4 x 10⁶ Btu). The heat of dissociation for limestone (Oates 21-2) at 900°C (1700°F) is 1,686 kJ/kg (725 Btu/lb). Then the energy needed to dissociate the limestone into quicklime is approximately 2.5 x 10⁶ kJ (2.4 x 10⁶ Btu). The thermal decomposition of calcite can be written as:

\[
\text{CaCO}_3 + \text{heat} \leftrightarrow \text{CaO} + \text{CO}_2
\]

(1)

100g 56g 44g

After the calcite is dissociated, there remains 1500(56/100) = 840 kg (1,850 lb) of lime. The melting point of CaO is 2580°C (4680°F) and the mean specific heat is 0.762 kJ/kg-K (0.182 Btu/lb-°F) (Oates 118). The sensible energy to heat the lime from 900°C (1700°F) to the melting temperature of 2580°C (4680°F) is 1.1 x 10⁶ kJ (1.0 x 10⁶ Btu). The heat of fusion for lime (Kelley 134) is 915 kJ/kg (393 Btu/lb). The amount of energy needed to melt the lime would be 7.7 x 10⁵ kJ (7.3 x 10⁵ Btu). Further energy would be needed to heat the liquid lime to its boiling temperature and then to vaporize the lime. The specific heat of liquid CaO (Chase 730) is 1.12 kJ/kg-K (0.268 Btu/lb-°F) so the sensible energy to heat the liquid lime to its vaporization point would be 2.5 x 10⁵ kJ (2.4 x 10⁵ Btu). The heat of vaporization of liquid CaO (Babeliowsky 1157) is 1.04 x 10⁴ kJ/kg (0.99 x 10⁴ Btu) so the energy to vaporize the liquid lime is 8.7 x 10⁶ kJ (8.2 x 10⁶ Btu). Then, the total energy needed to vaporize the stones is 1.5 x 10⁷ kJ (1.4 x 10⁷ Btu).
Water-Soaked Sacrifice

Four pots of water were poured on the altar three times. While this certainly heightened the miracle, it was also likely a direct affront to Baal who was supposed to be the god that provides rain which had been lacking in the land for over three years (Baukal, Hydrotechnics 67). It is not known exactly how much water was used to saturate the sacrifice. Typical larger Israelite pots held approximately 32 liters (8.5 gal) while smaller pots held about half that amount (King and Stager 139-46). The pots used in this narrative were more likely the smaller pots (Monson 80). Therefore, the twelve pots of water poured on the offering may have totaled from 192 to 384 liters (51 to 101 gal). Using the smaller volume, this equates to approximately a total of 191 kg (421 lb) of water. Using 4.2 kJ/kg-K (1.0 Btu/lb-°F) as the specific heat of water (Cengel and Boles 902) and assuming the water was heated from 20 to 100°C (68 to 212°F), this equates to a sensible energy requirement of 6.4 x 10^4 kJ (6.1 x 10^4 Btu). Using a heat of vaporization of 2257 kJ/kg (970 Btu/lb) for water (Ibid.), the energy required to vaporize the water would be 4.3 x 10^5 kJ (4.1 x 10^5 Btu).

Bull

Elijah’s animal sacrifice was a bull. Domesticated cattle in the Bible were likely of the brachyceros type (Jonas 94). The two most common breeds in Palestine today are the Arabian and the Golan which have average weights of approximately 225 and 263 kg (496 and 580 lb), respectively based on a sample of 78 cows (Jonas 96). It is impossible to know how large the bull was that Elijah sacrificed, especially since some sacrifices were of animals approximately

11. The ages and genders of the 78 cows were not given so it is unknown how many were bulls that may have been one year old.
one year old (e.g., Lev. 9:3) (Borowski 215).\footnote{Borowski noted that one year old cows were typically referred to as calves and older cows as bulls so it can be assumed Elijah’s sacrifice was an adult male cow.} For the sake of this analysis since it is unknown how big the bull was that Elijah sacrificed, it will be assumed it was the smaller bull and weighed 225 kg (496 lb).

It might be assumed the wood piled on the altar would have provided enough energy to consume the bull without any additional energy such as a fire from heaven. However, that wood would not have naturally burned because it was soaked with the water poured over the sacrifice. The fire from heaven would likely have consumed the bull before the wood because it was on top of the wood shielding it initially from the heavenly fire. The bull would have likely been incinerated before all of the water evaporated from the wood. Therefore, for the purposes here it will be assumed that energy was needed to incinerate the bull and to evaporate the water from the wood, but not to burn the wood. Once the wood was dried, it would have released heat when it burned. Since the bull would already have been incinerated and the water evaporated, the energy from the wood would not have been enough to consume the stones which normally held the wood for a normal sacrifice. Therefore, the energy from the burning wood will be assumed to have a negligible effect in this analysis.

Specific data on the energy required to burn a bull carcass could not be found. According to the U.S. Department of Agriculture, the following materials are recommended for the open-air burning of an unspecified size adult bovine carcass: 3 bales of straw or hay, 3 pieces of untreated heavy lumber, 50 lb (23 kg) of kindling wood, 100 lb (45 kg) of coal pieces 6-8 in. (15-20 cm) in diameter, and 1 gallon (3.8 liters) of liquid fuel (not gasoline) (U.S. Dept. of Agriculture 14-57). As can be seen, this is not very specific as the exact mass and type of each fuel are not provided.
An alternative approach is to assume the bull was approximately 60% water by mass. This fraction was determined from data collected from the carcasses of 58 Holstein and Angus bulls (Fortin et al 604-14). Lacking further information, it will be assumed the rest of the bull, particularly the fat which contains significant heating content, does not require any additional energy to burn. This estimate is likely the least amount of energy required to incinerate the bull. Using the same approach as for the water poured on the sacrifice, 4.6 x 10^4 and 3.1 x 10^5 kJ (4.4 x 10^4 and 2.9 x 10^5 Btu) would have been required to heat the water in the bull up to the vaporization temperature and to vaporize the water, respectively. The total estimated energy requirement then is 3.6 x 10^5 kJ (3.4 x 10^5 Btu).

Another approach is to consider the energy needed to incinerate a cow in a modern carcass incinerator. These combustors are well-insulated and nearly adiabatic chambers, so the energy requirements should be close to the energy needed just to incinerate a carcass. Fuel requirements were taken from the manufacturers’ data sheets to determine the energy required to incinerate a 225 kg (496 lb) bull. An Addfield (www.adfield.co.uk) model TB Animal Carcass Waste Incinerator, Inciner8 (www.inciner8.com) model I8-250, and The Incinerator Company Ltd model TICA 900 Animal Carcass Waste Incinerator would require approximately 1.1 x 10^6, 1.4 x 10^6, and 9.9 x 10^5 kJ (1.0 x 10^6, 1.3 x 10^6, and 9.4 x 10^5 Btu), respectively of energy to incinerate a 225 kg (496 lb) bull. These are all relatively close to each other. The average of these three is 1.2 x 10^6 kJ (1.1 x 10^6 Btu).

Since the incinerators are not 100% thermally efficient, the actual energy just to incinerate a bull would be lower than 1.2 x 10^6 kJ (1.1 x 10^6 Btu). The energy estimated assuming the bull was 60% water of 3.1 x 10^5 kJ (2.9 x 10^5 Btu) likely underestimates the total energy required. A closer estimate is likely somewhere between these two values. For the purposes here, an average
of these will be used: $7.6 \times 10^5$ kJ ($7.2 \times 10^5$ Btu).

Discussion

The minimum estimated energy requirements calculated above are summarized here:

<table>
<thead>
<tr>
<th>Energy to:</th>
<th>Energy (kJ)</th>
<th>Fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destroy the stones:</td>
<td>$1.5 \times 10^7$</td>
<td>92</td>
</tr>
<tr>
<td>Evaporate the water poured on the sacrifice:</td>
<td>$5.0 \times 10^5$</td>
<td>3</td>
</tr>
<tr>
<td>Destroy the bull:</td>
<td>$7.0 \times 10^5$</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>$1.6 \times 10^7$</td>
<td>100</td>
</tr>
</tbody>
</table>

As can be seen, the vast majority of the energy is needed to destroy the stones, with much less needed for the water and the bull.

The energy distribution to destroy the stones is as follows:

<table>
<thead>
<tr>
<th>Energy to:</th>
<th>Energy (kJ)</th>
<th>Fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat limestone to dissociation:</td>
<td>$1.5 \times 10^6$</td>
<td>10</td>
</tr>
<tr>
<td>Dissociate limestone into lime + CO$_2$:</td>
<td>$2.5 \times 10^6$</td>
<td>17</td>
</tr>
<tr>
<td>Heat solid lime to its melting temperature:</td>
<td>$1.1 \times 10^6$</td>
<td>7</td>
</tr>
<tr>
<td>Melt lime:</td>
<td>$7.7 \times 10^5$</td>
<td>5</td>
</tr>
<tr>
<td>Heat liquid lime to its vaporization temperature:</td>
<td>$2.5 \times 10^5$</td>
<td>2</td>
</tr>
<tr>
<td><strong>Vaporize liquid lime:</strong></td>
<td>$8.7 \times 10^6$</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td>$1.5 \times 10^7$</td>
<td>100</td>
</tr>
</tbody>
</table>

Most of the energy to destroy the stones is used to vaporize the liquid lime.

This estimate is the bare minimum assuming no heat losses. In fact, the heat losses would have been very high because there was no insulated chamber surrounding the altar to hold in the heat. Given the high heat flux and relatively low ambient temperature compared to the flame, the radiant losses to the environment would have been very high. For the sake of argument, assume at least double the amount of energy would have been needed to account for the heat loss to the environment. The losses were likely higher than that but we’re attempting to estimate the minimum energy needed so a conservative estimate is used here.

The next consideration is how much power would be required which depends on how long it took for this miracle to occur. Since that is not known, a range of times will be considered
with as short as 1 second and as long as 1 minute. Figure 1 shows the minimum estimated power that would be required depending on how long the fire impinged on the sacrifice, assuming the rate was steady.

![Figure 1](image.png)

Figure 1  Power (GW) required as a function of time (s).

A typical power plant is on the order of approximately 500 MW. Based on the above analysis, that would have been the minimum amount of power used even if the flame impingement lasted for as long as a minute.

According to Edersheim (1 Kings 18), “That day Carmel witnessed one of the grandest scenes in the history of Israel.” It is tempting to give Elijah too much credit for the victory on Mount Carmel. To put this narrative in proper context, Pritchard (113-4, italics his) wrote, “This is the story about God. It is not about Elijah. He’s just the instrument through whom God works an incredible miracle.”

God’s use of fire in this miracle was particularly significant, “The veneration of fire by most
nations is not surprising if we consider that there is probably no agency more powerful for good or ill in the universe, than fire” (Bronner 54). The fire sent from heaven to the altar on Mount Horeb “provides stunning confirmation that YHWH is G-d” (Sweeney 209). On the uniqueness of this fire, Wood (92) wrote, “Fire that consumes stones and dirt cannot be kindled by human hand.” Ryken (479) described it as no mere fire but a “mighty conflagration.”

Conclusions

The purpose of this exercise was to determine where most of the energy would have been needed for the fire miracle on Mount Carmel and to get an order of magnitude estimate of how much power this would have required. The calculations attempted to estimate the minimum requirements, so the actual amount of energy used on Mount Carmel was likely much larger than estimated here. Based on the calculations, it appears most of the energy would have gone to destroy the stones and the amount of power required would have been comparable to today’s power plants. Archaeologists have found altars in Palestine dating back to the Old Testament that are much larger than the size used here, where the energy needed to vaporize them would have been much larger than calculated here. The flame temperature needed to vaporize the altar stones would have been higher than could be produced by normal air-fuel flames and could not have been produced naturally.

This would have been a spectacular and awe-inspiring event that would likely not have been forgotten by any who were present that day. The onlookers must have been far enough away from the heavenly fire that none were injured but undoubtedly they felt the heat from the flames. Add to that the fire was displayed against the night sky and it would likely have rivaled the best fireworks displays today.
Works Cited


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Observations on Things Measured in the Bible

John Tixier

Abstract

As a new engineering professor at a Christian university that allows an extra five minutes in each class for spiritual and devotional instruction, an approach in the Engineering Technology Measurements Laboratory classroom sessions was taken by focusing devotions on the topic of Measurements in the Bible. This included terms of measurement, things that are or can be measured, and insights into measurable subjects. In general, observations were made systematically based on daily Bible reading, starting with the first words “In the beginning…” and continuing through the Pentateuch during the semester. In addition, some general observations from New Testament and other Old Testament readings were also made. As such, measurement topics can be broken into two main categories: physical substances and metaphysical topics. Physical substances include the obvious metrics concerning weight, size (length and volume), and value (worth), as well as the general numbering (counting) of physical objects. Time (durations and dates), is also considered as a physical quantity. Insights can be gathered based on the emphasis that God seems to place on certain lengths of time or timing of events, numbers or amounts of things, and the value of certain items. Special notice should be taken when God gives someone a measuring assignment (e.g., Rev 21). But even more interesting may be the intangible matters related to Christian living that give expectations of measurement. Jesus speaks often of faith as something that can be measured – He cites people as having little (e.g., Mt 6:30, 8:26, 16:8) or much (e.g., Mt 8:10, 15:28) faith. Paul talks about faith growing (e.g., 2Cor 10:15, 1Thes 1:3), as if one should be able to measure it – perhaps relative to our trials requiring a certain amount of faith (should we consider how to measure in “faith units”?). Peter offers his readers grace in abundance (1Pet 1:2, 2Pet 1:2) and expects them to “grow in the grace…of Jesus” (2Pet 3:18), as if grace is something that can be measured. Jesus even states how one can measure the greatest love (Jn 15:13). Similarly, hope, joy, and knowledge are all referred to as something measurable in the life of the believer. This paper presents some of these observations from the perspective of an engineer, of both tangible and intangible objects of measurements in the Bible, and offers some associated implications for the believer.

Introduction

This paper was inspired by a few of the observations that were made by myself, with the aid of some of my students over the course of the semester as we focused our devotional experience on the topic of measurements in the Bible. The paper begins by defining what measurement is and then provides an overview of measurement terms found in the Bible. It describes the God who measures, and observes several examples of tangible measurement topics from both Old and New Testaments. These include general observations in Genesis and specific observations on time, followed by two examples from the book of John. Observations are also offered regarding measurements of intangible subjects in the New Testament such as faith and love, from the teachings of Jesus and Paul. Additional background on the inspiration for this paper is provided

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in Appendix A. The paper is by no means a comprehensive reference. Rather, the objective is to highlight that we serve a God who has invented measurements as part of His creation and seems to take measuring things very seriously, including the spiritual growth of the believer.

Measurements Defined

To measure something is to determine a certain set of its properties in reference to a standard. At its simplest, it is a form of counting. Properties can include (but are not limited to) size, weight, duration, quality, or merely amount. Measurements are so important to our daily life that we often communicate in measurement terms without thinking about it. One does not have to be an engineer to measure the height and weight of a child and record it on a growth chart for future reference, or to track the fuel efficiency of a car in miles per gallon upon filling up at the pump. When a package is mailed, or a bag checked at the airport, one is cognizant of the necessity of measuring the weight of the item.

Quantitative measurements use numbers and units. Units can be pure (feet, meters, seconds) or mixed (dollars per pound, miles per hour). But qualitative measurements are also regularly made, typically in terms of general reference. Terms such as all, some, every, most, and their opposites are used in qualitative measurement descriptions. Moreover, qualitative comparisons are used as a form of measurement. For example, higher, wider, larger, and better (and their superlatives – ending in est) are qualitative terms implying that something is in some way bigger than something else (or possibly its own self over time). If something is observed to have increased, one understands that it has expanded in some way over what it used to be. The measurement context may be implied or explicit; the increase may be quantified or relative. Whether the increase is in reference to a child’s growth, a person’s salary, or the speed of a car, anyone in the discussion has been trained from childhood to understand the measurement, whether or not exact numbers are being used and regardless of the technical background of the participants.

For an engineer, much of his or her profession relies on detailed measurements. The engineer doesn’t take measurements for granted as the layman might in the examples previously cited. Typically, correct measurements are critical for the success of projects and mistakes can mean loss of dollars (that managers will measure) or even loss of lives (that lawyers will measure, typically in terms of dollars). One of the most famous engineering measurement mistakes was in 1999 when NASA lost what was intended to be the first interplanetary weather satellite, designed to orbit Mars. Details are easily available on the internet; the root cause of the loss was attributed to the failure of different teams working on the project to coordinate their measurements. The NASA team used metric units while a contractor used English units. The failed translation of English units into metric units resulted in the loss of the $125M probe. The BBC provides a summary of 10 such mistakes, including a miscalculation that cost the lives of the team of explorers to the South Pole on an expedition led by explorer Robert Scott in 1910-1912. As a result, they did not measure out sufficient supplies for the trek and experts determined that they died of starvation. Engineers may refer to such mistakes as “gross blunders” as they are the results of carelessness on the part of the person making the measurement or associated calculations.
These extreme examples show the importance of accurate measurements, at least in certain applications. But are measurements important when it comes to reading the Bible and understanding truths that apply to our lives?

The God Who Measures

There are several well-known passages in the Bible that refer to measuring, and when considered as part of a study on the topic of measurements, give us some insight into God’s nature. Three aspects of measurements relative to the God of the Bible are examined in this section. First is the biblical requirement for accurate measurements, based on the character of God. Second is God’s use of measurements in His judgments. Third are the references, mostly poetic or prophetic, to God measuring His creation.

Accurate Measurements

Proverbs 11:1 says “the Lord detests dishonest scales, but accurate weights find favor with him.” (the KJV says dishonest scales are an “abomination”.) Two more times in Proverbs, the same sentiment is given (20:10, 23), even mentioning not only weights but differing measures that are detestable. Proverbs 16:11 further states that “honest scales and balances belong to the Lord.” In the spirit of James 1:17 (every good and perfect gift is from the Father above), combined with the well-known Christian principle that “all truth is God’s truth,” it can be directly inferred that accurate measurements are godly measurements, regardless of the application. These verses give the sense that God is displeased with dishonest measurements, whether in the literal sense of cheating for dishonest gain, or in the figurative sense of prejudice – using different standards in making judgments and assessments of people. Conversely, God is pleased with those who make an attempt to measure accurately and devise systems for accurate measurements. God’s concern for accurate measurements is not isolated to proverbial statements; they are embedded in the Mosaic Law. In Leviticus 19:35-36, the Israelites are commanded to “…not use dishonest standards when measuring length, weight or quantity. Use honest scales and honest weights… I am the Lord your God…”. That is, accurate measures flow from the nature and character of the God of Israel, and He requires the same of His people. The same sentiment is reiterated in Deuteronomy 25:13-16 where Moses restates to the people:

Do not have two differing weights in your bag—one heavy, one light. Do not have two differing measures in your house—one large, one small. You must have accurate and honest weights and measures, so that you may live long in the land the Lord your God is giving you. For the Lord your God detests anyone who does these things, anyone who deals dishonestly.

Micah condemns the people for exactly this crime: “Shall I acquit someone with dishonest scales, with a bag of false weights?” (6:11). By being prepared with two different weights representing the same standard, a person has purposefully designed and implemented a system to deceive using a method of measurement. He can use one standard for buying and another for selling in order to gain a dishonest advantage. Clearly, our God takes measuring seriously and expects honest and accurate measurements. For engineers, whose vocations are directly and
implicitly related to measuring – and doing so accurately – they can be confident that they are fulfilling a godly calling.

Relative to dishonest measurements in the figurative sense of prejudice, in his discussion on living out one’s faith, James (chapter 2) offers a direct example of such discrimination in his condemnation of how his readers might treat a rich man and a poor man differently. In verse 9, he minces no words in saying that by showing such partiality or favoritism “you sin”. So in a direct sense, measuring rightly and accurately, whether figuratively or literally, even in the case of engineering measurements, is a godly activity and is pleasing to Him.

Measurements in Judgment

The judgment of King Belshazzar in Daniel 5 is a familiar passage to many. When Daniel is finally called on to interpret the mysterious writing on the wall (5:26-28), he finds three phrases directly related to God’s measuring of the King:

Here is what these words mean:
Mene: God has numbered the days of your reign and brought it to an end.
Tekel: You have been weighed on the scales and found wanting.
Parsin: Your kingdom is divided and given to the Medes and Persians.

Daniel explains that because the King did not “honor the God who holds in his hands your life and all your ways,” that judgment has come upon him. Although the reference to being “weighed on the scales” is figure of speech, the references to “numbering his days” and “dividing his kingdom” can be understood as referring to God’s literal intentions. God not only expects accurate and just measurements, as discussed earlier, but he also uses measurements in his judgments.

God has made it clear that He requires honest measurements from His people. Therefore, it is not surprising to find an example of God’s judgment for disobedience of His people in this regard. In the following passage, the prophet provides a reference to dishonest measurement (Amos 8:4-6):

Hear this, you who trample the needy
and do away with the poor of the land, saying,
“When will the New Moon be over
that we may sell grain,
and the Sabbath be ended
that we may market wheat?”—
skimping on the measure,
boosting the price
and cheating with dishonest scales,
buying the poor with silver
and the needy for a pair of sandals,
selling even the sweepings with the wheat.

Another familiar, yet difficult, passage deals with the judgment of the flood. A focus on measurements immediately reveals the basis for the judgment. The narrative is set up by the
statement in Genesis 6:5 that “[t]he Lord saw how great the wickedness of the human race had become on the earth, and that every inclination of the thoughts of the human heart was only evil all the time.” Four qualitative measurements terms are used relative to the concept of good/evil and are highlighted in that verse. These four adjectives offer comparison in a way that places each of the references at the extreme end of whatever scale might be used to measure the concept of evil. While it is clear that the literary tool of hyperbole is being used (one can imagine that kindness and generosity were not completely absent from all of humanity), the point of the story seems to be that it was so overwhelmingly bad that God goes on to express in some sense His “regret” and need to “start over.” A final conclusion to the story can be drawn once it becomes obvious as the story of humanity continues after the flood, that even by starting over with the single most righteous man on earth, God was not able to find a human solution to the problem of sin. Hence the need for a divine savior is confirmed.

In the New Testament, Jesus also relates measurement as a matter of judgment, as recorded in the synoptic gospels (e.g., Matthew 7:1-2), “Do not judge, or you too will be judged. For in the same way you judge others, you will be judged, and with the measure you use, it will be measured to you.” Jesus goes on to point out how easy it is to identify the “splinter” in someone else’s eye while ignoring the “plank” in your own. This is obviously figurative language and while there may not be a definitive physical standard for judging, one can easily understand the implication that God expects fair and honest judgments, even in dealing with people. Jesus appears to warn that “what goes around comes around,” in that when you use an unfair standard to judge others, it will eventually be used on you.

Measuring Creation

While the familiar verses of Genesis 1 lay out the creation story, another passage in Isaiah (40:12) relates God’s sovereignty over creation as one who does so using measurements:

Who has measured the waters in the hollow of his hand,  
or with the breadth of his hand marked off the heavens?  
Who has held the dust of the earth in a basket,  
or weighed the mountains on the scales  
and the hills in a balance?

And again in verse 15:

Surely the nations are like a drop in a bucket;  
they are regarded as dust on the scales;  
he weighs the islands as though they were fine dust.

This is poetic language with the prophet using figures of speech. But even so, the references again leave us with the understanding that our God values measurements, and has used them since “the beginning.”

When God finally responds to Job, He does not provide a direct response to Job’s demands for a hearing or for justice. Rather, He gives Job some perspective, and relates His power and presence in the original creation with references to measurements (Job 38:4-7):
Where were you when I laid the earth’s foundation?  
Tell me, if you understand.  
Who marked off its dimensions? Surely you know!  
Who stretched a measuring line across it?  
On what were its footings set,  
or who laid its cornerstone—  
while the morning stars sang together  
and all the angels shouted for joy?

God asks Job if he is familiar with the measuring tools He has used. Although the layman may quickly pass over the subtleties, civil engineers immediately call to mind surveying tools, plumb lines, and compaction tests, as well as understanding the proper use of a cornerstone (at least in ancient times), precisely constructed and placed to accurately establish the three construction dimensions of a building. Earlier, in one of Job’s discourses, he waxes on about wisdom (28:23-27):

God understands the way to it  
and he alone knows where it dwells,  
for he views the ends of the earth  
and sees everything under the heavens.  
When he established the force of the wind  
and measured out the waters,  
when he made a decree for the rain  
and a path for the thunderstorm,  
then he looked at wisdom and appraised it;  
he confirmed it and tested it.

Even before his personal encounter with God, Job not only alludes to God’s measuring a certain aspect of creation, but even mentions the associated concept of “testing,” which any engineer knows may be used to confirm or validate measurements.

Thus, it is easy to see that not only is “measurement” a biblical concept, but our God has been intimately involved in measuring from the beginning of creation. While the passages cited above use figurative and poetic language, the concept is used in a manner that allows the engineer to relate to and identify with the measurement concepts discussed. It is apparent that God has arranged everything He created in its proper position, by design, and has confirmed it with divine measurements.

Description of Bible Measurements

The Bible does not define measurements so much as it simply uses terms, units, and amounts of measurements, as if the reader understands the references. In fact, because they are rarely defined in the text, most study Bibles offer a table of weights and measures. Table 1 provides a list of weights and measures reproduced from the ESV Study Bible. The ESV provides the table in alphabetical order. It provides a caveat that the equivalents are approximate since “weights and measures varied somewhat in different times and places in the ancient world,” but
are based on the best generally accepted information. Other study Bibles provide similar information and caveats, also stating that the footnotes go on to explain the biblical terms in modern units. Obviously, similar information is available through a variety of sources, both in print and on the Internet. Appendix B provides an expanded list obtained from BibleHub.com. It can likely be inferred from a glance at this list that most of us are unfamiliar with many measurement terms used in the Bible. The main point here is that the Bible is full of measurements, which had an exact amount in the original context. The original terms were understood by the author and his audience, just as readers of this article would be familiar with gallons, feet, and pounds. For this reason, most Bible versions convert units of measure from the original term to a modern term (an example is given below in the discussion on John 2). Most of these conversions are based on archeology and historical records, as the Bible typically provides no internal conversion. As with any other Bible passage, the author wrote under the assumption that the reader would understand the context. It is beyond the scope of this paper to offer a detailed explanation or evaluation of biblical weights and measures in their original context; rather the point is made to reinforce that measurements in general are an integral part of biblical narrative.

Table 1. List of Biblical Weights and Measures (ESV Study Bible)

<table>
<thead>
<tr>
<th>Biblical Unit</th>
<th>Approximate American and Metric Equivalents</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>bath</td>
<td>6 gallons or 22 liters</td>
<td>1 ephah</td>
</tr>
<tr>
<td>beka</td>
<td>1/5 ounce or 5.5 grams</td>
<td>10 gerahs</td>
</tr>
<tr>
<td>cor</td>
<td>bushels or 220 liters</td>
<td>10 ephahs</td>
</tr>
<tr>
<td>cubit</td>
<td>18 inches or 45 centimeters</td>
<td>6 handbreadths</td>
</tr>
<tr>
<td>daric</td>
<td>1/4 ounce or 8.5 grams</td>
<td></td>
</tr>
<tr>
<td>denarius</td>
<td>a day’s wage for a laborer</td>
<td></td>
</tr>
<tr>
<td>ephah</td>
<td>3/5 bushel or 22 liters</td>
<td>10 omers</td>
</tr>
<tr>
<td>gerah</td>
<td>1/50 ounce or 0.6 gram</td>
<td>1/10 beka</td>
</tr>
<tr>
<td>handbreadth</td>
<td>3 inches or 7.5 centimeters</td>
<td>1/6 cubit</td>
</tr>
<tr>
<td>hin</td>
<td>4 quarts or 3.5 liters</td>
<td>1/6 cubit</td>
</tr>
<tr>
<td>homer</td>
<td>6 bushels or 220 liters</td>
<td>10 ephahs</td>
</tr>
<tr>
<td>kab</td>
<td>1 quart or 1 liter</td>
<td>1/22 ephah</td>
</tr>
<tr>
<td>lethech</td>
<td>3 bushels or 110 liters</td>
<td>5 ephahs</td>
</tr>
<tr>
<td>log</td>
<td>1/3 quart or 0.3 liter</td>
<td>1/72 bath</td>
</tr>
<tr>
<td>mina</td>
<td>1 1/4 pounds or 0.6 kilogram</td>
<td>50 shekels</td>
</tr>
<tr>
<td>omer</td>
<td>2 quarts or 2 liters</td>
<td>1/10 ephah</td>
</tr>
<tr>
<td>pim</td>
<td>1/3 ounce or 7.5 grams</td>
<td>2/3 shekel</td>
</tr>
<tr>
<td>seah</td>
<td>7 quarts or 7.3 liters</td>
<td>1/3 ephah</td>
</tr>
<tr>
<td>shekel</td>
<td>2/5 ounce or 11 grams</td>
<td>2 bekas</td>
</tr>
<tr>
<td>span</td>
<td>9 inches or 22 centimeters</td>
<td>3 handbreadths</td>
</tr>
<tr>
<td>stadion</td>
<td>607 feet or 185 meters</td>
<td></td>
</tr>
<tr>
<td>talent</td>
<td>75 pounds or 34 kilograms</td>
<td>60 minas</td>
</tr>
</tbody>
</table>
Some measurement terms and items that can be measured that are introduced in Genesis for the first time are listed in Appendix C, as an example for the reader. Terms and concepts introduced in the first book of the Bible include time (days and years, age and calendar), light, counting (numbers – both cardinal and ordinal), direction (east), temperature, music, metallurgy, pain, weight and value.

Standards

At some point, engineers determined that it would be appropriate to standardize measurements. After all, if everyone has their own standard, then how can any measurement be accurate? This paper will not detail the variety of organizations that have established standards that most engineers are familiar with, especially as relates to their own field. But, just as God established measurements as explained above, He also required standards. As referenced in Leviticus 19:35, God refers to standards for length, weight, quantity (volume). It is apparent that standards were established because when Solomon built the temple, the Bible says that he used “the cubit of the old standard” (2 Chronicles 3:3). A cubit was defined as the length of the forearm to the tip of the fingers, or about 18 inches. But since everyone’s arm length is different, then a standard was needed. Apparently by Solomon’s time, there were new standards, and Solomon chose to use the old standard. A standard for weight is referenced in 2 Samuel 14:26 as the royal standard of shekels. Ezekiel references a standard for volume: “The ephah and the bath are to be the same size, the bath containing a tenth of a homer and the ephah a tenth of a homer; the homer is to be the standard measure for both.” (45:11). The next verse offers a rare Bible reference to a conversion standard, in this case for weight: “The shekel is to consist of twenty gerahs. Twenty shekels plus twenty-five shekels plus fifteen shekels equal one mina.” (45:12). Micah condemns the Israelites for using an unapproved standard: “Am I still to forget your ill-gotten treasures, you wicked house, and the short ephah, which is accursed?” (6:10). So just as it was observed earlier that God values accurate measurements, it naturally follows that establishing standards is also a godly pursuit.

Regarding the cubit then, when God gives Noah the directions for building the ark, He says “This is how you are to build it: The ark is to be three hundred cubits long, fifty cubits wide and thirty cubits high” (Genesis 6:15). The NIV footnotes this as “about 450 feet long, 75 feet wide and 45 feet high or about 135 meters long, 23 meters wide and 14 meters high.” But if the old standard is used, the ark was probably even bigger. When the angel is measuring out the wall of the new temple with Ezekiel, he is using a measuring rod. “The length of the measuring rod in the man’s hand was six long cubits, each of which was a cubit and a handbreadth” (40:5). This is a reference to the “long cubit", perhaps of the “old standard.” If Noah used this standard, instead of the default standard, then the ark was much longer than 450 feet. The Ark Encounter, which Answers in Genesis promotes as a life size representation of Noah’s ark, is 510-feet long, based on the length of the Hebrew long cubit. They claim that to be 20.6 inches.

Other major topics on which God placed a strong emphasis on measurement were the instructions for building the Ark of the Covenant and the components of the Tabernacle in Exodus, and the measurements of the new heavens and the new earth in Ezekiel and Revelation. But the details will not be pursued here.
Time

To initiate systematic observations of things in the Bible that are or can be measured, the first verse is a good place to start: “In the beginning God created the heavens and the earth.” The first subject that can be measured is related to time. Some additional observations on matters related to measuring time in the Bible are made as follows.

The word “beginning” in Genesis 1:1 is an immediate reference to time-based measurement. Several engineering observations can be made regarding this measurement term:

- everything (defined from v1:1 as the heavens and the earth) had a beginning,
- everything was created (a term replete with engineering connotations) by God, and
- everything that had a beginning includes not just physical substances, but also time itself.

Engineers are often concerned with time; for example, they measure process rates and rates of change, they conduct time and motion studies, and they also have projects and contracts – with beginnings, durations, and endings that are defined by a schedule. None of these concepts have meaning without understanding time. But it is interesting that the Bible does not attempt to explain time any more than it does most measurement terms; it merely begins using related terms and assumes some understanding by the reader. One exception perhaps is quickly found in v1:3 where a day is defined as an evening followed by a morning. The first six days, as related by the account in Genesis 1, are so defined. As one continues to read in Genesis, terms related to time stand out to someone focusing on measurement.

In v1:14, it says that God put the “lights in the vault of the sky to separate the day from the night, and [to] let them serve as signs to mark sacred times, and days and years…” Thus, the basis for marking time is established. This purpose is apparently not lost on Adam and his offspring because in v5:3, Adam appears to have taken God seriously about “marking the years,” to the extent that he was able to mark the birth of his own son in terms of years from his own “birth.” The value of marking time was perpetuated, as the birth and death years for each of Adam’s descendants are documented in Chapter 5. By the time the account of Noah is given, a calendar has been established as the exact date of the start of the flood is recorded (measured by the durations listed in Genesis 5 as 1654 years from Adam):

In the six hundredth year of Noah’s life, on the seventeenth day of the second month—on that day all the springs of the great deep burst forth, and the floodgates of the heavens were opened. And rain fell on the earth forty days and forty nights. (Genesis 7:11-12)

And the exact date of the end of the flood is recorded as well when “on the seventeenth day of the seventh month the ark came to rest on the mountains of Ararat.” (Genesis 8:4). The reason for these exact dates recorded in Scripture can be studied and debated, but their inclusion is a sign to the Christian engineer that marking time is important to God. In fact, according to Genesis 1:14, it is commanded. Therefore, establishing a calendar and tracking birthdays (as in Genesis 5), for example, appear to have their origin in the Bible.

It is interesting to note that days, years, and months are based on astronomical phenomena. But the basis for a 7-day week has no astronomical source. It is seemingly as arbitrary as a 5- or a 10-day week might be. The basis for measuring by days, months, and years is related to the
observed astronomical relationship of the earth, moon, and sun. But a week, which means seven in Hebrew, has its basis in the creation account of Genesis 1, and the subsequent requirements that God places on his people to observe the seventh day of each week as holy. Thus, the biblical basis of each of these four time-measuring units can be clearly understood; Christians should not be ashamed to point these facts out when explaining their belief in the Bible, and even in the first chapters of Genesis.

Historians are certainly interested in remembering the passage of time relative to certain important events (although often events are not deemed important until long after they have occurred), but engineers are also careful to mark time. As mentioned earlier, the engineer is very cognizant of schedules. It can be observed that whether or not God gave Noah a schedule, He did make certain to record the timing of the important events of the flood account. While schedules are not overly common in Scripture, the engineer would notice that it is not too long after this when God gives Abraham a schedule when he makes His covenant with him saying, “Know for certain that for four hundred years your descendants will be strangers in a country not their own and that they will be enslaved and mistreated there.” (Genesis 15:13).

Perhaps the most famous schedule in the Bible is the prophecy of Daniel 9 concerning the timing of the Messiah. Jesus condemned the Jewish leaders for not knowing or understanding this schedule when he weeps over Jerusalem following His triumphal entry and says, “If you, even you, had only known on this day what would bring you peace…” (Luke 19:42). He goes on to prophesy the destruction of Jerusalem and the temple “…because you did not recognize the time of God’s coming to you.” (Luke 19:44). Jesus expected them to understand and adhere to the schedule of God’s salvation and condemns them severely for their failure. Paul confirms the nature of God’s schedule for salvation through the life, death, and resurrection of Jesus Christ when he says “…when the set time had fully come, God sent his Son, born of a woman, born under the law, to redeem those under the law, that we might receive adoption to sonship.” (Galatians 4:4-5).

Therefore, it is apparent that God establishes and keeps schedules. The Christian engineer can be confident that identifying and keeping schedules is a godly practice. Of course, there are many other Christian principles that should be considered (beyond the scope of this paper) when establishing, maintaining, and adjusting schedules.

Physical Measurement Examples from the New Testament

There are many measurement terms in the New Testament, both physical and intangible. Two examples are provided here: the water jars used at the wedding in Cana and the feeding of the five thousand.

In John 2, at the wedding in Cana, John is careful to record the number and size of the jars, as well as their normal function – holding water for ceremonial washing. The NIV translates the volume of the jars as 20 to 30 gallons (and provides a footnote converting to metric). Knowing the density of water (and therefore wine), and estimating the weight of the stone jar, the engineer can do a mental calculation and quickly conclude that moving these jars was no small effort. The
The jar itself could weigh perhaps on the order of fifty pounds and hold around 200 pounds of water. As an alternative to handling the jars, it is possible they were kept in place and filled using smaller jars. Either way, it was no small effort to “do whatever he tells you,” as they were instructed by Mary. The engineer can envision and explain this without having to resort to a commentary. And because they were servants, they did what they were told — in verse 7, Jesus tells them to fill the jars with water; they filled them to the brim. Whether they carried the jars to the water or the water to the jars, they did more than was required. They don’t ask “why,” or say “that’s stupid,” or tell him “these aren’t your jars.” They just respond in quick, unquestioning obedience, exceeding expectations. How do we respond when the Master tells us to do something? As an aside, an interesting study can ensue if one is reading the KJV, which says the jar holds two to three firkins. A firkin was a unit of measure for casks of ale or beer in the 17th century (when the KJV was published). A quick look-up in a concordance shows that the Greek word (NIV — gallon, KJV — firkin) is metrētēs, which means “a measurer, especially a certain standard measure of capacity for liquids.” This is the only occurrence of that word in the Bible. Further investigation reveals that the measurer is the name of a utensil known as an amphora, which is a species of measure used for liquids and containing somewhat less the nine English gallons or about 40 liters.

Another interesting passage that speaks of measurements is in John 6 (and parallel synoptics) where Jesus feeds the crowd (“about five thousand men were there”) with a boy’s grocery basket. John records the following measurements:

- Philip’s estimate of how much it will cost to “buy enough bread for each one to have a bite!” (or half a year’s wages, literally 200 denarii). Philip has apparently done some mental math and quickly concluded the impossibility of the situation.
- The size of the crowd, first qualitatively — v4 “... a great crowd coming toward [Jesus]...”, then John adds that “...the men sat down, in number about five thousand.” (KJV) Matthew adds, “besides women and children.” And Luke points out that Jesus told his disciples to “Have them sit down in groups of about fifty each.” Therefore, it may be that John remembered how many groups there were and did the math; however, it is not clear how the math accounts for just the men, keeping the women and children separate (often preachers will at least double the size of the crowd, but it is never clear what the right cultural multiplication factor should be). And the story is still known as the feeding of the five thousand (even Jesus later refers to it as such – Matthew 16:9).
- The size and amount of the groceries: “five small barley loaves and two small fish...” Not only is it a small amount of produce (number of items), the items themselves are judged to be comparatively small. While it would be no less of a miracle if there were several times as many items, being instead relatively large, the point is well taken that it was the willingness of the boy to offer his groceries (faith of a child?) that is one of the significant points of the story. But it is even more dramatic given the small size and number.
- The amount of food remaining: “they...filled twelve baskets with the pieces of the five barley loaves leftover...”. No specific information is available on the actual size of the basket so it is probably of a generally common size that the original audience would understand. Strong’s says the Greek word is “of uncertain derivation; a
(small) basket.” It is only used in this context and parallel passages. But it is important to the story teller that they measured the number of baskets. While it could be a coincidence that it is one per disciple, not much reported in the Bible is recorded by way of coincidence.

Once again the Bible relates details of measurements so that different perspectives on the understanding of the passage can be observed by those who may be interested. At the very least, one can conclude that it testifies to the accuracy and veracity of the account. The account in John 6 (and parallel passages) does not appear to be the product of an invented story; the numbers provided appear to be consistent with someone who recorded – or at least remembered – some data and reported on it later. It is obviously not scientific data, and is not designed to be treated as such. But the numbers and measurements lend credence to the story.

Spiritual Measurements

Perhaps the most interesting aspect of applying an understanding of measurements in the Bible is to make it personal. When one reads with measuring in mind – not just physically, in terms of amounts of things or passage of time as has been examined thus far, but spiritually – a new perspective can be gained. Two areas that will be examined here include references to faith and love specifically, followed by spiritual growth in general.

Faith

Most Christians are familiar with Jesus’ remarks concerning various peoples’ faith; references from Matthew are given as examples (emphasis added in italics):

- If that is how God clothes the grass of the field, which is here today and tomorrow is thrown into the fire, will he not much more clothe you—you of little faith? (6:30)
- When Jesus heard this, he was amazed and said to those following him, “Truly I tell you, I have not found anyone in Israel with such great faith…” (8:10)
- He replied, “You of little faith, why are you so afraid?” Then he got up and rebuked the winds and the waves, and it was completely calm. (8:26)
- Then he touched their eyes and said, “According to your faith let it be done to you” (9:29)
- And he did not do many miracles there because of their lack of faith. (13:58)
- Immediately Jesus reached out his hand and caught him. “You of little faith,” he said, “why did you doubt?” (14:31)
- Then Jesus said to her, “Woman, you have great faith! Your request is granted.” And her daughter was healed at that moment. (15:28)
- Aware of their discussion, Jesus asked, “You of little faith, why are you talking among yourselves about having no bread? (16:8)
- He replied, “Because you have so little faith. Truly I tell you, if you have faith as small as a mustard seed, you can say to this mountain, ‘Move from here to there,’ and it will move. Nothing will be impossible for you.” (17:20)
In each of these passages, it seems that Jesus has used some spiritual tool or reference to measure the person’s faith. In a sense, He is able to measure how much faith they have, and compare that to some sort of a faith standard that allows Him to determine if the amount is large or small.

Paul also refers to qualitative measurements of faith:

- Accept the one whose faith is weak, without quarreling over disputable matters. One person’s faith allows them to eat anything, but another, whose faith is weak, eats only vegetables. (Romans 14:1-2).
- For though I am absent from you in body, I am present with you in spirit and delight to see how disciplined you are and how firm your faith in Christ is. (Colossians 2:5)
- So then, just as you received Christ Jesus as Lord, continue to live your lives in him, rooted and built up in him, strengthened in the faith as you were taught, and overflowing with thankfulness. (Colossians 2:6-7)
- We sent Timothy, who is our brother and co-worker in God’s service in spreading the gospel of Christ, to strengthen and encourage you in your faith, (1 Thessalonians 3:2)
- Night and day we pray most earnestly that we may see you again and supply what is lacking in your faith. (1 Thessalonians 3:10)
- We ought always to thank God for you, brothers and sisters, and rightly so, because your faith is growing more and more, (2 Thessalonians 1:3)

In these passages, Paul speaks of faith in terms of strength and weakness. In engineering, this can be related to measuring a force; it would not be strange for a mechanical engineer to describe how much force a hydraulic cylinder can apply, or how much torque a motor shaft can supply, and characterize it as weak or strong for a certain application. A biomedical engineer may be concerned with replicating the muscle performance of the human body. Muscle strength can be characterized qualitatively as weak or strong, or quantitatively by the amount of weight it can lift. Certainly an athlete knows how to strengthen his muscles by lifting weights and exercising, and does so with a quantitative measurement of amount and repetitions.

Peter speaks of faith in reference to value:

- These [trials] have come so that the proven genuineness of your faith—of greater worth than gold, which perishes even though refined by fire—may result in praise, glory and honor when Jesus Christ is revealed. (1 Peter 1:7)
- Simon Peter, a servant and apostle of Jesus Christ, to those who through the righteousness of our God and Savior Jesus Christ have received a faith as precious as ours. (2 Peter 1:1)

Therefore, it appears that faith can be measured not just in terms of amount but also of value. Do you consider your faith as something that can be quantified? There is no such thing as a unit of faith, as there is for a unit of force or value, but perhaps there should be. Then the amount of faith units required for a certain trial could be determined, and one could assay whether they have enough or need more. While this is not how faith works, the analogy should be helpful. One is tempted to allow that this is all figurative language, and perhaps it is. But the measurement concept should compel each of us to think about our faith and the tool that Jesus is using to measure it. Is he putting you in the little or great category? Is your faith growing? Is it weak and in need of strengthening? Do you consider your faith as precious and valuable?
When Paul tries to give the Corinthians some perspective on their suffering and says “…our light and momentary troubles are achieving for us an eternal glory that far outweighs them all.” (2 Corinthians 4:17, NIV; “…eternal weight of glory” KJV), he is not trying to say that glory has weight or is something that can be directly measured on a scale. He is using a figure of speech; but the engineer, who deals with weights and measures, may possibly have a more vivid picture of the comparison than a layman. Ultimately, we may have to rely on the athletic example more than the engineering example and admit that faith, like muscle strength, grows by exercise – lifting spiritual weights. It seems clear that God wants us to think in these terms, as well as to thank Him for the opportunities to increase our faith, which obviously come through trials and depending on Him. At the time, we may consider it “unfortunate.” But through the lens of faith, and with an understanding that these “unfortunate” experiences are some of the tools God uses to grow our faith, they shouldn’t seem so “unfortunate.”

Love

Jesus also expressed some measure of love when he stated to his disciples, “Greater love has no one than this: to lay down one’s life for one’s friends.” (John 15:13). Paul used the superlative when in the list of spiritual characteristics: “the greatest of these is love.” (1 Corinthians 13:13). Paul goes on to apply measurement terms when he states his prayer for the Ephesians:

> I pray that out of his glorious riches he may strengthen you with power through his Spirit in your inner being, so that Christ may dwell in your hearts through faith. And I pray that you, being rooted and established in love, may have power, together with all the Lord’s holy people, to grasp how wide and long and high and deep is the love of Christ, and to know this love that surpasses knowledge—that you may be filled to the measure of all the fullness of God. Now to him who is able to do immeasurably more than all we ask or imagine, according to his power that is at work within us, to him be glory in the church and in Christ Jesus throughout all generations, for ever and ever! Amen. (Ephesians 3:16-21)

Paul’s reference to four dimensions of love would be a subject for another time. But the observation that, like faith, love is something that can be measured and should be growing, is something that should sink deeply into the heart of every believer. This is not your love, it is the love of Christ in you. And you can be full to the measure of the fullness of God! But it takes His power at work in you, not your own efforts.

Implications and Conclusions

The Christian engineer has a basis for performing and maintaining accurate measurements based on the Word of God. It is the Christian worldview that provides a basis for accurate measurements. The non-Christian and especially the atheist does not have a basis for developing a system of accurate standards. The secular engineer would state that it is obviously a good idea to have a system of standards that are uniform and accurate. But this begs the question of what the basis is for being a good idea. Another secular engineer could just as easily make the argument that it is actually personally beneficial to have different sets of standards and measurements (along the lines of what is prohibited by the Lord in the Old Testament). Without a reference to absolute truth, as from the God of the Bible, there is no basis for accurate
standards. The Christian engineer should be confident in the Biblical basis for his or her vocation, including making accurate measurements; it is not just a good idea, it is godly.

It was observed that an engineer relates marking time and the development of a calendar to a schedule. Engineers often grow up to be project managers and executives, many of whom tend to adhere to schedules religiously. But even the project engineer is cognizant of deadlines and deliverables. The Christian engineer also observes that God values and follows schedules. Much has been made of Nehemiah as a great builder and manager; many studies have been done and the details were not pursued here. It was observed that God’s plan of salvation followed a schedule. Paul confirms that Jesus came “in the fullness of time…” (Galatians 4:4). But the Christian engineer may also observe that his own life is on a schedule, managed by God. The familiar verse that says “And as it is appointed unto men once to die, but after this the judgment…” (Hebrews 9:27, KJV) serves to highlight that the life of every person is on a schedule, with a deliverable at the end. One might observe that it is unfair not to know the date of that deliverable. It is said that hunting is the only sport where the other team doesn’t know they are playing (and unfortunately for the deer, that sport also ends in death). But the fact of death for all humans is no mystery. Another might respond with an inquiry: how would you live differently if you knew the final date on the schedule? God knows the date for each person. In Psalm 90, Moses says that the average life is “seventy years, or eighty, if our strength endures,” (v10). He goes on to request aid from the Lord to “Teach us to number our days, that we may gain a heart of wisdom” (v12).

As part of that schedule, God expects spiritual growth. The author of the book of Hebrews tells his readers that “In fact, though by this time you ought to be teachers, you need someone to teach you the elementary truths of God’s word all over again.” (5:12). God’s expectation is for spiritual growth. This is something one should be interested in measuring. How much have you grown in the past year, three years, decade? Has your faith grown stronger? It was observed that Jesus commends great faith and condemns little faith. Paul offers us an example prayer that we should pray for others (and seek the answer to the prayer) to be filled full of Christ’s love. Paul tells us that God is using the circumstances of our lives to make us into the image of His Son (Romans 8:28-29, 2 Corinthians 3:18). This is what exercises our faith and makes it grow. Christian engineers do well to consider the purpose of the project of life and that there is a divine schedule, even if they don’t know the date of the final deliverable. The implications of how to live in preparation for the final deliverable, in all aspects of life, are not difficult to envision.

Here is an appropriate closing benediction: But grow in the grace and knowledge of our Lord and Savior Jesus Christ. To him be glory both now and forever! Amen. (2 Peter 3:18)

Appendix A – Inspiration for the Paper

The inspiration for this paper has two convergent sources, both based on experiences of mine. First, as a believer who tries to obtain input from the Word of God on a regular – if not daily – basis, such as a One Year Bible or other daily reading plan, I have sometimes taken an approach to select a theme for the year (or that course of through-the-Bible reading) for systematic focus. Some themes I have considered in the past include finances, pain and suffering, salvation,
science and technology, redemption; the list is virtually endless. By concentrating one’s devotional attention on a certain theme, it allows the reader to dig deeply for treasures that can (and do) easily otherwise go unnoticed. For example, when reading about Namaan in 2 Kings 5, there are many lessons to be learned. One could easily pass over the remark in verse 2 about the Jewish servant girl who told Naaman about Elisha, who could heal him. But when focusing on the theme of pain and suffering, one stops to think that this poor child had been abducted from her family. Who loved her. And whom she no doubt misses greatly. And may never see again. But without pouting or self-pity or even an attempt to negotiate her freedom, she informs the man responsible for her predicament that she has a solution for his suffering. What a faithful perspective – she could be considered a poster child for loving one’s enemy. Would that we all could respond to adversity in such a fashion. Without digressing any further from the topic of the paper, hopefully this brief tangent illustrates the depth of insight possible with such a devotional focus.

The second source of inspiration for the topic came when God abruptly changed my career. After thirty years in industry, the Lord made it clear to me that He had a new assignment for me – as a professor of engineering technology at a Christian polytechnic university. How this happened, while amazing and perhaps inspirational, is not germane to the paper. I eventually learned that an Engineering Measurement Lab was included among my course assignments. Knowing that the university provides an extra five minutes of class time for devotional instruction, it occurred to me that it could be interesting to focus on a theme of measurements in the Bible, using a systematic daily reading as the basis.

Appendix B – Expanded Table of Bible Measurements
From BibleHub.com

<table>
<thead>
<tr>
<th>Lengths</th>
<th></th>
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</tr>
</thead>
<tbody>
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<td>0.73 inches</td>
<td>1.85 centimeters</td>
<td>Jeremiah 52:21</td>
</tr>
<tr>
<td>Handbreadth (4 fing.)</td>
<td>2.92 inches</td>
<td>7.4 centimeters</td>
<td>Exodus 25:25</td>
</tr>
<tr>
<td>Span</td>
<td>9 inches</td>
<td>22.86 centimeters</td>
<td>Exodus 28:16</td>
</tr>
<tr>
<td>Cubit</td>
<td>18 inches</td>
<td>45.72 centimeters</td>
<td>Matthew 6:27</td>
</tr>
<tr>
<td>Long Cubit</td>
<td>20.4 inches</td>
<td>51.9 centimeters</td>
<td>Ezekiel 40:5</td>
</tr>
<tr>
<td>Fathom</td>
<td>6 feet</td>
<td>1.829 meters</td>
<td>Acts 27:28</td>
</tr>
<tr>
<td>Reed (6 cubits)</td>
<td>8.75 feet</td>
<td>2.73 meters</td>
<td>Ezekiel 40:5</td>
</tr>
<tr>
<td>Furlong</td>
<td>1/8 mi., 660 feet</td>
<td>201.2 meters</td>
<td>Revelation 14:20</td>
</tr>
<tr>
<td>Stadion</td>
<td>697 feet</td>
<td>185.4 meters</td>
<td>Luke 24:13</td>
</tr>
<tr>
<td>Sabbath day’s journey</td>
<td>3/5 mile</td>
<td>0.9656 kilometers</td>
<td>Acts 1:12</td>
</tr>
<tr>
<td>Day’s journey</td>
<td>20 miles</td>
<td>32.19 kilometers</td>
<td>1 Kings 19:4</td>
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<table>
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<tr>
<th>Weights</th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Gerah</td>
<td>1/50 ounce</td>
<td>0.567 grams</td>
<td>Ezekiel 45:12</td>
</tr>
<tr>
<td>Bekah (10 gerahs)</td>
<td>1/5 ounce</td>
<td>5.67 grams</td>
<td>Genesis 24:22</td>
</tr>
<tr>
<td>Pim (2/3 shekel)</td>
<td>1/3 ounce</td>
<td>9.45 grams</td>
<td>1 Samuel 13:21</td>
</tr>
<tr>
<td>Unit</td>
<td>Conversion</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>Shekel</td>
<td>2/5 ounce 11.34 grams</td>
<td>Exodus 30:23</td>
<td></td>
</tr>
<tr>
<td>Mina</td>
<td>1.25 pounds 0.567 kg.</td>
<td>Ezra 2:69</td>
<td></td>
</tr>
<tr>
<td>Talent</td>
<td>75 pounds 34.02 kg.</td>
<td>Ezra 8:26</td>
<td></td>
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### Liquid Measures

<table>
<thead>
<tr>
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<th>Conversion</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log</td>
<td>0.65 pints 0.31 liters</td>
<td>Leviticus 14:10</td>
</tr>
<tr>
<td>Kab</td>
<td>2.6 pints 1.2 liters</td>
<td>2 Kings 6:25</td>
</tr>
<tr>
<td>Hin</td>
<td>0.98 gallon 3.7 liters</td>
<td>Numbers 15:4</td>
</tr>
<tr>
<td>Bath</td>
<td>5.9 gallons 22 liters</td>
<td>Isaiah 5:10</td>
</tr>
<tr>
<td>Homer</td>
<td>59 gallons 220 liters</td>
<td>Ezekiel 45:11</td>
</tr>
<tr>
<td>Kor</td>
<td>59 gallons 220 liters</td>
<td>Ezekiel 45:11</td>
</tr>
<tr>
<td>Metretes</td>
<td>10 gallons 37.85 liters</td>
<td>John 2:6</td>
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</table>

### Dry Measures

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</thead>
<tbody>
<tr>
<td>Kab</td>
<td>2.6 pints 1.2 liters</td>
<td>2 Kings 6:25</td>
</tr>
<tr>
<td>Omer</td>
<td>2.3 quarts 2.2 liters</td>
<td>Exodus 16:36</td>
</tr>
<tr>
<td>Seah</td>
<td>7.7 quarts 7.3 liters</td>
<td>2 Kings 7:1</td>
</tr>
<tr>
<td>Ephah</td>
<td>0.63 bushels (5.9 gal.) 22 liters</td>
<td>Ruth 2:17</td>
</tr>
<tr>
<td>Lethech</td>
<td>3.16 bushels (29 gal.) 110 liters</td>
<td>Hosea 3:2</td>
</tr>
<tr>
<td>Homer</td>
<td>6.33 bushels (59 gal.) 220 liters</td>
<td>Leviticus 27:16</td>
</tr>
<tr>
<td>Kor</td>
<td>6.33 bushels (59 gal.) 220 liters</td>
<td>Ezekiel 45:14</td>
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### Money

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<thead>
<tr>
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<th>Reference</th>
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<tbody>
<tr>
<td>Denarius</td>
<td>Day’s wage</td>
<td>Matthew 20:2</td>
</tr>
<tr>
<td>Drachma</td>
<td>Est. 0.035 oz. silver Est. 1 gram silver</td>
<td>Luke 15:8</td>
</tr>
<tr>
<td>Didrachma</td>
<td>Est. 0.07 oz. silver Est. 2 grams silver</td>
<td>Matthew 17:24</td>
</tr>
<tr>
<td>Talent, silver</td>
<td>Approx. 100 lb Approx. 45.4 kg</td>
<td>Ezra 8:26</td>
</tr>
<tr>
<td>Talent, gold (Alternate)</td>
<td>Approx. 50 lb Approx. 22.7 kg</td>
<td>Ezra 8:26</td>
</tr>
<tr>
<td>Talent, gold (Alternate)</td>
<td>Approx. 120 lb Approx. 54.4 kg</td>
<td>1 Kings 9:28</td>
</tr>
<tr>
<td>Talent, gold (Alternate)</td>
<td>Approx. 60 lb Approx. 27.2 kg</td>
<td>1 Kings 9:28</td>
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### Time

<table>
<thead>
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<tbody>
<tr>
<td>Sunrise</td>
<td>6 AM 06:00</td>
</tr>
<tr>
<td>First hour</td>
<td>7 AM 07:00</td>
</tr>
<tr>
<td>Second hour</td>
<td>8 AM 08:00</td>
</tr>
<tr>
<td>Third hour</td>
<td>9 AM 09:00</td>
</tr>
<tr>
<td>Fourth hour</td>
<td>10 AM 10:00</td>
</tr>
<tr>
<td>Fifth hour</td>
<td>11 AM 11:00</td>
</tr>
<tr>
<td>Sixth hour</td>
<td>Noon 12:00</td>
</tr>
<tr>
<td>Seventh hour</td>
<td>1 PM 13:00</td>
</tr>
<tr>
<td>Eighth hour</td>
<td>2 PM 14:00</td>
</tr>
<tr>
<td>Ninth hour</td>
<td>3 PM 15:00</td>
</tr>
<tr>
<td>Tenth hour</td>
<td>4 PM 16:00</td>
</tr>
<tr>
<td>Time Period</td>
<td>Time</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Eleventh hour</td>
<td>5 PM</td>
</tr>
<tr>
<td>Sunset</td>
<td>6 PM</td>
</tr>
<tr>
<td>First watch of night</td>
<td>6 PM - 9 PM</td>
</tr>
<tr>
<td><strong>Second watch</strong></td>
<td>9 PM - midnight</td>
</tr>
<tr>
<td><strong>Third watch</strong></td>
<td>Midnight - 3 AM</td>
</tr>
<tr>
<td><strong>Fourth watch</strong></td>
<td>3 AM - 6 AM</td>
</tr>
</tbody>
</table>

Appendix C – Observations on the first appearance of various measurement terms in the book of Genesis

Chapter 1 (verse)
1. – Time (beginning)
2. – Contents (empty); 1:20 (teem); 1:28 (fill)
3. – Light
3. – Quality (good)
5. – Counting (1st day; ordinal numbers)
5. – Time (day)
14. – Calendar (mark time – sacred time, days, years)
16. – Counting (numbers – two lights)
16. – Comparison (greater and lesser light)
28. – Growth (increase)

Chapter 2
8. – Direction (east)

Chapter 3
8. – Temperature (cool of the day)
16,17 – Pain

Chapter 4
21. – Music
22. – Metallurgy and manufacturing

Chapter 5 (verse)
4. – Age

Chapter 6
15. – length (cubit)

Chapter 7
11. – Calendar (years and months)

Chapter 23
15. – Weight and value (worth 400 shekels)
Chapter 29
(27) – week

End Notes

1 All Bible references, unless otherwise noted, are taken from the New International Version (NIV). © 1984, 2011 by Biblica.


An Engineering Program Built Around Work

Mark Nowack*
Geoffrey Akers*

ABSTRACT: The College of the Ozarks began a four-year multi-disciplinary engineering program in the fall of 2016. This is the first four-year engineering program at a federally recognized work college. The program content and overall structure are influenced by the work program, College goals, and a desire to minimize impact on existing College programs. At the College of the Ozarks, all full-time students work to help cover the cost of education. The campus is built with student labor and college functions are largely conducted by students. This College work component provides challenges in areas such as student schedules and workload. However, the graded work experiences also provide opportunities to increase work maturity, build ties between the program and the campus community, and enhance Christian formation efforts. In addition to the unique work component, the College’s regionally-focused mission to provide a Christian education based in the liberal arts for those who could not otherwise afford it results in a unique student population and customer base. Comparisons to other engineering programs highlight both the challenges and the value of the two-part approach, which accommodates the general education component while providing both breadth and opportunities for engineering discipline-specific concentrations.

Keywords: work college, curriculum, multi-disciplinary engineering, program development

A Mission-Driven Institution

College of the Ozarks is a work college. Like the other eight federally recognized work colleges, it engages students in an integrated work-service-learning experience. Although this economic model is only operating at small institutions,1 the institutions are diverse in focus and approach to education.2 College of the Ozarks’ unique focus traces back to its founding as a high school in 1906 by a Presbyterian minister to address the extreme needs present in the Ozark region.3 The mission of the now four-year liberal arts and sciences college remains as it was at its founding, focused on providing an education to financially needy youth:

The mission of College of the Ozarks is to provide the advantages of a Christian education for youth of both sexes, especially those found worthy, but who are without sufficient means to procure such training.

Working in exchange for schooling remains the centerpiece of the College experience. Some of the 100 workstations have existed since the beginning, such as management and care of beef and dairy cattle, and meal preparation. Others, such as working the IT help-desk and staffing the number two rated small hotel in the U.S.,4 are more recent. Some workstations reduce college

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costs, such as custodial and construction. Others, such as the restaurant, hotel, and farmer’s market generate income. Regardless of their workstation, all students spend a minimum of 15 hours a week during the semester plus, one 40-hour week, laboring to contribute to their tuition-free education each semester. Students with the greatest financial need are able to work 40-hour weeks on campus through the summer in return for room and board for a year. A third of the students also work off campus to provide funds for books, clothes, and spending money.

Work at College of the Ozarks is intended to be more than simply a means to a financial end. The underlying college ethos is that work is part of our royal charge to watch over and exercise dominion over creation that runs throughout the Biblical narrative from the first to the second Eden. As such, work is a worthy and sanctifying experience, essential to enjoying our relationship with the Creator. It is also something that benefits from being performed in a cooperative community that provides encouragement and opportunities to practice Christ-like behaviors that will serve students well after graduation. It is not by accident that the first all-college chapel service each semester takes place during a day reserved for work station orientation and students attend with their work station coworkers and supervisors.

The College vocational, Christian, patriotic, cultural, and academic goals work together to produce graduates who positively impact the region. It would be unusual to find an Ozark school district without a College of the Ozarks educated teacher, just as many fire departments in the region have veterans of the College fire station, and numerous water treatment plant operators learned their trade at the College plant. Similarly, many Ozark pulpits and Christian non-profits are staffed by College graduates. While it is the business of a Christian institution to help students find a suitable vocation, this paper instead focuses on the work done by the students in the College work program which is not necessarily aligned with a future vocation. We will, however, discuss how this work program creates Christ-like character traits that are important across all vocations, particularly engineering.

College of the Ozarks is now unique among work colleges by virtue of having a four-year engineering program. Being a work college does not a priori mean the curriculum is different than that of other institutions. However, addressing the needs of the Ozarks region and supporting the College mission have uniquely shaped the engineering curriculum content and structure.

A Focused, Regional Endeavor

According to Chronicle of Higher Education, the College is the 7th most selective private four-year college in the nation, with a 12% acceptance rate. Not surprisingly, the primary admission criteria are financial need and Ozarks region residency. Not only do many students come from financially stressed home situations, but also from financially challenged school districts. As a result, worthy students may arrive poorly prepared in math, science, and communication skills. The engineering curriculum is designed to accommodate these students as much as possible, for example allowing them to start in trigonometry, or in remedial English composition, and remain
with their cohort. The entire College faculty is incentivized to help students succeed as rapidly as possible, since a student staying longer not only fails to bring in additional revenue but also denies a slot to another prospective student. Similarly, the program size is capped, since additional engineering majors would come at the expense of reductions in other majors. “Growth” must be in terms of improved student retention.

As with most regionally focused engineering programs, the faculty and staff visited employers in the region to understand their needs and the characteristics they desire in our graduates. Industry is dominated by small to medium size family-owned businesses, primarily in the areas of tourism, agriculture, and light manufacturing. The work of many smaller firms is often diverse and must adapt to follow the economy. They either employ a few engineers or contract out their engineering work. Firms know of the College either by reputation or family ties or, often, because they have hired a graduate. It has become a common request to provide engineers who get along with those different from themselves and are not above doing the lowly jobs\textsuperscript{10} — characteristics “like the last College of the Ozarks graduate we hired”.\textsuperscript{11} Larger firms add several additional requests: engineers with roots in the area who will stay more than two years, who are willing to learn, and who have effective communication and interpersonal skills, both for effectiveness within the firm as well as with customers. Based on conversations with employers, teaching general workplace skills seems to be neglected in bachelor-level higher education. Perhaps the assumption is that these skills are learned at home or at a first job. This does not appear to be a broadly valid assumption based on our discussions with regional employers and College administration. As a result, the College strives to ensure workplace skills such as effective communication and getting along with coworkers are addressed prior to graduation.

So, a challenge for the program is to produce versatile entrepreneurial engineers who retain the desired characteristics of humility, a good work ethic, responsibility, getting along well with others, and effective communication. It is the opinion of the department faculty and staff that one key to producing these traits in engineering graduates is the work program in its overtly Christian context.

Students receive semester grades for their work from their work station supervisor, and their work GPA is reported on their transcript. The result is a work program that students take seriously and thus is able to shape them in interesting and helpful ways. In their work stations, students work and interact with a wide variety of students, faculty, staff, and the public. They do not get to choose the coworkers with whom they must cooperate to successfully accomplish their assigned tasks, with the result that graduates tend to possess a workplace maturity desired by employers. Their supervisors model Christian leadership and, in many workstations, the students get to practice their supervisory skills under the mentorship of the work station supervisor. Such mentorship is critical to developing Christ-like character traits.\textsuperscript{12} Students learn life skills such as dealing with conflict in the workplace, following instructions, punctuality, accepting responsibility, and reaping the benefits of quality work. A great example of the latter is the cleanliness of our toilets. Students generally do not want to remain on custodial crews, so they
strive to get a good work grade and supervisor recommendation, thereby maximizing their chances to secure a workstation more to their liking in the future. The result – our restrooms may be among the cleanest of any engineering program in the country. Moreover, they tend to stay clean, because students learn to respect the fact that their fellow students are the ones cleaning up after them.

Conflict resolution skills, cheerfulness, reliability, humility, respect, teamwork and appreciation are among the “others first” attributes valued by employers and are an integral part of the work program and Christian formation efforts at the campus. A persistent challenge for functionally organized Christian institutions is to help the students live coherent lives as described by Garber and to avoid unnecessary and detrimental compartmentalization of work, spiritual, and academic development. For College of the Ozarks, the ubiquitous work program seems to be a key to bridging the divides. For example, the common work station grading rubrics specifically incorporate desired character traits that are part of the College’s Christ-like Character Initiative: wisdom, hope, humility, citizenship, and courage. The rubrics are included in the appendix. Note that these may be further adapted to the specific tasks required by each work station. The common work program provides opportunities in the engineering program to discuss work as a blessing and how students’ developing workplace skills and attitudes will benefit an engineering profession, something that is critical as many of our students have limited exposure to professions beyond those of the teachers they encountered in school and pastors in church.

Challenges and Solutions

Implementing an engineering program at a Christian, liberal arts work college is not without challenges. Foremost among them is the increased student workload due to simultaneously fulfilling College and engineering program objectives. Second is fitting into the existing College structure while minimizing negative impacts to College finances and faculty and staff workload. College of the Ozarks’ general education component consists of 43 credits, and our math and science sequence is 36 credits, a bit larger than the ABET-required 32 found in the vast majority of engineering programs, as highlighted in the Table 1 comparison. As a small school with limited teaching resources, the luxury of engineering-specific math and science courses is beyond our means, so we must use or augment what resources are available; for instance, to accommodate the engineering program schedule, the math department now offers previously existing courses more frequently. One benefit of this approach is the new program uses existing courses that are proven and tailored to the typical Ozark-region high school graduate. The math and composition sequences, in particular, are designed to assist students arriving with deficiencies. As an example, the pass rate for the courses in the calculus sequence is over 80%.

Another example involves the fact that we could only fit the extant Chemistry I course into the curriculum. We feel strongly that our graduates should know how chemical engineers formulate and tackle problems. The result is that our introduction to chemical engineering course must introduce a few topics that would normally be covered in a second chemistry course. Thus, we have a somewhat unique course, which makes finding suitable texts a challenging proposition.
This is on top of limitations due to cost. While some of our students have textbook scholarships, paying for expensive texts contributes to the trend of working off campus during the semester, an activity that is detrimental to academic success for many students.

Accommodating the liberal arts, Christian, and patriotic courses that are critical to character formation stands in contrast to many engineering programs with general education content as low as 18 credits. To put it in perspective, in Figure 1 we plotted the ABET general education category for the programs in Table 1 against their ABET engineering science and design credits. Our core program is the open marker labeled “1”. Points below and to the right are those programs pursuing a more technically focused curriculum balance, likely in response to their particular competitive landscape. As those programs strive to ensure their graduates secure good positions, maximizing engineering credits is viewed as critical. However, given our focus on retaining those desirable attributes of prior College graduates, we retained the entire general education core that is critical to providing those attributes.

Even with such challenges, we also have a distinct advantage in our regional focus on an area of the country that tends to be ignored by many graduates of established schools. This provides some flexibility in our approach to meeting industry calls for broadly educated engineers. We acknowledge that some of our students and their potential employers may want more traditional specialization than our core program offers. To that end, we are creating optional concentrations, which add four courses, placing the student’s engineering course exposure on par with more traditional programs. That credit count with the concentration is shown by marker “2” in Figure 1. Creating these concentrations raises some interesting stewardship questions for us. First, it means a student would likely attend for an extra semester. Recall that doing so prevents a new freshman from enrolling. Needless to say we expect to be somewhat selective with concentration candidates. Also, as a small school, we are unable to offer the number of courses required to implement this approach across multiple engineering disciplines; instead, we are starting with the College’s traditional strength (agriculture) and foundational disciplines (civil, electrical, mechanical, and industrial/systems) and are pursuing partnerships with other schools who possess online and remote delivery courses.

Nearly all programs we examined encourage internships and many actively aid their students’ efforts to locate internships. Yet far fewer give students program credit for their internship efforts and, as a result, faculty participation is often limited. Of the eight benchmark programs in Table 1, only four give any credit for an internship, with only one of those offering an opportunity for use of an internship as a technical elective and one as a broadening elective. Recall that, as a work college, we mentor and grade work and include it as an integral part of the formation process. Thus, to not consider an internship as an extension of other work maturity development efforts would be inconsistent with our approach. Adding the internship credit, which is required for a concentration, results in the credit profile shown by marker “3” in Figure 1.
<table>
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<td>32</td>
<td>48</td>
<td>-</td>
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<tr>
<td>CofO engineering</td>
<td>136</td>
<td>36</td>
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<td>Benchmark 1</td>
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<td>Benchmark 4</td>
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<td>Benchmark 8</td>
<td>126</td>
<td>32</td>
<td>76</td>
<td>18</td>
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</table>

Table 1. Credit comparison against eight benchmark programs

![Credit Comparison Chart](chart.png)

Figure 1. Credit comparisons with program alternatives

Time is precious and particularly so for our students. To complete our program and work at least 15 hours a week (more if a student is banking hours in anticipation of future interruptions such as student teaching or athletics) students are in violation of the 60-hour rule. Add to this off-campus employment and extracurricular activities, and students’ academic performance suffers, with demoralization not far behind. We are quite challenged to effectively encourage diligence and enjoyment of God-ordained work, including course work, in our engineering students. We discourage off-campus employment and seek ways to reduce the cost of textbooks and provide financial help to those students who do not have book scholarships.

The next few years promise to be exciting, with a variety of challenges awaiting us and our first graduating class. For example, past College graduates have commented on the shock of leaving the protective bubble of the College and local community. To help students encounter the broader world, the College travel program provides free trips to students, again aligned with the College goals. As this paper was being written, for example, one of the engineering majors was in Vietnam as part of a series of patriotic trips escorting veterans back to the battlegrounds where they fought. Here, the students received a critical cultural lesson in addition to a patriotic one.
We expect and encourage our students to participate in mission trips and internships that take them outside of their historic comfort zones. These valuable experiences will add to the workload challenges our students face.

Other engineering program plans include giving back to the College through tutoring and similar activities in our student-built facilities. The goal is to counter the “math and science are too difficult” mentality that can hinder non-STEM majors’ engagement with their world, and reinforce the value of liberal arts to engineers. The objective is to engage in some meaningful way with each academic department, with the aim of furthering the ability of our graduates to engage their world. For example, with the psychology department we are exploring inviting a psychology professor into an engineering course to discuss topics dealing with value-laden technology. We are also considering an acoustics elective which would be designed for music, mass communication, and engineering majors.

Finally, and very much a work in progress, is a desire to supplement ABET knowledge and skill assessment with an assessment of developing attitudes. As with our other efforts, we will not be doing this alone but as part of the larger College community and the Christ-like Character Initiative, and we are excited to integrate this initiative into the engineering program.

Summary

As with other engineering programs that align with their constituencies, the College of the Ozarks curriculum is aligned to the unique needs of the Ozarks region and to the existing College structure and philosophy. It is the work program that makes the College of the Ozarks’ engineering program unique among other programs. Work, the general education component, and communal worship are common bonds for the College community and as such play a critical role in developing an inclusive and common community identity. Learning effective stewardship of time and resources is a natural outgrowth of the communal work approach, which provides a fertile ground for lessons in citizenship, in addition to academic and Christ-like character development, thereby addressing all five of the College goals for graduates and we believe, creating desirable attributes in our engineering graduates.
Notes

1 Work college sizes range from 110 to 1625 students.
11 Employers care about the behaviors of their workforce which Anson notes for engineers may be perceived as simply “practicing engineering ’Christianly.’” An effective way to ensure these Christ-like practices are produced is to view a vocation, engineering or other, as a calling. Anson, Scott. "Why Engineer - A Biblical Perspective on the Engineering Profession." *Proceedings of the 2015 Christian Engineering Conference*. Seattle, 2015. 80-90.
13 Ibid, Ch 5.
16 Ecclesiastes 2:24.
**Appendix: Work Grading Rubrics**

<table>
<thead>
<tr>
<th>Work Traits</th>
<th>Grade Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RELIABILITY</strong> Absenteeism and punctuality; degree to which assigned schedules and tasks are met Trustworthiness, diligence in completing assigned tasks, does not give up when frustrated, can be depended upon to get tasks done even in the absence of the supervisor.</td>
<td>0</td>
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<tr>
<td>Unreliable</td>
<td>Extremely reliable</td>
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<tr>
<td><strong>TEAMWORK/COLLABORATION</strong> Willingness and ability to work with others: collaboration and support Displays humility when working with others, serves and supports others, has a joyful heart when working with others, is fair and creates workplace harmony, demonstrates justice and shows personal responsibility and teamwork when working with others.</td>
<td>0</td>
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<tr>
<td>Does not support team or group tasks</td>
<td>Continuously outstanding team member</td>
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<td><strong>INITIATIVE/MOTIVATION</strong> Self-starting and ability to adjust and adapt as needed to change Demonstrates courage and pushes beyond self-limits, perseveres through change and disappointments, and maintains a good attitude.</td>
<td>0</td>
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<tr>
<td>Takes minimal or no initiative and is inflexible</td>
<td>Completes all tasks with minimal or no direction and is flexible</td>
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<td><strong>RESPONSIBILITY/ACCOUNTABILITY</strong> Work ethic, takes responsibility for actions, integrity, and proper care of equipment when applicable Demonstrates hope with a good work ethic, displays self-control, courage to admit mistakes, ethical in all matters, even when others are not.</td>
<td>0</td>
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<tr>
<td>Poor work ethic, irresponsible</td>
<td>Outstanding work ethic, shows great responsibility and integrity</td>
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<tr>
<td><strong>QUALITY OF WORK</strong> Degree to which pride is taken in successful performance of all tasks and work is of high quality Seeks to hold to high standards, demonstrates wisdom by consistently pursuing improvement in performance and knowledge of work to be done, listens and seeks advice of others, and maintains a joyful attitude, no matter the circumstances.</td>
<td>0</td>
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<tr>
<td>Little or no regard for quality of work</td>
<td>Performs highest quality work at all times</td>
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<tr>
<td><strong>COMMUNICATION SKILLS</strong> Ability to effectively communicate with supervisor, peers and/or customers Treats others with honor and respect, courage to raise difficult issues/questions without a demeaning attitude, compassionate, patient, and calm.</td>
<td>0</td>
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<tr>
<td>Makes little effort to communicate effectively</td>
<td>Maintains clear and concise communications</td>
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The Craft of Storytelling in Engineering Education

Ethan Brue

Abstract

For all the efforts over the last decade or more to attract, retain, and engage more students in STEM education, the challenge remains. Most programs have focused on creating gateway programs that attempt to sell the content of engineering as fun and entertaining. While there is little doubt that the task of engineering will be existentially pleasing, it is not a re-casting of the content alone that will attract and keep students in STEM disciplines. In both industry and education, the challenge of engineering is rarely one of content, but rather one of underlying motivation and purpose. History demonstrates that tenacious engineers and their engineering feats emerge most often from transcendent narratives.

Reference to the primacy of story within the task of higher education extends beyond the walls of Christian education. Scholars and writers in our post-modern culture increasingly use the language of narratives and meta-narratives when discussing worldviews. While Christians disagree with the proponents of post-modernism on many foundational issues, there is general agreement that overarching narratives (i.e. stories) play a powerful role in shaping an individual’s life. The power of story lies in its inherent wholeness. A good story, in all of its complexity and nuance, resists dissection, analysis, and explanation. A story simply invites us to participate in the narrative, to see ourselves inside the story.

I will reaffirm in this paper that the central task of our life-long Christian education is to work, live, and play inside the Biblical narrative of the kingdom of God. However, traditional STEM pedagogies rarely reflect the holistic character of engineering as a human activity and inadvertently sever engineering from its context in the bigger story. Thus, our pedagogical techniques and curricular structure often contradict what we intend to teach as Christian educators.

Refining our story-telling in the engineering curriculum is a potential means of retaining more students in STEM. More importantly, is an essential element of teaching integrally Christian. I will propose three approaches to accomplishing this. The first method integrates historical narrative into the engineering curriculum, the second involves blending contemporary narrative into classroom discourse, and the third involves the use of Biblical narrative within the context of technical subjects in a way that resists a counterproductive sacred-mundane dichotomy.

Escaping the straight-jacket of “scholarship”

Technological systems always have biases, that is, things that they can do and things that they cannot do. Systems of education and scholarship are no less constrained. Conferences, journals, and publication systems come with a built-in epistemology. There

1 Dordt College, Sioux Center, IA
is great irony that fact that one of the most influential Christian writers of our time is using a “rational” technological medium to debunk the epistemology and anthropology that has for the last 100+ years assumed humans to be “brains on a stick”\(^1\). It is like watching an 8-hour television documentary series on the dangers of television or lecturing on active learning strategies. However, since academics and professionals rarely accept sitting around the campfire or gathering around the water cooler as viable professional development hours, we have no options. We are obliged to share these ideas on teaching and learning in the wrong medium. As we all know, stories are told, not argued, posited, or analyzed.

Outside of the story, my topic is about “ways of knowing”. It is a topic that begs for further analysis and development in the context of Christian engineering education. Let it suffice to say that I believe our “ways of knowing” in engineering education have traditionally been monopolized by rationalistic ways of knowing. The technical conference paper culture is an artifact of the science societies of the enlightenment and is biased toward one particular type of knowing.

I am going to suggest (but not argue or defend) that without rejecting the powerful tool of knowing that comes from rational/scientific abstraction that typifies engineering education, we can embrace another, equally powerful means of knowing in story-telling that may better help us achieve our goals as Christian engineering educators.

Many people fail to recognize that most of our “knowing” is of the pre-theoretical type. As we travel to this conference, we have crossed bridges and have flown in airplanes. I will risk being presumptuous, but I suspect that none of us have even the slightest knowledge of the maximum Von Mises stress in either the airplane wing or bridge cross member as we made our way to this conference. Either we are careless, dangerously naïve, or incompetently ignorant in the face of impending doom, or there is another kind of knowing that is more powerful and significant than the theoretical knowing we hold so dear in journal publications and conference presentations. How did you assume the bridge or plane was safe? Experience.

Experience is at the core of the largest percent of our knowing. Experience, the stuff of story; not just the extraordinary, mystical, stunning, shocking, or overwhelming, but simple experience. The tears of a mother or father, the sound of the wind in the cottonwoods, the pop of an actuator at just the right time in a well-designed mechatronic device. Before any knowing is theoretical, it is experienced.

If our aim as educators is to nurture in our students in both knowledge and wisdom, then I believe our traditional pedagogical toolbox may not have all the necessary tools. We are in the business of training faithful disciples, not just engineers. You need both narrative and argument to train a holistic engineer.

The notion of both education and spiritual formation as belonging to the story-telling business is not new. Daniel Taylor, professor of literature at Bethel University asserts, “All the academic disciplines…are in the storytelling business”.\(^2\) Eugene Peterson declares, “Story is the primary way in which the revelation of God is given to us. The Holy Spirit’s genre of choice is story…”\(^3\) If it is true that all academic disciplines are in the storytelling business and that story is the genre of choice for the work of the Holy Spirit who leads us into all knowing, even engineering know-how, then how is this
reflected in our pedagogy? Are we using the right mediums and methods to create the space for the work of the Holy Spirit in our engineering students?

Without further apology, this will be a bit of an anti-paper -- a rejection of the very core of what an academic paper is supposed to be. I will tell stories, but not without a disclaimer. Teaching is intensely personal. To be an effective Christian teacher your pedagogy needs to grow out of the “guts” of who you are as a child of God. Therefore, I will not suggest that what fits me will fit every instructor. Just as there is more than one way of knowing, there is more than one way of teaching.

**Finding that “little bit of cathedral”**

Over the last 30 years, there has been minimal progress as a whole in attracting and retaining students in STEM fields. For years, we have asked engineers to grind through some of the most arduous and rationalistic subjects as a professional initiation ritual before they ever get a taste of the creative problem solving and design processes. Recognizing this curricular incongruity, we have recently worked to sell engineering as fun, exciting, rewarding, empowering, and self-fulfilling, only to discover that the effort and tedium that one must expend on an art before the canvas comes alive or the concerto resembles music is often a price many are unwilling to pay. The art of engineering requires a patience with the early years of learning the grammar and techniques of the artist. I tend to agree with Samuel Florman, that the solution is not to reshape the individual’s perception or experience, but rather to reacquaint them with a dream of the future possibilities that the craft of engineering (once mastered) holds out to them. In other words, to teach them how to imagine the “new creation.”

What Florman understands is that doing engineering is a religious endeavor. The activity calls us into a posture of transcendent imagination and escape the prison-house of the “plodding technician.”

Not only cathedrals, but every great engineering work is an expression of motivation and of purpose which cannot be divorced from religious implications. This truth provides the engineer with that many would assert to be the ultimate existential experience…The age of cathedral building is long past…but every manmade structure, no matter how mundane, has a little bit of cathedral in it, since man cannot help but transcend himself as soon as he begins to design and construct.4

Here lies our problem. We want men and women to dream about doing engineering, but we give them nothing to dream about that transcends themselves or their profession. They are given derivations rather that story, proof rather than poetry, and empirical correlations rather than myths. It is no wonder we cannot retain our students as engineers.

The apologetic aspiration of the Holy Spirit is to open our eyes to our deepest desires, which is a common theme in much of what C.S. Lewis writes. The engineering texts so often miss what our age-old poems and mythologies have been telling us for centuries. He suggests that at the core of our being, “we want something else which can hardly be put into words – to be united with the beauty we see, to pass into it, to receive it into
ourselves, to bathe in it.”5 And he suggests that those who have immersed themselves in the Biblical narrative will take imagination seriously.

“For if we take the imagery of scripture seriously, if we believe that God will one day give us the Morning Star and cause us to put on the splendor of the sun, then we may surmise that both the ancient myths and modern poetry, so false as history may be very near the truth as prophecy…We cannot mingle with the splendors we see. But all the leaves of New Testament are rustling with the rumour that it will not always be so.”6

Lewis understands that within the myths and poetry we write in our culture often lies a truth that no theory or derivation will ever be able to express. Christian engineering education needs to create more prophecic myth. I believe part of the solution to retention problems in engineering is to learn how to tell better stories. Stories have the power to tap into our deepest longings and translate them into robust motivations.

However, not all stories engage students with the same transformational or motivational power. As Neil Postman describes a concept first introduced by Northrup Frye, a story is able to come alive in a listener or culture when it achieves resonance, which is the right combination of context and connection so as to “acquire a universal significance.”7 In other words, regardless of the setting, the listener of a story with resonance is able to hear the story and easily relate it to their experience in an entirely different place and time. However, for effective learning, it is also true that a story with substantial dissonance can also be a powerful teaching tool. If the listener is forced to take a look at their own experiences and exclaim “but my world is different because…” the story has also been a pedagogical success. For the instructor, good storytelling begins with listening to the audience. Ensuring that they are either experiencing resonance or dissonance (but not ambivalence) is the determining factor as to whether the story is told well.

Re-telling Engineering History

One of the ways we tell stories to each other is through our ongoing creating and re-creating of history. In a previous paper at the annual ASEE conference8, I discussed the importance of integrating historical narrative in the engineering curriculum. It is important for engineering students to recognize that engineering is a human activity not an impersonal force. As a human activity, it emerges from the context of a larger story of obedience and disobedience, success and failure, progress and regress. It is a story that is unfinished and that they are a part of. In historical context, they see their dreams not as originals, but as oft-plagiarized products of generations past. However, contrary to how history is often taught, it is not the dates, times, or artifacts that are most important to re-tell, since these are the parochial products of the story. Rather what needs to be emphasized are those longings and desires that resonate across time or clearly clash with contemporary paradigms. David McCullough has recently captured the essence of the development of the aeroplane.9

On December 17, 1903, a cathedral was built on the sands of a North Carolina beach. A dream took shape in the form of a technological artifact. Many historians still miss the point of this event at Kitty Hawk. What took flight was not cables, struts, and pistons, but rather a play-filled work of art, expressing the dreams of homo faber, humanity the culture makers. The story of the Wright brothers seems to reinforce the notion that in the
activity of culture making, the artist often arrives before the scientist or entrepreneur. If it happened in reverse order, the drama would cast Samuel Langley in the lead role, not Orville or Wilbur Wright.

As is often the case in the most momentous technological change, an expression of a deeper yearning or belief is at work. As the story unfolds from inauspicious Dayton, Ohio to the boondocks of Kitty Hawk, the story is far less about the technology, and more about the makers. In today’s world in which some mega-corporations will employ as many patent attorneys as engineers, we often connect innovation to work rather than play. Commerce seems to spur innovation. With history’s grandest technological achievements, the story unfolds differently. When we enter the Wright story, we do not find Orville and Wilbur the employees, but rather we see gymnasts, football players, pond hockey players, bike riders, skate sharpeners, book lovers, naturalists, art connoisseurs, musicians, suffragists, worshipers, and committed family members. There is nothing in their identity that looks aeroplane-like. This is precisely the reason for the Wright brother’s success. In the early development of the first flyers, their identity was not bound up in the plane, but rather in the activity of creating.

One of the most striking features of the story is that we see a motivation for technological development arising not out of some practical need, but out of a desire to “play” and “explore.” Kitty Hawk should not be thought of as a testing ground. It was closer akin to a vacation than a project, and the memoirs from their experiences on the Atlantic coast read more like poetry than a lab report. Many historians comment on the tenacity of the Wright brothers, who spent far more time fixing the results of “failures,” than witnessing success.

The engineer takes from the story a deeper understanding of technology as an art, a playful expression of a joy or longing. It is easy for the artist or athlete to resonate with this story. Failure is the motivator. For the artist, the absence of conflict ruins a story. For the athlete, the absence of a challenging competitor ruins play. Creativity thrives in an environment of resistance, non-mastery, and nuance. In contrast, modern science abhors complexity and contingency. Its guiding principle is transparency and control, in which the eradication of mystery and failure is paramount. Engineering cannot survive in a rational-scientific environment. How we tell the story matters.

**Personal and Life Story in Engineering**

Contemporary story -- autobiographical, fiction, or non-fiction -- all have a place in the engineering classroom. The most effective ones are derived directly from personal experience (in some way or another) as an engineer in the world. For resonance, the most important consideration is to keep them broad as life itself. Serving as an engineer is far from being just technical, it includes all the joys, pains, challenges, mistakes, etc. of being human. A second goal in developing such narrative is to avoid explanation. Simply tell it. Force the students “into the story” and give them the power to read between the lines. Like a good sermon, the application should primarily be the work of the congregation, not the preacher.

I often start class with narratives. Here are two examples that I have used in System Dynamics and Controls class. It is a class that leans toward the more abstract on the continuum of engineering courses. Therefore, I believe one of the challenges to teaching
a course like linear systems from a Christian perspective is to periodically draw students into the more complicated rhythm of engineering, the overtones of life itself.

System Dynamics and Controls – Narrative #1 – Reflective Memoir

Time. It’s a significant part of this course. It’s a significant part of differential equations class, right? You are always looking for the “solution” which means what? (…a representation of the response as a function of time…). However, have you ever noticed how seemingly insignificant time is to “real life”? Have you noticed how time gets censored out of our histories, our best stories? Time simply makes for dull narrative. Take war stories for instance. Everyone has heard of the Charge of the Light Brigade, or Pickett’s Charge, or Custer’s Last Stand, or D-Day. But these are all stories that took minutes or hours...while wars took years. In other words, statistically speaking, being a soldier will mean a great deal more of picking your finger nails than picking any fights. Hours and hours are simply dull, wasted, uneventful. In between those story making events lies a great deal of humdrum. Engineering doesn’t escape this fate.

I learned this in my first position in industry. It was the consulting industry...you know “feast or famine” (explain). Not soon after I started I hit a famine. Which makes me wonder as I look back...is there a Christian perspective on killing time? My whole education was about designing responsible technology, about transforming technological systems into obedient service.

But what if I found myself in a place and time that has no immediate need for my shaping and forming? Give it some thought. I have a few ideas...but there are no answers in the back of the book on this one. All I know is that based on my experience, it seems our most powerful witness may be how we actively steward our waiting.

In this first engineering position, I had a colleague who was Ivy-league educated at Princeton. Unfortunately, I’m afraid that in their zeal to teach him everything about engineering, they forgot to teach him anything about time stewardship. When there wasn’t work...he’d waste it. Spit-wads over the cubicle walls, solitaire, downloading demeaning images...he didn’t last long. It seems that a persons true character is either determined or developed in the “between times,” in the “waiting.”

You know the stories...a David moonlighting as music therapist for a manic-depressant king, a Samuel dusting the temple furniture in a patched up ephod. They spent a good portion of their life “killing time” before they really got to serve...OR maybe that’s exactly how they served. The first material we are typically given to design with is time.

Time is more than a variable. It is a God breathed creature that needs reclamation as much as you and I. So as an engineer, don’t treat it like anything less...give it some thought.
“So what d’you find out?”...The voice on the other end of the phone was Ted Barnum, a partner of the firm from upstairs, the rather heavy set one who didn’t smile much.

“Not much” I said, “they weren’t very helpful”...I have this way of understating things...truth was, they gave me a verbal lashing.

“Why not?...you were just looking for a budget quote”...There was a hint of jest and sarcasm in his voice.

“yeah, but when I told them I was from BVP Associates, they laid into me about not playing that damn game with me...”

“So why in the hell did you tell ‘em?” ...he said, not in an angry sort of way...but rather in one of those ways that made me feel just slightly smaller than the computer mouse that I was fidgeting with.

“I don’t know”...I didn’t really have anything more to say. I guess my mom always taught me to tell who was calling. But I doubt Ted would care what my mom thought. Besides, I had never been told that one must hide one’s identity when calling for a budget quote on a set of Diesel Generators.

There was one of those uncomfortable lulls in the conversation. The phone in the cubicle across from me was ringing. I felt like answering it.

“Oh well...we’ll have to try to find out some other way...I’ll take it from here” He hung up. I think I said “O.K.”...but not before the “click” on the other end.

It was an odd exchange. The oddest thing about it was that I never knew the full story until I was accused of being a corporate spy. I guess Ted had a project in which he was bidding on a job with a series of microturbines. Somehow he knew that Wartsilla Diesel was also bidding on the project. Instead of doing the engineering work required to deliver a good product, Ted was more concerned with simply undercutting the competition...he just needed their bid. He never told me this. I was the unsuspecting ignorant fool in the middle. This was the last time Ted ever asked me to do any work for him. To be honest, I wasn’t disappointed.

We deal with a lot of hypothetical situations in this course; some are not so far from my experience. In fact I think the most “far out” situations in my engineering education came in the engineering ethics coverage. Ethics courses always assume that a person is rationally conscious when confronting moral dilemmas in engineering. I’m not so sure.

Honesty sometimes looks a lot less like “a noble George Washington with ax in one hand and confession in the other” and more like an unsuspecting butt of a bad joke. It’s a norm we call openness in communication...try to make it a habit...you may find yourself being accidentally honest. And even though in the process you look like a naïve fool...it may just keep you from having to work with Ted again. End of story.
Biblical Narrative as Science and Engineering Narrative

In a previous paper, I challenged us to look carefully at how scripture guides and directs all of our learning. Biblical instruction should never let a specific story be severed from the grand narrative, that is, those central themes that echo across and through scripture. This has led me to develop stories such as the Naaman story as an example of technological paradigms in conflict and to challenge students to become more attuned to contemporary blinders. Other stories, such as the experience on Mount Carmel, also provide great instances of not just “kingdoms in conflict,” but technological and scientific paradigms in conflict. Religious belief forms the basis for all modeling and manipulating the world around us. It has not changed. Modeling is never neutral. Such re-narrating of biblical stories tend to tell like an Aesop Fable. They end with a moral. This can be a dangerous use of scripture, if it is not understood as a broader scriptural theme, or assumed to be the only message of a particular passage.

A second form of narrative is to draw students with traditional fluid mechanics textbooks or material science texts into the larger biblical narrative. Aside from reinforcing a principle of fluid mechanics, it teaches an important principle about understanding Scripture. Scripture should not be understood as some type of static spiritual encyclopedia for reference or inspirational drug. It must be understood as a dynamic narrative that calls us into its story.

Here are three examples that come from a series of five reflections on the miracle narratives, specifically the miracles of nature. The objective is to tell a story while subversively disabuse them of the popular (but pagan) notion of natural law and replace it with the more fundamental law of grace.

Meditation I: Jesus Doesn’t Do Miracles

John 2: Jesus Changes Water to Wine

1On the third day a wedding took place at Cana in Galilee. Jesus’ mother was there, 2and Jesus and his disciples had also been invited to the wedding. 3When the wine was gone, Jesus’ mother said to him, "They have no more wine." 4"Dear woman, why do you involve me?" Jesus replied, "My time has not yet come." 5His mother said to the servants, "Do whatever he tells you." 6Nearby stood six stone water jars, the kind used by the Jews for ceremonial washing, each holding from twenty to thirty gallons. 7Jesus said to the servants, "Fill the jars with water"; so they filled them to the brim. 8Then he told them, "Now draw some out and take it to the master of the banquet." 9They did so, and the master of the banquet tasted the water that had been turned into wine. He did not realize where it had come from, though the servants who had drawn the water knew. Then he called the bridegroom aside 10and said, "Everyone brings out the choice wine first and then the cheaper wine after the guests have had too much to drink; but you have saved the best till now." 11This, the first of his miraculous signs, Jesus performed in Cana of Galilee. He thus revealed his glory, and his disciples put their faith in him.
I am convinced that Jesus never really knew how to do a good miracle. Let’s be realistic, if you’re going to go through all the work of doing a top-notch, high-power, knee-shaking miracle, you’ve got to know how to sell it to the audience. Ask any Las Vegas magician – “it’s all in the presentation”. The problem with the so-called miracles of Jesus is that if you blink you miss ‘em. The only ones who really see them are the ones who have their eyes opened. Jesus is clearly not in sync with the broader audience. Simply put, he at least needs to make his miracles look like a miracles. Instead he makes them look as routine and mundane as brushing your teeth! Sometimes we hear them one too many times and we become dull like the disciples. Like the disciples, we think what Jesus does is pretty wild. But in our amazement, we’ve missed the point. In all of the “miracles of nature” that Jesus does (i.e. those miracles in which he in some way subdues or transforms the non-human creation) the weirdest characteristic of them all is the nonchalance and “matter-of-factness” with which he does them. He acts as if nothing unusual happened!

Jesus turns water into wine. Why use only water? How mundane. If you want to get peoples attention you’ve got to use something with “pop” or “smoke” or “color” – or at least ask for a rare chemical like hexochlorobenzene. Don’t ask for water - colorless, everyday, ordinary water. Water is just too common a substance for a good miracle. To make matters worse, Jesus simply tells the servants to “fill the jars with water”, an ordinary activity with an ordinary substance. Then without even a word, or incantation, or procedure, there is wine. What happens is entirely predictable - a waste of a good miracle! The miracle is so subtle that most people at the wedding don’t even notice. They just wonder why the good stuff has been saved until everyone is stone drunk. For most of the wedding guests (including Jesus) nothing unusual happened. And they were right!

Jesus doesn’t do the extra-ordinary. He doesn’t do the supernatural. He’s not into magic. He only does what comes natural for him as Lord of the Universe. He rules. From the beginning of creation every atom, every electron and every quark has been at his beck ‘n call.

On that ordinary wedding day in Cana the hydrogen and oxygen atoms situated in six 20-gallon ceremonial kegs awaited their commands from the Lord of the Universe, like they always do. He calls. They obey. Atoms have no choice. It just happens that of the many dances that the Lord of the Universe has them perform, a slight deviation from the dance they are most familiar with was called out. A few carbon atoms were called into the ring and with a do-si-do and a bow to your partner - water is wine. Nothing out of the ordinary for the Lord of the dancing atoms, just a playful change.

To claim that Jesus needs to do miracles is to claim that atoms normally do their own thing. They don’t.
With this in mind, always remember that material science is simply the study of some of the more frequently observed dances of the atoms. These are not the ONLY dances that are called out.

Meditation IV: Jesus Doesn’t Do Miracles

Mark 6: Jesus Walks on the Water

45 Immediately Jesus made his disciples get into the boat and go on ahead of him to Bethsaida, while he dismissed the crowd. 46 After leaving them, he went up on a mountainside to pray. 47 When evening came, the boat was in the middle of the lake, and he was alone on land. 48 He saw the disciples straining at the oars, because the wind was against them. About the fourth watch of the night he went out to them, walking on the lake. He was about to pass by them, 49 but when they saw him walking on the lake, they thought he was a ghost. They cried out, 50 because they all saw him and were terrified. 51 Immediately he spoke to them and said, "Take courage! It is I. Don’t be afraid." Then he climbed into the boat with them, and the wind died down. They were completely amazed, 52 for they had not understood about the loaves; their hearts were hardened.

In this episode we find Jesus sending his disciples ahead to Bethsaida. He says he’ll catch up with them later. He needs some time alone…to pray. As the sun sets, he looked out on the water from his vantage point and saw the disciples having quite a time getting across. They were fighting a major headwind. Nonetheless, it must not have worried him at that time. Six hours later or so he finally sets out to Bethsaida after them. He strolls out on to the water in their general direction. As he strolls toward the boat he realizes that due to the wind and due to his brisk pace, he is going to make it to Bethsaida before his disciples. Unfortunately, as he was about to pass by them they saw him and started going berserk. Realizing that he couldn’t leave his disciples going insane with fear in the boat, he changes course and heads over to settle the disciples down. Then he hops in the boat and settles for the conventional means of sea transportation. Although to comfort his friends and maybe to speed the trip up a bit, he turns down the volume of the sea a bit.

A bizarre story. Jesus acts as though walking on water is as ordinary as walking from the science building to east campus via the soccer field. He needed to get to Bethsaida. On that particular night he didn’t feel like taking the sidewalk. But then walking on water really isn’t something new. We cover it right here in fluid mechanics! Insects do it all the time. The creator spoils them. He commands the water molecules to link arms and carry these bugs wherever on the pond they desire. You can call it providential or you can call it the principle of surface tension, you’re likely getting at the same thing. Walking on the water is an ordinary occurrence. If God commands the water molecules to carry his bugs around like royalty, why do we find it out of the ordinary for water to carry around the King of the Universe? Jesus didn’t.
Mark 7: The Healing of a Deaf and Mute Man

31 Then Jesus left the vicinity of Tyre and went through Sidon, down to the Sea of Galilee and into the region of the Decapolis. 32 There some people brought to him a man who was deaf and could hardly talk, and they begged him to place his hand on the man. 33 After he took him aside, away from the crowd, Jesus put his fingers into the man’s ears. Then he spit and touched the man’s tongue. 34 He looked up to heaven and with a deep sigh said to him, "Ephphatha!" (which means, "Be opened!"). 35 At this, the man’s ears were opened, his tongue was loosened and he began to speak plainly. 36 Jesus commanded them not to tell anyone. But the more he did so, the more they kept talking about it. 37 People were overwhelmed with amazement. "He has done everything well," they said. "He even makes the deaf hear and the mute speak."

We’ve looked at Jesus’ “miracles” of nature and either Jesus is trying his hardest to make them look like ordinary every day occurrences, or they simply are ordinary occurrences for the master of the universe. But what we haven’t done is look at Jesus’ other miracles, those miracles in which he subdues and transforms, not the non-human creation, but humans themselves. It is important to make a distinction between the human and non-human creation because if we don’t everything that we have concluded about Jesus’ nature miracles seems to be refuted in the above passage. There is nothing ordinary about these miracles. Jesus makes them look magical or occult. Popular superstition at that time believed that there were magical powers in spit. It seems Jesus has succumbed to doing miracles more like the people think they should be done. However, the miracle deserves a closer look, because if we have our eyes open we see in this act an important distinction that Jesus is making between his human creatures and the rest of creation.

The first thing to note is that Jesus takes the man aside away from the crowd. This is a very important note. Clearly Jesus’ intention is not to perform a Las Vegas like vaudeville act. Jesus doesn’t do magic. The spit, the sighing, the gestures...they aren’t for an audience. They are for the one longing to be whole. Nonetheless, Jesus doesn’t make the healing look ordinary. But he could. Right? The proteins and atoms and cells gathered in the ears and eyes are waiting for their next command. And proteins always obey. They have to. They have no choice. Jesus could have just made it right. No spit. No sigh. No ritual. No touch. But Jesus must have known that this image bearer needed more than just genetic re-engineering. It seems as though Jesus knows that human beings are more than just a compilation of proteins. Maybe the Lord of creation is on to something!

With human beings Jesus heals wholly. He must know that pain and suffering are more than physics or biology.
Jesus spits and touches the man’s ears, he spits and touches the man’s tongue, and with a sigh deep enough to see, he speaks loud enough to be heard. He is telling the man what he cannot hear in words. In the speech of touch he says “I understand what it is like to be deaf and mute. I know you have been thought of as stupid, as dumb, as cursed by God. But I know your real problem because I am Lord of creation. I know what it is like to be misunderstood. Things aren’t supposed to be this way...he sighs. It is in your ears and tongue. And most importantly, I want you to know that contrary to what most people think, you ARE loved by God.”

Because with humanity Jesus is concerned about more than just restoration, he is also after redirection. Jesus spends time and touch with his human miracles because while restoration is instantaneous, redirection is a never-ending process. It can take thousands of years of love letters. You see, while atoms must obey, humans only obey when their eyes are opened so that they can see how much they are loved. In philosophy we try to understand this by making distinctions between structure/direction, subject/object functionality, and norms/laws. But for all practical purposes...it’s all about grace.

The Conclusion of the Matter

Finally, sometimes you need unadorned story. Story without direction or pointed purpose. The kind of story that leaves students wondering what that had to do with the class - the kind of story that may elicit more questions than answers. Some stories can teach about the existential pleasure of engineering, the nature of technology, the ambiguity of naturalism, literacy, pacifism, the cultural mandate, triumphalism, stewardship, the liturgy of presence, shalom, and the power of weakness, that is, if you have ears to hear and can read between the lines.

Reflection on Cherry Creek

I grew up in the valley of Rivendell (well...more or less). Just on the other side of the river, two miles north up Hwy 99 over the bridge, across the tracks and past the old Whiskey River nightclub, and then three miles along County Road 23 that cuts a winding way along the bluffs that overlook the Minnesota river valley. The cherry creek ravine cut through our neighbors land, just beyond his orchard. I wish I had time to tell you how beautiful it was...but that will have to be another story.

Our neighbor Dan; he lived just up the gravel road to the north when I was in grade school. You could see his place from ours. He didn’t do anything...for a living...I mean. He didn’t punch a clock or anything. Dad said he used to be a librarian. His wife taught kindergarten in town. He just tended his very large garden (like acres of flowers and organic vegetables), fixed Volkswagens, built an energy efficient home, and had a lot of books...he loved books...and he smiled a lot. As kids, we didn’t know a lot about Dan. My dad said that he was a
Mennonite. I didn’t have any clue what that meant. I figured it was someone who tended a large garden, fixed Volkswagens, built an energy efficient home, had a lot of books...and smiled a lot. Dad also said he was a pacifist. I didn’t know what that was either. I figured it was someone who tended a large garden, fixed Volkswagens, built an energy efficient home, had a lot of books...and smiled.

I want to tell you how Dan impacted me as I grew up. I’d like to tell you some fantastic story about him putting his arm around me and looking me in the eye and giving me some fabulous spiritual quote to live by that I never would forget. But I don’t have such a story. I only have this picture of someone who tended a large garden, fixed Volkswagens, loved books, and smiled a lot. In other words he simply occupied a rather small presence up Township 10 that climbs up from our place to overlook the Cherry Creek valley. That’s it.

Dan died a year ago. His Parkinson’s finally silenced him. For someone who loved words, it seemed a bitter curse to be inflicted with a disease that twists every word into an excruciating chore.

The other day I was reminded of Dan. I was sorting through my books. I found a book that he gave me with a smile. He thought I would enjoy it. It’s leather bound. It looks like a Bible. It’s not. It’s Trautwine. And if you’re well versed in engineering texts, you will recognize the title of a classic Civil Engineering Handbook in 1906. Actually, I’ve never read it. I’ve only skimmed it. But I think Dan’s life is somehow bound up for me in this copy of Trautwine.

Dan was not an engineer in any formal sense. But I wonder if I didn’t begin to understand what engineering was by living down the road from Dan. Since my years along the banks of Cherry Creek I’ve always found it difficult to understand folks who like to divide life into “technological” and “non-technological,” as if the task of technology was any less natural than tending a garden, reading books, fixing Volkswagens, or building homes. I’m also wondering that if pacifism has anything to do with the biblical concept of shalom, then maybe Dan was more engineer than I first thought. And if I ever had any grand delusions of bringing the kingdom with my technology, then this triumphalism has been kept in check by this powerful vision of this, I suppose rather weak and insignificant, Mennonite doing nothing more than faithfully tending a garden on the banks of Cherry Creek...Organic food for thought.

Storytelling is not a technique or classroom practice, it is a space you create. This space which allows life to be told in all its fullness, can be opened up in you teaching in a variety of ways. Creating this space for the narrative of scripture to play is what makes engineering education radically Biblical. Secondly, behind all the false data points of students disinterested, discouraged, and disillusioned about their engineering education, lies an empty motivation, a purpose that lacks a glimpse of the new heaven and new earth blueprint. Part of the antidote may be the reclaiming of story.
References


Engineering Through the Eyes of Faith

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Abstract

What is a biblical perspective of engineering? This paper seeks to answer some key questions related to the integration of faith and engineering. It is the second paper in a three paper sequel on this topic. It attempts to build from some initial concepts in a paper presented at the 2013 Christian Engineering Education Society (CEES) Conference [1] and deepen the analysis on common grace and use new examples and present new ideas on dominion mandate and its application to engineering and engineering education.

God is the Master Engineer. As an architect of His creation God presents wisdom as the basis of design in the universe. And this wisdom is no other than the Lord Jesus Christ. God is the source of all wisdom and all God’s creation reveals His intelligent design. Men’s knowledge is always secondary. By studying science and engineering, we are really reading God’s mind regarding His creation. We can imitate God by design and/or engineering for the good of ourselves and others.

The doctrine of common grace helps those in science and engineering professions to understand God’s dominion mandate, and His will and purpose for the entire human race. Engineering is part of God’s common grace to mankind. He gave man this gift to help fulfill His call to “subdue the earth.” Non-Christians are also bestowed this dominion mandate and they could contribute to the work of “subduing the earth” according to God’s common grace. Examples from optical engineering are used to demonstrate this “subduing” process.

Finally, implementation of these teachings in engineering curriculum is discussed.

Note: Except where noted, all Scripture quotes in this paper are from the New King James Version Bible.
1. Scope

There are multiple ways to approach integration of faith and engineering. Some would focus more on mission engineering and service learning activities and related reflections. Others might put more emphasis on career oriented training and discipline specific studies. One can approach integration of faith and engineering from a devotional standpoint – how to become a Spirit-filled engineer. Others approach it from the mental challenge of developing a Christian worldview and establish a system of Christian thoughts that relate to engineering, i.e., a “theology of engineering”. The focus of this paper is on the latter, i.e, the development of a system of thinking that relates engineering with theology. Figure 1 shows the various aspects of integration of faith and engineering.

![Integration of faith and engineering](image)

Figure 1 Diverse approaches to integration of faith and engineering
2. God the Master Engineer

Who was the first engineer? To answer this question, let’s first define what an engineer is. According to Merriam-Webster online dictionary, an engineer is “a person who has scientific training and who designs and builds complicated products, machines, systems, or structures.” [2]

Broadly speaking, God was the first “engineer.” Genesis 1:1 states, “In the beginning, God created the heavens and the earth.” Genesis 2:1-2 keeps on saying, “Thus the heavens and the earth, and all the host of them, were finished. And on the seventh day God ended His work which He had done; and He rested on the seventh day from all His work which He had done.” From the whole narrative in the first chapter of Genesis, God is obviously the creator of time (Genesis 1:5), space (Genesis 1:6-7), and the host thereof which includes both earthly and heavenly (angelic) beings.

Laurel D. [3] using examples from nature, demonstrates that God is the Master Engineer. Some of her examples include spider webs, plants, skeletons of vertebrates, and mollusk shells. She asserts in her paper,

The overwhelming complexity and intricacy in the design of nature should send all engineers humbly to the feet of the Master Engineer to learn whatever design lessons they can! There is no engineering school that can give them that depth of knowledge, understanding and wisdom. The book of nature gives instruction in physical design principles, economy, functionality, aesthetics, safety, recyclability and a holistic approach to design. These principles, drawn from the Master Engineer’s designs, should be engrained in engineering minds and reflected in every design. (Emphasis added)

God is the source of all wisdom (James 1:17). All God’s creation reveals His intelligent design (Psalm 19:1-7). Even the great Greek philosopher Plato, who was not a Christian, had to admit in his work Timaeus that the world is a handiwork of a mind [4].

One of the most convincing evidences for such intelligent design can be found in a tiny molecule machine called ATP synthase. Life depends on this incredible enzyme, and it is the world’s tiniest rotary motor [5]. Animations show the wonders of this design clearly [6] [7]. The following quote illustrates the matchless skills of our Master Engineer – God:
ATP Synthase is a molecular machine found in many living organisms. It serves as a miniature power-generator, producing an energy-carrying molecule, adenosine triphosphate, or ATP. The ATP synthase machine has many parts we recognize from human-designed technology, including a rotor, a stator, a camshaft or driveshaft, and other basic components of a rotary engine. This machine is just the final step in a long and complex metabolic pathway involving numerous enzymes and other molecules—all so the cell can produce ATP to power biochemical reactions, and provide energy for other molecular machines in the cell [8].

It would be unthinkable that these delicate biomechanical components in the ATP synthase would come together and start to function on their own. That would defy both logic and common sense. There must be a designer behind it. Just like when you see fully functional machinery with gears and motors running you know there must be a designer and an engineer behind it, when you see ATP synthase works the way it works you have to admit God is one who put these components together.

3. Man the Engineer

Men’s knowledge is always secondary. By studying science and engineering, we are really reading God’s mind regarding His creation. We can imitate God by designing/engineering for the good of ourselves and others. The first command from God to mankind as recorded in Genesis 1:28 is explicitly with regard to management and implicitly related to engineering:

Then God blessed them, and God said to them, “Be fruitful and multiply; fill the earth and subdue it; have dominion over the fish of the sea, over the birds of the air, and over every living thing that moves on the earth.” (Emphasis added)

This is commonly referred to as God’s dominion mandate or cultural mandate to men.

Then the LORD God took the man and put him in the Garden of Eden to tend and keep it. (Genesis 2:15, emphasis added)
Here, the word “tend” means “watch over”, “take care of”, which mainly speaks of man’s stewardship role in the environment we are given to live in. The word “keep” is related more to maintenance, which is a big part of any engineering project today.

God gives all engineers a mind to learn from His creation, to gain knowledge necessary to design and manufacture products to benefit the rest of His creation. We are commissioned by God to continue to “engineer” a better world on this earth and beyond.

ATP synthase speaks of wisdom, intelligence, capability, or rationality in its creator, some of the exact attributes of God as revealed in the Bible! When we investigate His handiwork, we are both obeying His command in Genesis 1:28 to do the work necessary to “subdue the earth”, and we have even more reason to praise and enjoy Him for His providence and genius [9].

4. The Distinction

An important distinction between God the engineer and man the engineer is that God can create something out of nothing (in Latin, “ex nihilo”). Man cannot. Thus God is far superior to man as an engineer. For example, in Genesis 1 the Scripture chronicles God’s creation of light. It took man over 6,000 years to study the nature of light and come up with a body of knowledge called “optics.” By the early 1800s, most scientists believed that light is a wave. In 1865 a Christian physicist James Maxwell discovered that electric and magnetic fields work together to produce light and light is an electromagnetic wave [10]. Later on, scientists discovered that light also exhibits particle properties. Scientists’ understanding of light continues to evolve.

In optical engineering, engineers strive to learn how to make use of the light God created. Laser, one of the major technological breakthroughs in the field of optical engineering in the 21st century, is now being used in almost all areas of life. For manufacturing it is used for high powered precision cutting and welding. Laser scanning revolutionized dimensional inspection and measurement due to its non-contact nature. Laser also revolutionized the business of shipping and logistics as it is widely used in package/item
identification via bar code scanning. Laser has also been heavily used in the medical field, providing healing and treatment to thousands of patients every day. It is also used in the entertainment industry (laser light concert, laser games), etc.

Some might argue that man can create new forms of light, such as the laser:

Lasers are a special form of light. Laser light does not exist in nature.

However, upon further analysis, we realize that the name LASER stands for Light Amplification by Stimulated Emission of Radiation. The laser light comes from solid state materials that God already created, as it is further explained here:

An atom gives out a photon of light if an electron in the atom falls from a higher energy level, or excited state, to a lower one. In most cases, excited electrons give off light in this way of their own accord. This is called spontaneous emission. In a few cases, the properties of the excited state prevent electrons from giving off light unless they are triggered by another photon of light. This process is called stimulated emission [12].

“Subdue it,” as stated in Genesis 1:28, implies “bending it to your purposes,” according to Blocki [13]. The creation and engineering of laser is a good example of this “bending” process:

The first laser, built in 1960, was a ruby laser. This type of laser contains a rod of synthetic ruby with mirrored ends. Bursts of white light from a coiled flashtube around the rod excite atoms in the ruby. Once one of the excited atoms manages to emit a photon spontaneously, that photon stimulates other excited atoms to emit light as it reflects back and forth between mirrors mounted at the ends of the rod. One of the end mirrors is half-silvered so the laser beam can undergo multiple reflections inside the tube and escape [12].

We can see from the above description that a useful, coherent laser beam is formed by literally “bending” the emitted light (that God created) multiple times using man-made mirrors. The coherent light can travel long distance without spreading. In other words, it
keeps a sharp focus, thus providing a powerful concentration of light energy and could be used in various applications. Clearly laser is the product of human engineering activities, and it is definitely not “ex nihilo,” or “created out of nothing.” Only God can create something out of nothing.

Another important distinction between God and man is that God is all-knowing, while man is not. Not all engineering failure is due to man’s sins. Some are simply the result of man’s limitation in knowledge. We are creatures. God is the creator. Human engineering activities are always limited in scope. As David Shaw quoted in his integration paper, “It is also important not to confuse our finitude with the results of the fall. Many of the limitations on our ability come from man’s finitude [14] which is equally shared by the Christian and non-Christian.” [15]

5. Common Grace and Engineering

A student once asked me this question, “Why are some non-Christians as successful, if not more successful, than Christians in the professional fields?” The only thing I could think of at the time was two verses from 1 Corinthians 1:26-27:

“Brothers and sisters, think of what you were when you were called. Not many of you were wise by human standards; not many were influential; not many were of noble birth.

But God chose the foolish things of the world to shame the wise; God chose the weak things of the world to shame the strong.”

I explained to him that if all Christians are more successful than non-Christians, then everyone would want to become Christians. It is the wisdom of God that He chose the weak to humble the strong. After I was exposed to the doctrine of common grace in Reformed circles, I was convinced that this doctrine can help answer a lot of such questions. It just made sense.

Common grace refers to the sovereign grace of God bestowed upon all of mankind regardless of their election. In other words, God has always bestowed His graciousness on all people in all
parts of the earth at all time [16]. Without God’s common grace, the human race would have been extinct a long time ago.

In Psalm 145:15-16 we see God’s common grace to all His creation:

“The eyes of all look expectantly to You, and You give them their food in due season. You open Your hand and satisfy the desire of every living thing.”

Many theologians and scholars and church fathers believed that the Noahic covenant (Genesis 8 and 9) is a covenant of common grace. Calling Abraham Kuyper the father of the doctrine of common grace, Cammenga [17] quoted him as saying,

“The firm historical starting point for the dogma of common grace lies in the establishment of the covenant of God with Noah after the Flood. To this significant and decisive event, in the last instance, not enough attention is paid. One too quickly passes on to Abraham and the patriarchs, and consequently the weighty significance of the Noahic covenant at first is pushed into the background and then is almost forgotten…. We must therefore begin by again placing the great significance of the Noahic covenant in its clear light.”

“The grace that is shown here is not particular, restricted only to the elect and leading to eternal life, but common, extending to all that have breath, and leading to a human existence on this earth, under this dispensation.”

“Its content lies exclusively in the sphere of natural life, has to do with temporal and not eternal blessings, and applies to unbelievers as well as to those who fear God…."

The doctrine of common grace would help lay members, especially those in professional fields such as science and engineering to understand God’s dominion mandate, and His will and purposes for the entire human race. God gives engineering talents and gifts to the godly and ungodly, just like He causes rain to fall and sun to shine on the righteous and the wicked. Engineering and technology is a vehicle by which man carries out the dominion mandate. This belongs to the common grace category. Wayne Grudem has this to say about common grace’s impact on mankind:
“The common grace of God in the intellectual realm also results in an ability [for man] to grasp truth and distinguish it from error, and [for man] to experience growth in knowledge that can be used in the investigation of the universe and in the task of subduing the earth. This means that all science and technology carried out by non-Christians is a result of common grace, allowing them to make incredible discoveries and inventions, to develop the earth’s resources into many material goods, to produce and distribute those resources, and to have skill in their productive work.” [18] (Emphasis added)

Another view of common grace comes from covenantal theology. Chapter 7 of the Westminster Confession of Faith [19] has this to say about God’s covenant with man:

“The distance between God and the creature is so great, that although reasonable creatures do owe obedience unto Him as their Creator, yet they could never have any fruition of Him as their blessedness and reward, but by some voluntary condescension on God's part, which He has been pleased to express by way of covenant.”

God has at least two covenants with men: the covenant of works and the covenant of grace. The Confession went on to say:

“The first covenant made with man was a covenant of works, wherein life was promised to Adam; and in him to his posterity, upon condition of perfect and personal obedience.

Man, by his fall, having made himself incapable of life by that covenant, the Lord was pleased to make a second, commonly called the covenant of grace; wherein He freely offers unto sinners life and salvation by Jesus Christ; requiring of them faith in Him, that they may be saved, and promising to give unto all those that are ordained unto eternal life His Holy Spirit, to make them willing, and able to believe.”

The Reformed Presbyterian Church of North America Testimony [20] made a comment on this section of the confession, which leads to their definition/interpretation of common grace:

“The Covenant of Works has not been revoked. All men remain under its requirement of perfect obedience and will have to give account according to it at the last judgment. In the Covenant of Grace Jesus Christ has fulfilled the requirements of the Covenant of
Works for His people. By His death Christ secured the delay of the full penalty of death for sin (the second death, Rev. 20:14-15) for all men. They therefore may enjoy the creation and have some fruitful toil in it for God’s glory, even though they be rebellious against Him. This is usually called common grace.” (Heb. 12:14; 2 Cor. 5:10, 21; Col. 1:16-20; 1 Cor. 8:6; Gen. 4:20-24; Ps. 76:10. Emphasis added)

6. Why Common Grace?

Mankind doesn’t deserve anything. All mankind deserves is immediate death, for the wages of sin is death (Romans 6:23). For mankind to continue to carry out the dominion mandate, God’s grace is essential. There are at least three purposes for God to provide common grace:

1. God wants mankind to continue on earth and flourish.
2. God is patiently waiting for more souls to come to Him for salvation, using common grace as a witness.
3. God wants to carry out His divine purposes for His Church.

Scriptures that directly support these views are Psalm 36:6, I Tim. 4:10, Col. 1:16-20, Acts 14:17, and Rom. 8:28. For example,

“Your righteousness is like the great mountains; Your judgments are a great deep; O Lord, You preserve man and beast.” (Psalm 36:6)

“For to this end we both labor and suffer reproach, because we trust in the living God, who is the Savior of all men, especially of those who believe.” (I Tim. 4:10)

The above two verses speak of “preserve” and “save,” both of which show God’s intention to keep man and beast from destruction or extinction. This shows God’s goodness and mercy. The very fact that God chose to delay punishment of sins of the human race is indicative of His common grace. Wayne Grudem in his popular book “Systematic Theology” said,

“It is not unjust for God to delay the execution of punishment upon sin and to give temporary blessings to human beings, because the punishment is not forgotten, but just
delayed. In delaying punishment, God shows clearly that He has no pleasure in executing final judgment, but rather delights in the salvation of men and women.” [18]

Non-Christians are in rebellion against God; their understanding is darkened. They don’t have a basis for true knowledge of the universe and God. However, non-Christians are also bestowed the dominion mandate and they could contribute to the work of “subduing the earth” according to God’s common grace. In engineering, the development of modern transportation systems involves both the saved and unsaved engineers. Without the unsaved engineers’ contribution, we wouldn’t be enjoying the convenience of modern technology we are enjoying now. And these technologies are also enabling missionaries to go out into the ends of the world to preach the gospel.

The existence of organizations and structures in human society is another evidence of God’s common grace. They help facilitate the delivery of God’s love to mankind. Examples include family, government, educational institutions, businesses and corporations, voluntary associates (such as many charitable and public service groups), and countless examples of ordinary human friendship [18].

7. What Should Our Responses Be?

We should thank Him for His special grace for us. We should also thank Him for His common grace to all men. One of the natural outcomes from a common grace perspective to life is a fresh respect and appreciation for our coworkers who are not Christians. As Tim Keller stated [21],

“Understanding common grace provides the basis for Christians to cooperate with and learn from non-Christians.”

The doctrine helps Christians to be more humble and ready to learn from non-Christians. Shaw recognized the danger of pride for Christian engineers:

“Christians are not necessarily more creative than pagans, since God gives His common grace, allowing apparently wise choices to be made by all sorts of men. There is the hazard of a sort of pride in being a Christian, where we start to believe that Christians
should, of necessity, be the very best in their fields, and if they are not it is because of weak Christianity or intellectual laziness. We should recognize that God, in His common grace, has given unbelievers great abilities too.” [15]

The doctrine of common grace could also be a good tool for use in evangelism. As it is pointed out in an article on common grace,

“Those who are ambassadors for Christ must be for both graces, the former grace often opens the door for the latter grace.” [22]

Sharing of the doctrine of God’s common grace with non-believers conveys to them a special recognition and acceptance that might benefit them and make them more receptive of the gospel. “The doctrine of common grace helps us to acknowledge God’s goodness in all of creation and enables us to pursue mission with love in a fallen world.” [21]

Max Deffenbaugh also noted the importance of teaching engineering students the doctrine of common grace as he shared in the 2009 CEES conference,

“When engineering students enter the workplace, their colleagues will include people of all faiths. It is a valuable lesson in helping students to work effectively and comfortably in diverse teams to appreciate the engineering excellence of their colleagues as a gift of God, even if their colleagues may not recognize it as such. Indeed it is a vital aspect of the students’ own Christian witness not to show religious favoritism in their professional interactions. Understanding engineering as a common grace activity is foundational to making students effective engineers and effective Christian witnesses in a diverse workplace.” [23]

8. Common Grace vs. Special Grace

God’s grace includes common and special (or saving) grace. “Common grace is the grace shown by the Creator to and for His creation. This ‘common’ grace is given regardless of the recipient’s awareness and acceptance of it. Special grace is bestowed upon those who enter into a personal relationship to the Creator through Jesus Christ.” [22]
Analysis may help us understand complex phenomena. However, analysis needs to work hand-in-hand with synthesis in order to have a holistic picture of life. The two covenants (covenant of works and covenant of grace) view espoused by the Westminster Confession of Faith helps us see more clearly the unique ways of God’s dealings with man, but we should not lose sight of the fact that the two covenants are one, as the same confession concluded. Why it is one? Through the failure of man to fulfill the covenant of works on his own, he sees the need of a Savior. The covenant of works leads man to the covenant of grace. And God knows from the very beginning that man cannot hold the other end of the stick of this covenant of works without His help. It is all a learning process for mankind to know that our life is in Christ. We are elected in Christ before the world existed (Ephesians 1:4). God’s plan is to draw us to gaze upon Jesus. If we trust in Him, we will see God’s good, acceptable and perfect will for us (Romans 12:2).

For analysis, God’s grace conveniently fits into common grace and special grace categories, but we should also recognize in the two graces this oneness that reflects God’s goodness. Just like the covenant of works leads us to see our inadequacy in our own strength, the relative peace and prosperity afforded us by the so-called “human flourishing” due to God’s common grace lacks eternal satisfaction in our souls. It cannot provide an ultimate purpose in our lives. So God’s common grace is meant to lead us to appreciate and receive His special grace, as it is clearly stated in the Scriptures (Acts 14:17, Romans 2:4). What common grace can offer the world is temporal, what special grace can offer a soul is eternal.

One of the best examples to illustrate the relationship between common grace and special grace is found in the Gospel story of Jesus speaking to a woman at the well. Jesus said to a Samaritan woman,

“If you knew the gift of God, and who it is who says to you, ‘Give Me a drink,’ you would have asked Him, and He would have given you living water.” (John 4:10)

Jesus then continued to tell her,

“Whoever drinks of this water will thirst again, but whoever drinks of the water that I shall give him will never thirst. But the water that I shall give him will become in him a fountain of water springing up into everlasting life.” (John 4:13-14)
Here obviously the natural water was provided to her through God’s common grace. Everyone can draw that water from the well – saved or unsaved. But if that is all she drank, she would thirst again. Only after she received God’s special saving grace that she became bold, and was no longer feeling the shame of sin. She delightfully proclaimed to the whole town the name of Jesus.

As Christian engineers, we have God’s special grace. It does not mean we no longer need God’s common grace, as we still need to go to work like the woman at the well still needs to go to the well to draw water to drink everyday even after she was saved. But her outlook for life had forever changed. She was delivered from the bondage of sin. She was liberated and had a new purpose in life. Similarly, Christian engineers can participate in their daily routine work with a renewed hope, purpose, and a perspective on life that is eternally meaningful. This is more abundant life. Without God’s special grace, no matter how successful people are in this life, there is still a void in their hearts that yearns for purpose, love and eternal meaning. Common grace can satisfy our stomach, but it cannot satisfy our soul. It can make human society “flourish”, but it cannot give us life more abundantly.

Special grace and common grace are also mutually beneficial. There is a dynamic interaction between the two. A peaceful life provided by God’s common grace helps the spread of the gospel, thus promoting the special grace of God. The reception of God’s special grace by certain people groups also enhances God’s common grace in that society. It helps form a culture that is more healthy for human survival and flourishing. A shining witness to this theory is the emergence of America on the world stage. The influx of Protestant Christians from Europe forever changed the makeup of the American population. The Church thus had a good witness and influence on the society. And God blessed America and it is now the strongest nation in the world. As postulated by Max Weber, the rise of the West is in large part due to the Protestant faith and its ethics [24]. The Protestant influence in America’s politics in the early days of its founding paved the way for the best government and legal system the world has ever seen. This in turn leads to enhanced common grace of God in the land and helps its people to flourish. The relative peace that America enjoyed since its founding helped her to become by far the most missionary-sending country in the world still to this date [25].
On the contrary, anti-God ideology and practices often lead to a reduced measure of common grace, as evidenced by the impoverishment of countries like North Korea. In China, the Mao-era brought man-made disasters to its people because the regime was basically anti-God and oppressive to Christians. After Mao, even though the economy seems to be high flying in the past three decades, the regime’s attitude and policy towards Christianity is still about the same. As a result, the moral value and social conditions continue to slide and there are massive environmental degradation and social upheaval in the country. Pollution is at such a dangerous level in China that it is already impacting the rest of the world [26].

The secularization of America in recent decades had caused a negative effect on God’s common grace on this nation. As God was continuously being pushed out of schools, courts and other public squares, America lost out on God’s protection as evidenced by the rise of terrorism against America in recent years. It is quickly turning into a country with the most national debts.

The revival of Christianity in China in recent decades is also pushing China towards a better future as a country. It already is the largest creditor to the US. China’s continued modernization will inevitably lead to more openness in media and press, and more freedom in political, economic and social and religious realms. And these are all good indicators of an increased measure of God’s common grace.

One special case that makes the distinction between common grace and special grace difficult is in relation to the Jewish people. The Jewish people are God’s elect, but a majority of them are not yet born-again Christians. In other words, a majority of them do not have the special (saving) grace. But they do receive a lot of common grace, as evidenced by a disproportionately large percentage of Nobel Prize winners being from among them:

“At least 197 Jews and people of half- or three-quarters-Jewish ancestry have been awarded the Nobel Prize, accounting for 22% of all individual recipients worldwide between 1901 and 2016, and constituting 36% of all US recipients during the same period. Jews currently make up approximately 0.2% of the world's population and 2% of the US population.” [27]

In other words, they do receive a “special” measure of common grace throughout their history. At a certain time in the future though, as Romans 11:25-32 seem to indicate, it will be massive
conversion of the Jewish people to receive special (saving) grace. This last point is not without debate among theologians, but if this interpretation of the passage stands to be true, the special grace to be bestowed on the Jews in the last days will be so commonplace that we can say, in days past common grace was special for the Jews, but in the last days special grace will be common for them (pun intended).

Other noted authors on common grace include Abraham Kuyper [28] and Gary North [29]. There are also those who disagree with the view of common grace, notably authors from the Protestant Reformed Churches [30]. They explain it through God’s patience, instead of God’s grace. In final analysis, no matter how you look at it, it is all God’s goodness and mercy towards mankind.

9. Implementation in the Engineering Curriculum

Throughout this study, the author had been actively engaging engineering students in the classroom about these topics. Some Christian colleges encourage integration of faith and engineering more than others, but since the materials are modular in nature, they can easily be integrated into any classes an engineering professor would typically be teaching and it would normally only takes up 1-2 lectures.

At Geneva College, the author would cover this material at the very end of a sophomore level solid mechanics class that is required of all engineering majors. At Anderson University in the Spring of 2016, the author covered this material at the beginning of a “Service Engineering” course (an elective) to give students some grounding in biblical worldview as it relates to engineering. At Mount Vernon Nazarene University in the Spring of 2017, the author covered this material in a one credit hour course on engineering ethics.

When discussing God being the master engineer, the author would show students animations of the ATP synthase [6][7]. Even though it is a topic of biology, the moving parts in an ATP synthase are very similar to mechanical components of gears and shafts and mechanical engineering students can readily relate to it. Students are also assigned to read an integration paper by Laurel Dovich [3] and engage in a classroom discussion and essay writing. Feedback from students are in general positive because, for one, they need information like this to guide
them in their careers and/or Christian walk. And, it provides a nice change of pace by breaking from the traditional coverage of “hard” engineering subjects. Students in general love it, because it is what a liberal arts based engineering education is expected to provide for them.

The following are course objectives that pertain to the contents discussed in this paper:

After successful completion of the course, students will:

1. Have a biblical understanding of engineering and technology
2. Have an understanding of the doctrine of common grace and its implications in engineering
3. Obtain a worldview of glorifying God in everything we do, whether it is working on mission engineering projects or working as a professional engineer in the industry

The following are sample student responses:

**Short Answer Question:** Why are some non-Christians as successful, if not more successful, than Christians in the professional fields?

**Student A Answer:** “Because if all Christians were more successful, everyone would want to follow Christ for the wrong reasons. God chose the weak to make them strong, He chooses the poor to make rich. Now, all good comes from God, and all men are allowed to succeed by the doctrine of “Common Grace,” in which all of humanity has God’s blessing over them simply from being created by Him. However, by taking the steps to follow God and choosing to turn against our sinful nature, a person’s life will most certainly be better. Maybe not financially, or relationally, as there are many people out there who have angst towards Christians, and the true enemy will most certainly try to persuade one from being born again, but having a relationship with Christ is far more rewarding than could ever be measured by any human standards.”

**Student B Answer:** “I know many good and successful people who are non-Christians. I believer through common grace, God can exercise his sovereignty and bring good to the world through a non-Christian. 1 Timothy 4:10 says, ‘That is why we labor and strive, because we have put our hope in the living God, who is the Savior of all people, and especially of those who believe.’ Non-Christians can still impact the world in countless
ways. God is the savior of all people and extends common grace to everyone, believer or unbeliever.”

The following are some sample student responses from reading Laurel Dovich’s paper [3] on the topic of God being the Master Engineer:

**Question:** What example(s) did the author use to illustrate the superior quality in God’s design and “manufacture” of His creation? Share something that struck you while reading this section of the paper.

**Student C Answer:** “The author shows examples of the superiority of God’s design, such as the building blocks of life (proteins, minerals, sugars), the human body, and many consistencies in design across different species of animals and plants. One thing that struck me in this section is that God created all of this from nothing. From the smallest atoms and molecules to the massive stars and planets, everything points to a single creator! Even just typing these words gives me chills thinking of the power behind our creator. Even more so, he invites us into a relationship with him. He designed us and loves us as well.”

**Question:** Which structural engineering example in nature is most inspiring to you? Why?

**Student D Answer:** “The spider web. The intricacy and strength in something so small is amazing. It makes me feel more capable because if God created a spider to create something like a spider web, he definitely has given humans massive resources to create.”

These sample student work demonstrate that the course objectives are met.

**10. Conclusion**

God is the mastermind of all creation. It is not a stretch to say, therefore, that God was the first engineer. As God’s image-bearers, men are also called to do engineering. Engineering is a gift from God to man, regardless of him being a Christian or not. This is part of God’s common grace to mankind. He gave man this gift to help fulfill His call to “subdue the earth”. However, due to the fallen nature of man, engineering will also be corrupted by sin. The only solution to this
problem is the redemptive work of Jesus Christ. The solution of sin problems in engineering rests with the gospel. The whole world needs Christ’s redemption. Man cannot have dominion over God’s creation on his own – God never intended it to be that way from the very beginning. All men need Christ. That is the true essence of a “new” dominion mandate – a Christ-centered dominion mandate.

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Bibliography


1.0 Abstract

Jesus instructs us to seek first the Kingdom of God. Seeking first the Kingdom of God is no small task. It is a process of striving to show God’s love in every situation by showing love to our neighbors and to the rest of the creation. It is serving in a way that enables them to flourish. Seeking first the Kingdom of God is striving for true progress in all its wholeness; it is seeking shalom [1]. Shalom is an Old Testament word which refers to the restfulness, contentment, beauty, and harmony of a life lived in perfect obedience to God’s will. Shalom is a condition in which everyone and everything is in right relationship all the time. When shalom is the order of the day, human and non-human creation are enabled to flourish by becoming everything God created them to be. Therefore, the call to seek shalom, which includes our work as engineers, is no less than a call to obedient living. With the goal of flourishing the whole of creation, we were made and have been remade to seek shalom as we lovingly meet technological needs around us.

God is glorified through our care-filled engineering of the creation when it leads to blessing for all. Our engineering work seeks shalom when it is motivated by love for God and neighbor, is guided by Kingdom knowledge of community and place, and results in holistic flourishing.

This paper is a first step toward exploring the practical implications of seeking shalom through our work as engineers. Seeking first the Kingdom of God requires knowledge of that Kingdom and our role in it. I strive to develop a comprehensive, biblically-based, and creationally-informed understanding of flourishing that can serve as a meaningful guide for living before the face of God (coram Deo). While the underlying principles are as broad as all of life, I generally illustrate them using engineering examples.

2.0 Introduction

Shalom is an Old Testament word which refers to the restfulness, contentment, beauty and harmony of a life lived in perfect obedience to God’s will. Shalom is a condition in which everyone and everything is in right relationship all the time [2]. When shalom is the order of the day, human and non-human creation are enabled to flourish by becoming everything God created them to be at their appointed time and place. This condition existed before the fall of Adam and Eve into sin and its complete restoration is assured through Christ’s death and resurrection. Christ’s work restores the possibility of a right relationship with God but also with each other and the rest of the creation. By the ongoing work of the Holy Spirit, we are prodded and enabled to seek Christ’s Kingdom first and to find it. His Kingdom is a kingdom of right relationships. It is a kingdom of shalom [1]. Although the victory is won, believers are called to continue to wage war against the powers of evil by proclaiming the good news until Christ returns. We are called to be His disciples by seeking first His Kingdom.

Seeking first the Kingdom of God is no small task. It is a process of striving to show God’s love in every situation by showing love to our neighbors and to the rest of the creation. It is serving in a way that enables them to flourish. As a first step, we need to deny ourselves and pay attention to the needs around us rather than our own. It requires that we get to know those around us, enabling us to help them become what God intended them to be – redeemed, loving
servants of Christ. However, seeking shalom is not just limited to our relationship with others, it also applies to our interactions with the rest of the creation. It requires that we understand the rest of the creation well enough to know how best to manage it so that it too can flourish as God intends. Everything we do impacts our neighbor and the rest of the creation in some way. The call to seek shalom is a call to no less than obedient living, which includes our work as engineers.

Engineered artifacts, whether physical items or a set of procedures, are designed to be used. When put to use, the artifact helps shape the nature of the relationships between the user and the various aspects of their surroundings, including other people. Our technologies mediate the relationship space by enabling some ways of relating while making other ways of relating more difficult [3]. An electric toaster requires the use of electricity to use it to make toast. It dictates a small part of the user’s energy relationship with their surroundings. Likewise, a two-slice toaster shapes the user’s relationship with others around the breakfast table differently than what a four-slice toaster would. It can be fruitful to see our engineering work as fundamental in designing ways in which the user is encouraged to relate to the world. Focusing on the relation shaping character of design, begs us to consider what kinds of relating we ought to be encouraging. It inspires us to seek shalom in and through our work as engineers!

This paper begins to explore the practical implications of seeking first the Kingdom of God in the context of our engineering work by clarifying our view of where we are headed and what we will need to get there. We begin by acknowledging a God-placed human desire, which strives to make things better, as we explore the creational roots of that desire. Next, we dig into the detail of understanding shalom and flourishing from a biblical perspective. This equips us to close the paper by considering what holistic flourishing might look like in the context of a specific engineering example.

3.0 In Search of “Better”

I dare say that everyone is in favor of progress as long as its definition fits their view of what would lead to a better life. Everyone’s idea of “better” is shaped by their underlying beliefs about the world and their role in it. This is often referred to as their worldview [4]. These core beliefs guide their choices, often unconsciously, as they go about their daily activities. Humans are culture makers and our choices reflect who or what we value, love, and worship. [5] Our priorities often reveal our definition of the good life and how we think we can get there; they reveal our view of progress.

To a large degree, communities and cultures cohere by sharing a common vision for what constitutes progress and its corresponding definition of “better.” Members of communities tend to have their worldviews shaped by the community’s vision for “better,” which in turn acts to reinforce the culture’s direction. While there are undoubtedly local variations, American culture is often considered to be predominately driven by an individualistic pursuit of personal gain and self-fulfillment [6]. In the extreme, the individualist, selfishly seeks happiness through acquiring the financial resources and the corresponding freedom, to do what he wants, when he wants, independent of anyone else. According to this view, progress is narrowly defined as whatever facilitates this self-indulgence, regardless of all else. Individualism, as it is lived out by particular people, is rarely expressed or professed this forcefully. More often, self-seeking
tendencies manifest themselves as a culturally acceptable lack of active concern for nearly anyone or anything else. Our culture encourages us to insulate ourselves from the needs around us. It is common, even expected, to seek one’s own happiness by doing things and having things that make us feel important, independent, accepted, powerful, secure, successful, and fulfilled. However, seeking meaning in these things is ultimately fruitless, leaving us in want and setting us up to repeat the cycle.

The danger for Christians is clear. Material possessions and comforts are part of God’s good creation and can often be legitimately enjoyed and used for His glory. However, if we lack a clear, biblically-based vision of true progress and flourishing, it is easy to passively accept the culture’s directives as truth, at which point, these so-called material blessings become stumbling blocks. Our choices reveal our true loves and, based on the brokenness we often leave in our wake, it may be hard to distinguish us from unbelievers. Therefore, it is paramount, particularly in the area of technology which is treated as being on the cutting edge of progress, that Christians have a clear vision for life in God’s Kingdom and the flourishing that results. The required vision must enable us to meaningfully engage the everyday world and bring healing and hope as we seek to shed light on the Kingdom of God. We need a biblically-based vision for Kingdom progress.

4.0 Biblical Directives

God reveals Himself and His will for us through the Bible and through the creation [7]. A vision for responsible action and true progress must therefore align with God’s revelation and our role in His Kingdom.

4.1 Image Bearing

The first chapters of the Bible tell of God’s creative handy work in fashioning all “that is.” It is there that we first learn that humanity has been created in the image of God and is therefore unique. When I ask my students what they think it means to be created in the image of God, they often identify their creativity or their ability to reason as sure signs of God’s likeness. This is the response we might expect from engineering students immersed in the world of design, but it is the same response that has been given by many Christians through the ages. While I agree that these abilities may be part of what it means to be made in the image of God, I believe a more consistent understanding of this biblical principle is put forth by Douglas John Hall in his book *Imaging God: Dominion as Stewardship* [8]. Hall argues that being made in God’s image is less about describing what we are and more about helping us to understand what we should be doing. He gives a robust biblical and historical basis for claiming that we have been created to bear God’s image by being His representatives to the rest of the creation, including our neighbors. Everything we do is a response to God’s call to bear His image. Therefore, all our actions should be in line with His will so that the whole of creation can see and experience God’s glory through us. This is beautifully consistent with what we read about Christ in Colossians 1:15, “For He [Christ] is the perfect image of the invisible God” (NIV). This passage is calling our attention to actions rather than attributes. Christ provides the perfect example of what it means to be an obedient image bearer and we are to pattern our lives after His. We are called to be Christ-like in all we do. Therefore, our creativity, our rationality, our desires, and our ability to love, are not the essence of what it means to be created in the image of God, but rather, are gifts from God,
enabling us to be His representatives. Practically speaking, these abilities are the means of our authority to rule over the creation.

4.2 Service Mandate

As seen in the early chapters of Genesis, being an image bearer points us naturally to our call to be loving stewards. Immediately after being told we are created in the image of God in Genesis 1:27, we are given insight into the nature of this task in the next verse: “God blessed them and said to them, ‘Be fruitful and increase in number; fill the earth and subdue it. Rule over the fish in the sea and the birds in the sky and over every living creature that moves on the ground.’” (Gen 1:28, NIV) Notice that God blesses us and gives us authority, or control, over creation so that we can be a blessing. We are to be a blessing by being fruitful, bearing fruit like the rest of creation (Gen1:11-12; 1:17-18; 1:22; 2:9). Humans are to contribute their part to the flowering of creation by using their gifts to subdue the earth and fill it with blessing, revealing God’s glory as responsible image bearers. Richard Mouw explains:

“The command to “fill” the earth here is not merely a divine request that Adam and Eve have lots of babies. The earth was also to be “filled” by the broader patterns of their interactions with nature and with each other.” [9]

Our relationship to the rest of creation, in light of our authority to subdue, is further clarified in Genesis 2:15, “And Jehovah God taketh the man, and causeth him to rest in the garden of Eden, to serve it, and to keep it.” (Young’s Literal Translation) The call issued in these verses is not an edict to indiscriminately develop culture. Based on Cal DeWitt’s study of the Hebrew terms for the phrases “to serve it” and “to keep it” [10], I have argued elsewhere [11] that the command given here is best understood as a call to be of service to the garden by helping it to prosper. We are to be stewards.

The role of steward is often narrowly understood as dealing with our use of resources or the environment. However, it is actually much broader, encompassing our whole lives. It is not a separate part of our Christian calling; it is the whole of our walk. Using our unique gifts, each of us is to serve God by dedicating our entire selves to be of service to others and the rest of creation, by enabling them to flourish by becoming what God intended them to be. God has given us freedom and responsibility in our actions and calls us to loving service as we tend to the needs of creation, including our neighbors. For this reason, I have made a habit of referring to these verses as the “Service Mandate,” although the term “Cultural Mandate” is more commonly used.

As God’s perfect image bearer, Christ epitomizes the faithful steward. He teaches:

“You know that the rulers of the Gentiles lord it over them, and their high officials exercise authority over them. Not so with you. Instead, whoever wants to become great among you must be your servant, and whoever wants to be first must be your slave - just as the Son of Man did not come to be served, but to serve, and to give His life as a ransom for many.” (Matthew 20:25-28, NIV)

Paul echoes these same teachings in Philippians 2:1-11 and also in Galatians 5:13, while Peter instructs us, “Each of you should use whatever gift you have received to serve others, as faithful stewards of God’s grace in its various forms.” (I Peter 4:10, NIV) We glorify God and become more Christ-like when we lovingly give ourselves up in order to assist others and the rest of
creation, to be what God created them to be. God expects us to serve Him by being of service to the whole of creation, enabling it to flourish in every conceivable way.

4.3 Shalom, Flourishing, and the Kingdom of God

If we are to reveal God’s glory and His likeness by being a blessing to others and the rest of creation, then we need to have a clear understanding of what is involved in this flourishing task. We start by describing the relationship between our stewardship task and the Kingdom of God. In the New Testament, Christ teaches that through him the law is fulfilled and God’s Kingdom has come, although it is not yet fully revealed. He then calls each of us to be His disciples by seeking first His Kingdom (Matt. 6:33), a kingdom of shalom [1]. Cornelius Plantinga Jr. writes:

“The webbing together of God, humans, and all creation in justice, fulfillment, and delight is what the Hebrew prophets called shalom. We call it peace, but it means far more than mere peace of mind or a cease-fire between enemies. In the Bible, shalom means universal flourishing, wholeness, and delight – a rich state of affairs in which natural needs are satisfied and natural gifts fruitfully employed. … Shalom, in other words, is the way things ought to be.” [12]

Jonathan Hiskes puts it this way:

“The image of shalom woven through Scripture offers glimpses of creator, humanity, and the earth dwelling in peace….It’s a vision marked not by the absence of forbidden acts but by the presence of healthful ones – dancing, singing, feasting, inventing, building, resting – all alongside a God who laughs and plays.” [13]

Shalom, then, is a condition in which everyone and everything is in right relationship all the time [2], where “right relationship” is typified in being a blessing to the other. We are to be a blessing by enabling human and non-human creation to become everything God created them to be. People are to be equipped to use their gifts for service and the rest of creation is to be brought to its full fruition. Harmonious flourishing existed before the fall of Adam and Eve into sin and its complete restoration through Christ was envisioned by Isaiah (Isaiah 11) and John (Revelation 21).

Our flourishing duties certainly involve allowing non-human creation to thrive in all its created diversity, but they also include responsible unfolding or development of the creation through cultural activities, including technology. Through responsible engineering, we make it possible for creation to bring praise to God in ways it could not without human involvement. In keeping with God’s plan of shalom, obedient design unfolds creation in such a way that the whole of creation, including humanity, flourishes. Therefore, flourishing is not an end in itself, but is rather a harmonious means of opening up the creation through time as God intended with each specific piece singing its part to His glory. In other words, we can be of service to creation by enabling it to flourish as a growing chorus of praise with ever-increasing diversity. When we steward or serve creation in this way, we cultivate shalom, revealing His Kingdom and bearing His image. When shalom is operative, flourishing results.

4.4 Broken Relationships

Of course since the fall, the realization of this comprehensive potential for beauty and harmony has been seriously crippled by the work of Satan and the distortion of sin. In the absence of God’s grace, the misdirected heart of mankind flees from obedient, loving, selfless service and
instead embraces self-centered autonomy from God. Tragically, we run away from our true image-bearing identity and instead reflect the images of the idols we serve (Psalm 115:4-8). This rebellious choice comes with a high cost. Our relationships with God, with each other, and with the rest of the creation are broken, and fruitfulness is often replaced by barrenness, violence, destruction, and death.

4.5 Redemption and Our Current Task

But out of love for the cosmos He created, God sent Christ to conquer sin and death restoring our relationship with God and reestablishing His kingship (John 3:16-17). Christ’s victory over Satan sets us free to once again serve as God intended. Christ’s work restores the possibility of a right relationship with God, but also with each other, and the rest of the creation. By the ongoing work of the Holy Spirit, we are prodded and enabled to seek Christ’s Kingdom first and to find it. Christ’s Kingdom is a kingdom of right relationships: a kingdom of shalom [1]. Although the victory is won, believers are called to continue to wage war against the powers of evil by proclaiming the good news until Christ returns. We are called to be His disciples by seeking first His Kingdom. We bear witness to His kingship by not only verbally proclaiming the gospel but by also bearing the image of the King in everything we do.

“Redeemed humanity is directed to exercise dominion, stewardship, and justice, guided by the mind of Christ. Redeemed humans are not to shun their powers of intellect, creativity, and technique. Rather, they are to use them for the wise and loving management of creation, developing, the full potential of everything in creation – stone, beast, or human – and lifting all of that creation to share in their adoption as sons and daughters of God.” [14]

Embracing our call to steward, we can be of service to others by helping them glimpse Christ’s Kingdom as we strive to show the way things are supposed to be in all areas of life, including our design work, “erecting signposts of the Kingdom,” as Goudzwaard says.[15]

Seeking shalom, in a world where many others are not, is an impossible challenge outside of God’s grace. Serving and giving of ourselves, while others do not, can feel like a burden stirring our sense of injustice. Therefore, we must daily deny our selfish tendencies and focus on the needs of others (Luke 9:23, 1 John 3:16). In a sin-twisted world, our efforts to be of service can also be misguided, rejected, or futile. Seeking shalom yields blessing but it also inevitably leads to suffering on this side of Christ’s return.

5.0 Flourishing as True Progress

We live in “enemy occupied territory” [16], as C. S. Lewis would say, and our cultural status is not that unlike Israel’s during their exile in Babylon. At that time God, through Jeremiah, counseled the Israelites to “seek the shalom of the city where I have sent you into exile, and pray to the Lord on its behalf, for when it flourishes you will flourish.” [17] This verse is not suggesting that we simply acquiesce to the surrounding culture’s vision of progress, but rather, we are to be a blessing to those around us, directing them to freedom in Christ through the prosperity and the peace found only in Kingdom living. True progress occurs when we take steps, or encourage others to take steps, that seek shalom in all its wholeness. All other actions lead down paths of destruction. Everything we do is either directed toward the Kingdom and true progress or away from it.
As facilitators of flourishing, it is critical that we understand the full scope of this task as it applies to every moment of every day, including our engineering. We consider the foundation of fruitfulness here and then apply it to a specific engineering example in the following section.

5.1 Goal

Our actions only result in flourishing if they serve our chief end: “to glorify God, and enjoy Him forever.”[18] An important implication of this is that seeking shalom and flourishing cannot be a goal in itself. Striving for harmony, love, a healthy environment, or any other good thing in isolation from Christ’s Kingdom, is futile. Flourishing only finds true meaning when done in service to the Creator and to His glory. As the Westminster Catechism makes clear, even our enjoyment which we might be tempted to consider as being self-directed, is to be focused in God. The contrast between seeking shalom and the stereotypical western view of progress, which seeks personal gain and glory, could not be greater. Flourishing occurs when creation in all its fullness brings glory to God by being a blessing. And to be a blessing to another means that they have either been equipped to be a blessing to someone or something else, or they have been enriched in such a way that they can enjoy God more fully.

5.2 Motivation

“Love the Lord your God with all your heart and with all your soul and with all your mind and with all your strength.’ The second is this: ‘Love your neighbor as yourself.’ There is no commandment greater than these.” Mark 12:30-31 (NIV)

“For God so loved the world that he gave His one and only Son, that whoever believes in Him shall not perish but have eternal life. For God did not send His Son into the world to condemn the world, but to save the world through Him.” John 3:16-17 (NIV)

“Follow God’s example, therefore, as dearly loved children and walk in the way of love, just as Christ loved us and gave Himself up for us as a fragrant offering and sacrifice to God.” Ephesians 5:1-2 (NIV)

If our lives are to be God glorifying, then we must be motivated by a sincere love of the world just as God is (John 3:16, I Cor. 13). Love is a gift from God, through the work of the Holy Spirit, which stirs in us a desire to serve while simultaneously undermining self-centeredness. It is the greatest gift (I Cor. 13:13) because it lays the foundation, enabling all other gifts to be used in grateful service.

5.3 Communal

Flourishing is always communal. Individuals do not flourish, communities do. Efforts that fail to consider the whole of the community will fall short of achieving shalom. The most basic understanding of the communal aspect of our task recognizes the interconnectedness of the creation. All created things exist in context. Everything we do depends on and affects other people and parts of creation, shaping our collective future. This is why humans are called to be of service to the whole of creation. There is a mutual interdependence between God, humanity and the rest of creation. Obviously, the whole creation including humanity depends on God, but mysteriously, it also seems that God has chosen to need us, and loves us deeply. We depend on
creation and each other for sustenance, but also see God’s majesty, power, and sustaining care displayed through the beautifully intricate world. Non-human creation needs us to open up its potential and care for it so that it continues to flourish to God’s glory. However, sin breaks down our communal relationships. Unable to fully be what it was created to be, the creation groans under the weight of the curse (Romans 8:22). Our treatment of others and the rest of creation is our response to God’s call and, therefore, has implications for our relationship with God.

Stewards are responsible individually and communally. The interdependent nature of the created order requires a holistic approach to engineering as well as the rest of our activities.

Being aware of this interconnectedness can help us avoid negative impacts, however, the communal aspect of our prospering work goes beyond damage control. It demands that all our actions seek shalom. Flourishing always promotes right relationships. In community we are to love God above all, love our neighbors as ourselves, and care for the rest of creation. However, our call goes beyond just getting our own house in order. It also includes the loving encouragement of others to be good stewards and for them to spur us on.

5.4 Kingdom Knowing

Humans and their managerial responsibilities are woven into the very fabric of creation. As we have seen, these responsibilities involve being of service to our neighbor and the rest of creation by enabling them to be what God intends them to be. However, to serve in this way requires knowledge of God’s will; it requires Kingdom knowing. Kingdom knowing is more than just information gathering. It is the mysterious and time consuming, Spirit led work, of knowing in the context of a loving relationship, made meaningful in its connection to the biblical narrative. This type of knowledge leads to wisdom. It is knowing that leads to right action because it is born out of Christ-centered caring. According to Steve Garber, it is the biblical way of knowing:

“What does it mean to ‘know’? If we were to take the Hebrew scripture, from Genesis to Malachi, listening to and learning the way that knowledge is understood, it would come to something like this: to have knowledge of means to have responsibility to means to have care for.” [19] “We must not only know rightly, but do rightly. And we must know and understand and love – at the same time.” [20]

Information becomes meaningful when it is understood in the context of God’s call to loving service. This is wisdom foraged only while actively seeking first His Kingdom in community.

Kingdom knowing is grounded in God’s revelation to us through His written Word and through His creation. We learn to steward by listening to God’s Word and by intimately observing creation. Discernment requires transformed hearts and minds that are in tune with God’s will so that we can see and love the world as God does and be moved to serve it as Christ does (Roman 12:2).

Kingdom knowing is nurtured with habits that focus on needs beyond our own. By contrast, our culture worships, glorifies, and rewards self-seeking exercised within accepted limits. Ironically, in looking toward ourselves, we turn our back on others and our true identity. My own flourishing, the flourishing of those around me, and the flourishing of the creation within my reach, depend on my continual dying to my selfish self, while embracing my Christ renewed self. Habits of love, concern, and Kingdom-building action begin by getting over ourselves and directing our attention to the whole community that makes up our place. We need to develop a
habit of paying attention day-in and day-out. This kind of seeing requires that we look at the
world as Christ does. By grace through the work of the Holy Spirit, we can learn to recognize
the brokenness around us and know how best to help. Properly trained, we will see the Spirit at
work around us. However, our vision is easily distorted when our own needs and wants take
center stage.

A person’s ability to recognize brokenness and discord and be able to point to healing and
harmony is, to a large extent, determined by his or her view of the world. The human brain is
limited in its ability to handle the incredible amount of stimulation it receives from our senses.
Therefore, the brain physically filters and assigns meaning to incoming information based on
what a person believes to be true about the way the world really is [21]. If something is not
important to our understanding of the world or our attention is directed elsewhere, we literally do
not see it even though we may be looking right at it [21]. What we notice is determined by our
view of what is worth noticing. When our understanding of the world is distorted, so too will be
our seeing and our knowing. Further, our knowing of the world contributes to shaping our view
of the world and how we try to find meaning in it [21]. Therefore, in light of this feedback loop,
it is critical that the truth of God’s Word be embedded deep in our hearts compelling us “to love
what God loves, to feel what God feels” [22].

The creation responds to the Lord’s word for creation in one of two ways. Most creatures
respond with compulsory obedience. Rocks respond to God’s will for rocks by being rocks,
unless ordered (or reordered) to be bread. Water is always water, it seems, unless commanded to
become wine. However, humans enjoy limited freedom to choose the nature of their response to
the Lord’s word. For example, while our living bodies must obey God’s word for the physical
and biotic aspects of creation, humans have freedom in their response to God’s command to love
their neighbor. When we have freedom in our response, God’s commands are often referred to
as norms or divine oughts and we become response-able. Every interaction with God, others,
and the rest of creation is to be guided by norms. We are to live by God’s will. When we ignore
God’s normative structure, damage and brokenness result. When we are faithful to the will of
the Lord, blessing follows (Psalm 19:7-11). However, because of the presence of sin in the
world, the blessing that flows from normative action is never complete. Doing the right thing
does not result in complete harmony.

God’s normative structure is embedded into the very fabric of the universe. As such,
unbelievers, by God’s grace, are also able to recognize many of its patterns. For example, most
cultures recognize that children do best when raised by parents that love and care for them. We
have learned that polluting the air we breathe can lead to lung disease and therefore we should
avoid doing it. Business owners know they ought to care for their customers if they want to do
well. The Bible is loaded with normative wisdom to direct our interactions, but there is also
much we need to discern from the world around us. Flourishing requires that we pay close
attention to the results of our actions and learn from them. In order to enable my wife to
flourish, I have to get to know her. I need to pay attention so that I understand how I can best
help her utilize her gifts and overcome her weaknesses as she grows in her walk. Knowing
someone or something, then, is not a destination but a journey. It is an ongoing process of care-
filled experimenting to learn how best to facilitate prospering. This is not just true of our
relationships with others but also applies to our relationship with the rest of creation. For
example, we have learned that paint can extend the life of a steel part by protecting it from
corrosion. As we unfold the technological potentials in creation, we need to do so in wisdom that is born out of loving care and a heartfelt commitment to seeking shalom. We can develop normative principles based on biblical and creational revelation [23] but doing God’s will is always nuanced by the particulars of time and place. Therefore, it is appropriate for us to consider how seeking shalom is attempted in the context of a specific design example.

6.0 Example: Toys for God’s Kids [24]

One of our senior design teams from 2015-2016 worked on a project for the local chapter of Toys for God’s Kids (TFGK). TFGK is a national organization that utilizes volunteer labor to produce small wooden cars that are distributed to children in impoverished areas around the world. TFGK’s mission is to show God’s love through the simple act of giving a handmade toy to children that have very little. Most of the volunteers are retired men that enjoy woodworking. The local chapter approached our engineering students with the hope of improving their toy making process.

Every design project strives to make the world a better place. However, as we have seen, the key is in how we define “better.” The students began the project by visiting the toy shop where they were able to observe toys being built, meet some of the workers, and try their hand at some of the production steps. After visiting the shop and developing a relationship via several meetings with the leader of the local chapter, it became clear to the design team that “better” in this case could not simply be about manufacturing efficiency. Even though the organization strives to produce a large number of cars each year and increased production would benefit more children, putting toys in the hands of kids is only part of the flourishing equation. Making the toys is also rewarding work for the retirees. It gives them a common purpose and a place to gather and socialize with others who share their interests. A narrow analysis of the manufacturing process would have likely suggested implementing extensive automation to maximize production. However, the goal of this project was not maximum production but holistic flourishing. Therefore, the students attempted to know their customer and the context of the project through a relationship based on love. This led the design team to recommend a limited amount of automation. They focused on preserving the enjoyable aspects of making the toys while automating some of the more tedious tasks. In addition, the students also sought to improve the aesthetics of the work environment. Most of the edges of the car parts are rounded off using a router. The router is loud and needs to be running most hours of the day. To help mitigate the problem, the team designed a sound dampening attachment for the router. The muffler system significantly reduced noise levels in the shop area, thereby facilitating additional conversation and socializing.

The complete design required knowledge beyond the social habits of these retired wood workers. Knowledge of actuators, controls, the properties of pinewood, the physics of sounds dampening, etc. also informed the details of the design. Design for flourishing demands not only that we pay attention and know the larger context of our projects, but that we also serve in and through the details. Seeking shalom as an engineer requires a holistic approach.

Undoubtedly, this student project fell short of holistic flourishing in many ways. Biblical knowing requires more than just a brief encounter with others and with place, indeed, it continues to mature along with the relationships. However, even with its limitations, I believe
this project illustrates the transformative potential of seeking shalom in and through our design work.

7.0 Conclusion and Future Work

Seeking first the Kingdom of God is striving for true progress in all its wholeness; it is seeking shalom and flourishing. We were made and have been remade to seek shalom as we lovingly meet technological needs around us with the goal of flourishing the whole of creation. God is glorified through our care-filled engineering of the creation when it leads to blessing for all aspects of creation. Our engineering work seeks shalom when it is motivated by love for God and neighbor, is guided by Kingdom knowledge of community and place, and results in holistic flourishing.

By sketching out a biblical foundation for seeking shalom and flourishing, this paper intends to set the stage for future work which will consider the implications of this task as it pertains to the day-to-day work of engineers. “Seeking first the Kingdom of God,” “using your gifts and talents to God’s glory,” “seeking shalom and flourishing,” are phrases that become particularly meaningful when put into practice. Engineers need to be concerned about the broad implications of their efforts, but they also need to be obedient in their handling of the details. In this paper I have tried to articulate a broad, biblically-based perspective on engineering, but I hope that I have also developed sufficient groundwork to facilitate wrestling, in future papers, with the nitty-gritty detail of seeking shalom in and through our daily work as engineers.

8.0 Endnotes


[18] Question and Answer 1 from the *Westminster Shorter Catechism*.


[22] Garber, p. 87.


Safety and Its Ethical Challenges for the Christian Engineer in a Technological Society

by Anthony C. Comer*

Introduction

In every major corporation safety is a high priority and corporate policy statements stress the company’s commitment to keep people and the environment safe. For example:

“... we believe that it is possible to obtain the energy the world needs while also protecting people and the environment.” [ExxonMobil Corporation]

“Quality and safety are part of our very foundation. Safety is something we will never compromise.” [General Motors Corporation]

“...we’re committed to supporting our employees through systems and policies that foster open communication, maintain privacy, and assure health and safety.” [General Electric Corporation]

Although safety is a high priority, it comes at a cost. Corporations are in business to make profits by providing quality products and services for consumers at affordable prices. Engineers of these corporations are constantly challenged to find new ways of doing things in order to reduce operating expenses in a competitive global economy. Companies must keep pace with the latest technological innovation or face the prospect of going out of business. Constant economic pressures put engineers in positions to make tough decisions about where to cut costs. When safety is compromised for economic reasons or any other reason, people and the environment are at risk. Ideally, it would be best to make safety decisions independent of all cost cutting options. But sometimes safety and profits become mutually exclusive. In other words, if corporations take all the necessary safety precautions they would not be able to remain profitable and stay in business. However, if the company provides many good paying jobs and enables families in the community to rise to a higher standard of living, then an ethical dilemma

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exists. Does the community suffer with unemployment and a lower standard of living or does it accept a higher safety risk to the people and the environment? In addition, do all the people share the risk equally or does one segment of the population bear a greater safety risk? For the Christian engineer, the answer to these ethical questions may be different and rise to a higher standard than that required by a corporation’s code of ethics. A Christian engineer motivated by faith in God and acting on biblical principles will often reach different conclusions from those operating strictly from a corporate business model based on maximizing profits. This paper will explore some of the ethical challenges related to safety for the Christian engineer and propose strategies to help shape ethical safety standards for the future.

Safety – Defined

Safety is an ever present concern in everyday life. People want to be protected from things that would harm them or those they love. Wester’s dictionary defines safety as the state of being free from harm or danger; but no environment is totally safe. There is always some element of risk in every situation and the challenge one must face is to determine an acceptable level of risk (Manuele, 2013). Others have also defined safety in relative terms (Gloss & Wardle, 1984). Acceptable risk is a measure of the degree to which one is willing to be exposed to injury or harm and is determined by national safety boards and engineering societies. The American Society of Safety Engineers (ASSE), established in 1911, is an organization made up of professionals in a broad range of fields across the globe dedicated to occupational safety, health and environmental concerns. ASSE helps to establish industry safety standards and provide professional development to its members. Another organization involved in establishing industry standards is the American National Standards Institute (ANSI) which was formed in 1918. ANSI has representatives from several engineering societies, government agencies and
other organizations. The engineering societies include the Institute of Electrical and Electronic Engineers (IEEE), the American Institute of Mining and Metallurgical Engineers (AIME), The American Society of Mechanical Engineers (ASME), and the American Society of Civil Engineers (ASCE). ASSE/ANSI standards cover a broad range of procedures across all industries including respiratory protection, personal protection equipment (PPE), and fall protection/restraint. The Occupational Safety and Health Administration (OSHA) is the governmental agency responsible for enforcing safety standards in the workplace. Through safe design standards (ANSI/ASSE Z590.3) and adherence to management of change (MOC), people, property and the environment are deemed safe according to accepted risks. These accepted risks are based on the likelihood and severity of unsafe acts or situations.

Companies conduct safety audits and establish safety protocols to minimize risk. Usually these audits don’t consider remote possibilities like the terrorist attack on the world trade center towers that fell on September 11, 2001. However, since that attack, future tower designs will have to take this scenario into account and may result in enhanced safety design features. Once an event such as this occurs, it raises the probability of occurrence. Risks can be measured quantitatively or qualitatively. Quantitative analysis generally uses computer models such as the cost of safety model described by Hallowell (Hallowell, 2011). A qualitative analysis is more common and involves risk assessment matrices (Hansen, 2000). Implementing more safety protocols reduces costs of injuries but may increase costs in other categories. Generally, safety costs can run from 1 to 15% of project costs and consequently can affect the level of risk a company is willing to take (Hallowell, 2011). Safety is only one of several topics impacted by codes of ethics. To better understand ethical challenges for engineers one needs to understand ethical theory as it relates to the engineering profession.
**Engineering Ethics**

Ethical behavior by a professional is typically defined as actions that conform to a standard of conduct. Engineering ethics is a specialized field of applied ethics relating to the field of engineering and governed by the code of ethics established by engineering societies and professional organizations. Usually this standard is concerned with the health, safety, and welfare of the general population. All the professional engineering societies have a professional code of conduct which addresses ethical behavior for its members. Ethical theory is important because it can help when applying biblical principles to our ever-changing technological society (Holmes, 2007). Many ethical theories have been proposed but the ones most applicable to professional real-life situations are Utilitarianism, Deontology, and Virtue Ethics (Martin & Schinzinger, 1996). Utilitarianism is based on the greatest good for the greatest number of people. However, this theory can fall short if the good of the greatest number of people results in discrimination against those in the minority. Utilitarianism lacks a principle of equity. Deontology (duty ethics) does not focus so much on the consequences or intentions of one’s actions but rather seeks moral behavior based on mutual respect and generally accepted principles regardless if one is happy or not. Virtue ethics looks at the character of individuals which is something that can’t be taught but must be embraced by the individual. A person can grow in character by praying to God, reading God’s word, and serving in the church and community. Virtue ethics best supports the premise that Christian engineers have the greatest potential to impact codes of ethics and thereby raise them to a higher level.

On the backdrop of the Gulf oil spill in 2010 and the San Francisco Bay Area bridge collapse in 1989, some codes of conduct have been revised reflecting how much ethical behavior
is dominating the professional conversation within the last few decades (Code of Professional Conduct, 2012). Ethical standards include things like being honest, respectful, non-discriminatory, law abiding, and protecting people, property and the environment.

This emphasis on ethics has caused some to question how well engineering graduates are prepared to face the ethical challenges in the engineering profession. Following the Wall Street financial crisis in 2008, schools of business considered how they could better prepare graduates for more ethical behavior. Harvard Business School initiated a program that incorporates more courses on ethics into their MBA program (Burge, 2010). The Accreditation Board for Engineering and Technology (ABET) accredits programs at colleges and universities around the world. All ABET accredited engineering programs are required to incorporate ethics into the curriculum.

The Fundamentals of Engineering (FE) exam and the Principles and Practice of Engineering (PE) exam, which are professional licensure exams, both contain ethics questions but there is not enough coverage on ethics to adequately measure an engineer’s knowledge of the subject. Even if there were enough coverage, scoring well on a standardized test is not a predictor of future ethical behavior (Burge, 2010). However, keeping ethical decision-making in the minds of engineering graduates will improve overall industrial safety performance.

Baylor University’s undergraduate engineering program not only includes a course on ethics but as a Christian institution is also offers two religion classes, “The Christian Scriptures” and “The Christian Heritage. These classes should reinforce the ethical objectives in the ABET criterion as well as the mission of the university (Eisenbarth & Treuren, 2004). The Padnos School of Engineering (PSE) at Grand Valley State University in Michigan is making strides to incorporate ethics into more than just one ethics class for their academic program. They
proposed co-ops and service projects throughout the undergraduate program in an attempt to move beyond ethical decision making to a way of life for their students (Fleishmann, 2004).

Christian colleges and universities are in the best position to raise the ethical consciousness of its engineering students because 1) most of the faculty and staff are Christian, 2) the core curriculum incorporates biblical based education, and 3) worship and faith-based activities are woven throughout the weekly experiences of the students. The engineering programs at these faith-based institutions must meet both the ethical requirements of ABET as well as those of the institution. Ermer has concluded that both requirements are necessary for successful ethical decision making (Ermer, 2008). Christian ethics, however, go beyond the requirements of ABET, professional engineering societies and many corporations because they are based on biblical principles. The next section presents a few biblical references that support this higher standard for Christians in regards to safety.

What the Bible Says1

In Matthew 22:38, Jesus said, “… love your neighbor as yourself”. This is the second greatest commandments in the Bible. This scripture goes beyond secular codes of ethics regarding the safety of the general population and looks at the highest level of safety concern, which is love. For Christian engineers, the motive for general safety is to honor God and to love one another, while secular codes of ethics are often based on maintaining a public image and managing corporate profits. These contrasting positions can lead to significantly different outcomes for engineering designs and operations.

1 All scripture references are from the New International Version of the Bible.
One of the Ten Commandments is “Do not murder”. However, Jesus said just to be angry without cause was equal to murder in His eyes (Matthew 5:22). No federal or state law would convict someone of murder just for being angry, but a Christian should understand that loving his fellowman is not just refraining from murder but rather it starts with the intentions of the heart. Consequently, it could be said that societal ethical standards do not rise to the higher standard that is required for Christians and particularly Christian engineers.

In another instance with regard to loving your neighbor (Luke 10: 25-37), Jesus was asked “… who is my neighbor?” He replied by telling the parable of the good Samaritan who helped a wounded stranger who was left for dead on the side of the road. As Christians, we are our brother’s keeper and we must get involved in the lives of others for their safety and well-being. We don’t have the option to be a bystander. The Christian’s care and protection of others not only extends to those who have been harmed but also to prevent injury to others if we know they are in harm’s way. In Exodus 21:28-29, God holds owners responsible for the harm their animals cause to others when they know the animals have a violent disposition. Likewise, landowners are instructed not to harvest all of their crops but to leave some for the poor and the alien to eat (Leviticus 23:22). This shows the responsibility Christians have in business (harvesting) to not just make money but to care for the welfare of others.

The Bible also speaks to the Christian’s responsibility to protect the environment. One place this can be found is in God’s instruction to Adam in the Garden of Eden.

“The Lord God took the man [Adam] and put him in the Garden of Eden to work it and take care of it.” (Genesis 2:15)

Adam’s charge to take care of the garden parallels the Christian’s responsibility to take care of the planet we live on. The garden required work so that it would produce food for Adam and his family. This shows that protecting the environment is not only important because God
commanded it, but it is also necessary for human survival. Several Biblical texts are related to engineering safety design.

“When you build a new house, make a parapet around your roof so that you may not bring the guilt of bloodshed on your house if someone falls from the roof” (Deuteronomy 22:8)

This is an example of the safety regulations required for new residential construction. A parapet can be a short wall that prevents accidental falls from a roof. As Christian engineers, this same level of concern for others must be exhibited in construction project designs.

“But everyone who hears these words of mine [Jesus] and does not put them into practice is like a foolish man who built his house on sand. The rain came down, the streams rose, and the winds blew and beat against that house, and it fell with a great crash.” (Matthew 7:26-27)

Here we see that structures must be built on firm foundations in order to withstand occasional severe weather conditions. Digging deeper into the soil to reach bedrock takes longer and is more expensive but taking shortcuts is unsafe, unethical and foolish.

“Come, let us [all of mankind] build ourselves a city, with a tower that reaches to the heavens, so that we may make a name for ourselves and not be scattered over the face of the whole earth.” (Genesis 11:1-4)

This scripture makes reference to the tower of Babel which was under construction until God put a stop to it. This was an ethics problem because the people wanted to make a name for themselves, being both proud and egotistical. This led to sin because man felt he didn’t need God, an attitude that is the ultimate safety risk.

When it comes to engineering safety design, there is no one greater than God. God engineered animals to protect themselves in many different ways. Some animals release smells (skunk), some have hard protective shells (turtle & armadillo), some can camouflage themselves (chameleon), and others are strong and have long claws and sharp teeth (lion, bear). Even human cells have protective designs that defend against viruses. All these biblical references and
engineering designs of God confirm that the Christian engineer is in the best position for making ethical decisions in safe designs and performance practices based on his or her knowledge and level of faith.

**Common Ethical Challenges Relating to Safety**

Ethical challenges relating to safety are not limited to the engineering profession but are common throughout our society. For example, police officers and firemen risk their own personal safety, to protect their communities. Soldiers risk their lives for the safety of the nation knowing that some lives must be sacrificed for the overall greater good. In John 15:13 Jesus says “Greater love has no one than this, that he lay down his life for his friends”. Jesus sacrificed His life for us so that we would be safe from hell. He admonishes those who desire to be His disciples to do likewise and risk their personal safety for others because they love them. Service in the military is generally voluntary and soldiers are compensated with wages and other benefits but occasionally a draft is instituted where citizens are forced to serve. But a soldier serving out of a sense of faith and loyalty to God and country will fight a better fight than someone who serves primarily for the financial benefits. Jesus says:

> “I am the good shepherd. The good shepherd lays down his life for the sheep. The hired hand is not the shepherd and does not own the sheep. So when he sees the wolf coming, he abandons the sheep and runs away. Then the wolf attacks the flock and scatters it. The man runs away because he is a hired hand and cares nothing for the sheep”. (John 10:11-13)

We assume some level of risk to our families and ourselves when we travel in cars or planes, walk along the street, use electrical appliances, and cook on hot stoves. Any firearms we keep in our homes must be kept away from small children to avoid accidental shootings. The

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2 The ethical nature of compulsory military service has been challenged on a Biblical basis (Robbins, 1980).
foods and beverages we consume at our homes or at restaurants we hope will not poison us. We hope the cell phone we use is not emitting dangerous levels of radiation to our bodies or that the sun’s rays will not result in skin cancer to our families from overexposure. Most of these risks are deemed acceptable because of the small probability of injury. But there are other activities with higher probabilities that may raise ethical concerns. For example, in contact sports such as football, hockey, and boxing, concussions and other injuries are significant. Some parents are willing to allow their children to participate in these sports and other recreational and social activities even though the probability of serious injury may be high. This poses ethical concerns when we consider a parent’s obligation is to protect their children.

There is much less of an ethical dilemma when it comes to personal health risks people take because of bad habits such as overeating, smoking, excessive drinking of alcoholic beverages, and illegal drug abuse. Our bodies are the temple of the Lord. “If anyone destroys God’s temple, God will destroy that person; for God’s temple is sacred, and you together are that temple.” (I Corinthians 3:16). These are just some of the many examples which highlight the inherent safety risks associated with almost every aspect of everyday life. Nevertheless, applying biblical principles will result in better overall health and safety.

**Technology’s Influence on Ethical Behavior**

The explosion of Wi-Fi presents potential safety concerns to society through the use of social media. This danger can take many forms including exposure to excessive violence, inappropriate language, pornography, privacy infractions, and cyberbullying (Moreno, 2013). Some feel that a significant problem with our society is that we are dominated by technology. The many advances in technology are eroding the moral fiber of our existence (Ellul, 1964). Others describe technology as a dangerous enemy which has the capacity to destroy our way of
life instead of enhancing it (Postman, 1993) (Ferre, 1995). For example, people don’t talk face to face as much anymore because they can communicate through social media outlets such as Facebook and Twitter. Consequently, future generations have less of an opportunity to develop good interpersonal communication skills which hinders overall societal well-being. Poor communication can lead to conflict and conflict can lead to safety concerns. Granted, technology may require more diligence from family members, and especially parents, to spend quality time with one another. Nevertheless, parents focused on raising their children according to God’s word, will take whatever measures are necessary to put their children’s welfare ahead of the pressures of society and culture.

Another example of safety concerns with the use of technology is the increase in automobile injuries and fatalities due to cellular phone use and texting while driving. People can be so attached to their “smart phones” that they find it difficult to refrain from using them while driving. Most states have enacted legislation to make it illegal to text while driving. Although technology upgrades allow hands-free cell phone use while driving, this does not necessarily improve safety. Instead, drivers can multitask more conveniently, and distractions to driving persist.

Society has benefited from advances in technology as well. The internet provides a wealth of knowledge to anyone who connects to it. Through social media we can stay connected with friends and family. Often news is available on the internet before it is reported on local or national television. The widespread use of cell phones has helped expose the violence that Blacks and other minority groups have historically experienced from law enforcement by capturing the shooting of unarmed citizens on video. Self-driving cars are in production that will help avoid crashes, park your car, and take you where you want to go. This has tremendous
benefit for senior citizens who can’t drive. It would seem that with most new technologies there are benefits as well as liabilities and that the safety risk is not in the technology but rather in the user of the technology.

**Safe Engineering Design**

Safe design or operation of equipment is generally not an individual engineer’s responsibility. It typically involves teams, groups, organizations and corporations. Engineering designs involve many components so it is not as simple to relegate responsibility for safety to one individual as opposed to a group of individuals or a system or a company’s policy. This has been described as engineers’ ethics (individual) versus engineering ethics (corporate) (Basart & Serra, 2013). For instance, an oil refinery imposes cuts in the operating and engineering workforce due to low projected refining margins. Also, the maintenance budget is drastically cut as well. Consequently, critical equipment fails more frequently and the operators that are still employed are required to work more overtime and longer shifts. Eventually a tired operator is injured when she is splashed with acid from a leaking seal on a spare pump. Although it would be easy to blame the operator for this accident, there are several other things that could have contributed to this injury as well, including:

- Poor equipment maintenance
- Improperly installed pump seal
- Operator allowed to work too many hours
- Company policy to reduce the workforce
- Insufficient engineering supervision
When all of these contributing factors are considered we can see that keeping people safe is everyone’s responsibility and ethical considerations factor into all of them.

Case Histories

One of the worst environmental disasters in the history of the country occurred in the Gulf of Mexico from an oil spill in 2010 where a mobile offshore drilling unit exploded killing eleven men. Industrial giant BP Oil was found guilty of making unethical decisions and violating many safety regulations. These poor engineering and management decisions were made to save the company costs in the short term by deviating from established safe protocols (Hoke, 2013).

An example of infringing on the public safety from corporate unethical behavior is seen in the case of Volkswagen. In September of 2015, the Environmental Pollution Agency (EPA) determined that the exhaust from many Volkswagen diesel engine vehicles contained higher amounts of nitrogen dioxide (NO₂) than was reported. Pollution control devices on these vehicles had been engineered to deceptively report lower NO₂ emissions than were actually realized. This was done to appear to comply with the Clean Air Act (Andracsek, 2016).

In November 1984 in San Juanico, Mexico (near Mexico City) a liquefied petroleum gas (LPG) storage tank farm exploded and burned, killing over 500 people and injuring over 4,000, making this one of the worst industrial disasters in history. This incident was made worse because large residential areas were developed within a little over 100 meters from the industrial site (Kletz, 1988). Engineers and others should not permit residential communities to be located close to hazardous industrial sites.
Another ethical dilemma for engineers is the tendency to locate landfills near low income or minority communities. There is concern that these landfills may contribute to groundwater contamination and ultimately impact the health and safety of the community. Studies conducted in North Carolina show that solid waste facilities across the state were 2.8 times more likely to be located near predominately minority communities. Also, the homes in the vicinity of these facilities were 1.5 times more likely to be less than $60,000 in value versus homes greater than or equal to $100,000 (Norton, et al., 2007). In each of these cases, unethical behavior would be minimized if cost minimization was not the objective but rather glorifying God and loving our neighbor as ourselves.

**Ethical Challenges Faced by Different Engineering Disciplines**

*Biomedical Engineering*

Biomedical engineering deals with the application of engineering principles to biological sciences. Here engineers are confronted with the dilemma of how best to allocate limited resources to deal with the myriad of diseases and health concerns we face in the world. For example, cancer, heart disease, and diabetes to name a few all compete for research funding and the ethics of how these dollars are allocated is a dilemma. If engineers are more interested in their careers than the greater good to society, they will have a narrower view of how best to allocate resources. Imagine the impact to one’s personal career if a cure for cancer was found and research institutions and professionals were no longer needed. A case can be made that it is in the best interest of these institutions not to be successful because it would put many people out of work or require them to develop new skills. Equitable solutions have their best chance when
selfish motives are not the primary objective. The value to society as the controlling factor is more equitable and has been discussed by others (Wertheimer, 2015).

*Software Engineering*

Software engineering decisions have not normally been driven by safety concerns as much as economics. However, safety is taking on a more prominent role with concerns about cyber security even though making software systems secure is difficult to do (Bowen, 2000). The engineering standards required by other established disciplines such as electrical and mechanical engineers have not been required of computer engineers. The ethical implications will require raising the level of competency for engineers of critical systems. Some have even suggested that software engineers be licensed (Knight & Leveson, 2002). Because of the high level of web-based internet traffic, these critical systems include social media, financial institutions, patient medical information, and national security information. The safety and ethical demands for software and computer engineers will require more training and communication with clients to understand all the ethical implications. In fact, to truly address the ethical implications for the future, engineers should be engaged in lifelong learning that comes with experience (McBride, 2012). If a Christian perspective is not at the center of these discussions many implications may not be considered.

*Genetic Engineering*

According to Webster’s dictionary, genetic engineering is the science associated with intentional manipulation of genes of living organisms for the purpose of altering the organism’s characteristics. In vitro fertilization has been practiced for many years but some evidence shows that a significant rate of birth defects can be correlated with the procedure. This raises the issue
of whether or not the procedure is worth the risk based on the emotional motive which is to have a child. The safety of the unborn child becomes an important question for the Christian engineer to answer. According to the Bible, Adam and Eve were to be fruitful and multiply and replenish the earth by having children naturally through sexual intercourse. In vitro fertilization permits childbearing without using the mother’s own egg or even the husband’s sperm. Some argue that this is not ethical since it is not the way God originally intended. Genetic enhancement has also been questioned because the motive is often not based on the safety of the person (Deane-Drummond, 2005). Do we tamper with the physical attributes of a person such as size or intelligence to result in a so-called “superior” person? Again, this alteration from the natural birth process raises ethical challenges for the Christian engineer. Some may argue that genetic engineering which is designed to extend life or improve the quality of life such as the case with stem cell research to grow replacement organs or limbs is justified. But this is clouded by the fact that stem cells are often acquired from live embryos which would be killed in order to extract the stem cells (Davis, 2004). Here again engineers guided by Christian principles and focused on the general safety and welfare of individuals will make better decisions regarding genetic engineering.

*Other Engineering Disciplines*

When a consulting engineer conducts a traffic impact study for a proposed shopping area, he has several perspectives upon which to base this study: 1) the perspective of the land developer, 2) the city and other local governments, or 3) the general safety and welfare of the community. These perspectives should not be mutually exclusive since everyone has a moral obligation to protect the general safety and welfare of the community. But differing perspectives can occasionally put engineers in an ethical dilemma (Ethics Form, 2011).
Clean fuels initiatives are helping to shift energy sources to renewable types and away from fossil fuels such as coal and crude oil. Coal power is getting more expensive and coal reserves are diminishing. However, health concerns in this industry (black lung disease, mining safety) can be compromised when there is a greater need for working class jobs that pay higher wages. One fossil fuel that is gaining attention is shale oil. Shale uses fracking technology which has a smaller footprint than other fossil fuel recovery technologies. For the Christian petroleum engineer, the challenge is to design and operate processes to extract shale oil with minimal risk to people and the environment. Once the shale oil is brought to the surface, the practitioners of other engineering disciplines such as chemical engineering, design and operate the processes necessary to refine the shale and safely get products to consumers. Two primary concerns with fracking are global warming due to the release of methane gas into the air and earthquakes (Tucker & Tonder, 2015).

Civil engineers are involved in the design and construction of structures including roads, bridges, and buildings. Changes to designs which deviate from established safety rules must be compensated for and communicated to all parties involved in the original design or previous design changes (Hurol, 2014).

All engineering disciplines face ethical challenges related to safety and though the types of scenarios may be unique, Christian engineers applying biblical principles have the best chance of determining the most ethical solutions.

Conclusions

Safety for people and the environment will continue to be most important for corporations around the world and particularly here in the United States. Technology innovations will continue to present unique challenges to engineers on how to best produce products and
services without sacrificing safety. Economic pressures that corporations face to maximize profits and meet or exceed budget constraints constantly challenge engineers to develop ethical solutions regarding safety. Safety standards, while generally good, may unethically do more harm to poor or predominately minority communities. Engineers who are guided only by such standards are more likely to choose the quickest and lowest cost solution rather than safer, costlier options. Christian engineers are in the best position to make decisions based on biblical principles according to the word of God. In some cases, these decisions will go beyond existing safety standards established by corporations and government regulations. It will require motivations based on love and not maximizing profits.

This will require courage for the Christian engineer to stand against corporate culture and work to change policy that lines up with God’s word. Choosing to stand for what is ethically right when those in authority are opposed can result in losing one’s job (Rebbitt, 2013), but Christian engineers must not walk in fear nor be overcome with greed for wealth and power. It would be good to remember that God is our provider and protector and as the Psalmist said “In God have I put my trust: I will not be afraid what man can do unto me.” (Psalm 56:11 KJV). Christians must also remember that they have a responsibility to love God and their fellowman. The answer to an age-old question, “Am I my brother’s keeper?” is a resounding yes! Christians cannot delegate their responsibilities to others who will not maintain the level of integrity that God requires nor can they turn and look the other way. This would be a violation of their moral conscience and make them technical prostitutes (McIntyre & Bube, 1975).

The following strategies are suggested to improve ethical safety standards:

1) Incorporate objective functions into safety policy and procedures that provide a full range of
safe and ethical options for people and the environment, making sure that cost is only a secondary consideration.

2) Include persons that will be exposed to the safety risk in the decision-making process and give them significant authority.

3) Require company executives to be subjected to the same hazardous conditions which they approve for employees, customers, and the general public.

   Colleges and universities should continue to incorporate ethics classes in their education programs. Christian colleges and universities have the advantage in that they can integrate faith and learning in every aspect of college life for their students.

   The level of acceptable risk that Christian engineers apply in their work will not always be an easy decision but it requires engineers to put themselves in the shoes of those affected by their decisions. “So in everything, do to others what you would have them do to you, for this sums up the Law and the Prophets” (Matthew 7:12). If for example, a design engineer is willing to expose herself to the same risks as anyone else when using a product, then that product has a good probability of being acceptable to others. Unfortunately, in far too many cases, those in positions of authority who make the final decisions do not have to personally subject themselves to the same safety risk.

   The challenges for the Christian engineer in this technological society may be great. But the God whom they serve is greater. Therefore, it is their calling to meet this challenge with boldness and courage so that men might see their good (safe and ethical) work practices and glorify God in heaven.
References

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Digital Media Technology and Your Spiritual Life:
An Uneasy Alliance

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Abstract:
Digital media technology has become a part of our everyday lives, filling a substantial portion of the constructive minutes and hours of our days. This technology was created by engineers, and is being further perfected by engineers with each successive generation. As engineers, should we not be at the forefront of learning how this technology is changing our culture and be leaders in teaching responsible use?

Science has documented that technology use is changing how our brain functions. Its use creates new neural pathways and causes cognitive overload in the area of our brain that controls decision-making, impulse control, attention, focus and short-term memory – reducing those functions. Our digital media technology use encourages bad habits that affect our focus, productivity, busyness, reading skills and our personal interactions.

These changes in our brain processing also affect our spiritual life. Their distracting nature affects spiritual meditation, prayer and contemplation. The changes in our reading habits affect our study of Scripture, and storing God’s word in our hearts. Changes in how we interact with each other affect worship and fellowship, as well as how we relate to God.

Most people have wandered into using digital media technology without a conscious realization of how it is changing their lives and the function of their brain. As engineers, creators of technology, let’s lead the charge in educating ourselves to build protective walls around our spiritual lives, and educating others to do the same.
practicing the presence of the smartphone than the presence of God. We are much more likely to be tuned into the blessings of convenience, comfort and control than the blessings of God. The Bible admonishes to “work out your own salvation with fear and trembling” (Phil. 2:12) and “be all the more diligent to make [your] calling and election sure” (2 Pet 1:10). It behooves us as Christians to diligently evaluate how our hyper-connected life may detract from the presence of God in our life and the aspects of life He has created us to need for fulfillment. As engineers, creators of technology, should we not be at the forefront of the charge to make sure our digital use doesn’t shut God out of large swathes of our lives? Should we not shoulder the responsibility of educating others how to use our technology responsibly?

We need to step back from the stimulation of our gadgets to observe and understand the brain on technology and destructive behaviors that technology encourages, then contrast these with the disciplines required for a committed Christian life. After evaluating these two facets, if a dichotomy is observed, the last step is finding your way out of technology addiction, back to a thriving spiritual life.

I. The Brain On Technology

As technology changes at a rapid pace, and our devices are out-dated as soon as they are purchased, our amazing God-created brains are able to adapt to this fast-changing world, and accommodate new ways of processing. A landmark study of digital media technology use and the brain was done by Gary Small, a UCLA professor of Psychiatry, in which he performed brain scans of people while they searched the Internet (Carr 120-121). He divided his subjects into two groups – net-savvy and net-naïve. The net-savvy group had been using the internet for years, and the net-naïves had minimal exposure. While net-savvy subjects searched the internet, the dorsolateral prefrontal cortex lit up luminously, indicating high activity in that region of the brain. Net-naïves showed hardly any activity in the dorsolateral prefrontal cortex, although they were also searching the internet during the brain scan. The net-naïve group subsequently spent one hour a day online and six days later were rescanned. Surprisingly, the net-naïve brain scans looked identical to those of the net-savvy – after only six days of a small amount of online activity. Dr. Small’s research reinforced that our brains are amazingly adaptable to accommodate new patterns of behavior and input, an aspect that brain scientists call malleability or plasticity, and he demonstrated that the area of the brain intensely used during engagement with technology is the pre-frontal cortex.

A. Plasticity of the Brain

We used to think the brain was hardwired and unchangeable. Recent discovery of neuroplasticity means that we can alter the neurochemistry of our brain to change beliefs, thoughts, processes and emotions, based on everyday actions and experiences. In the brain, neurons process and transmit information through electrical and chemical signals. Neural pathways are associated with particular actions or behaviors. Every time we think, feel or do something we strengthen these pathways. Habits are well travelled pathways. New thoughts and skills carve out new pathways, repetition and practice strengthens these pathways, forming new habits – like the net-naïve subjects learning to use the internet. Brain plasticity allows us to adapt to using new technology.

The unfortunate side of brain plasticity is that old, unused neural pathways weaken, decay and disappear. The brain is like a muscle, operating on the use it or lose it principle. What should
alarm us about brain plasticity is what we are losing in trade-off for adapting to using technology as we do today. Our ever-increasing engagement with technology is deepening neural pathways that make it difficult to maintain practices that are essential to our soul care.

B. Cognitive Overload in the Prefrontal Cortex

In his brain scans, Dr. Small discovered that the dorsolateral prefrontal cortex is used intensely while online (Carr 120-121). The dorsolateral prefrontal cortex is the seat of decision-making, short-term memory and problem-solving. The prefrontal cortex in general is the seat of impulse control, attention and focus, directing our thoughts and determining priorities. When this area of the brain is overloaded with technology use, its ability to direct other functions is diminished. The cognitive overload in the prefrontal cortex makes it harder to focus, control impulses, make decisions to use our time wisely, and impairs transmission of information from short to long-term memory. It also impairs the problem-solving abilities we engineers pride ourselves in. Dr. Rhodes (100) likens the prefrontal cortex to the air traffic control center of the brain, and states that using technology is like having an air traffic controller with no sleep, trying to handle ten times the traffic that he’s been trained for. The persistent demands of digital life, where we’re bombarded by stimuli and under continual pressure to attend to multiple things at once, overloads the air-traffic control center of our brain. We lose our ability to concentrate, our ability to choose, and our ability to make decisions to effectively manage our mental life.

When the prefrontal cortex is overloaded, decisions come from the amygdala, the involuntary and automatic part of the brain that relies on reflexes, impulses, habits and emotions – rather than what is right and rational (Vohs and Baumeister 49; Rhodes 77-79, 99). When ideas or actions are repeated often enough, they develop deep neural pathways, and our brain releases them to the instinctual amygdala. The automatic routine triggered by pings and beeps on our devices have deeply entrenched neural pathways, that we no longer think about. Overloading the prefrontal cortex by digital media suppresses the conscious, executive function of our brain – to make critical decisions, to be self-aware, reflective, to plan, learn new things, pay attention (Hart and Frejd 192-193). The persistent demands of digital life take away our ability to consciously control our brain and allows the reflexive amygdala to take over the executive control of our brain, meaning that the ingrained technology-response neural pathways take over. We are thus less capable to make decisions to be less distracted by our technology, to focus on what is important, to take time to reflect and set priorities, to pay attention to material we would like to store in long-term memory or to pay attention to the people in front of us. Thus, it is in our best interest to understand what digital media technology use does to our brains and our patterns of life so we can choose how we want to use it.

II. Habits Digital Media Technology Encourages

Rather than the generalities of neural pathway decay and cognitive overload, let’s look at specific habits that technology encourages, keeping in mind the brain functions that interact with and drive these habits. I’ve classified these negative habits into five categories – the always “on” mentality that our portable technology encourages, the multitasking that our multiple screens and devices enable, our habit of filling time with the gaggle of things available on our devices, the changes in our reading habits when we’re skimming through the endless possibilities on our screens, and the changes in our personal relationships that are brokered by on-line services.
A. Always “on”

The portability of our digital media technology has encouraged us to be always “on”, always available. Some employers now expect employees to be reachable 24/7 by email or text. The lines between personal life and professional life have been blurred to the point that many employees think it is perfectly acceptable to check social media at work. Much of our always “on” mentality is self-imposed. Most people admitted to reaching for their smart phone the second they wake up, and checking it last thing before bed. A study done at Nottingham Trent University (Andrews et al.) attempted to quantify our portable media use. They had participants estimate the number of times per day they accessed their smartphones, then installed software on the portable devices to track use. The average estimate of use was 20 to 30 times per day, but the tracking software registered an average of 85 checks per day - over double the participants’ estimates. This is alarming since most of the staggering statistics on digital media use are based on self-reporting, and thus are sorely underestimated. It is also alarming that we have little awareness of the frequency that we check our portable technology. 55% of the recorded smartphone interactions were less than 30 seconds, indicating a subconscious checking for new messages or reacting to notifications. The study called these “habitual goal-and-reward-based actions.”

“Habitual” is the terminology the study conclusions used. Why are we so attached to our technology? Why do we feel compelled to feed this dragon? Our brain is wired to seek the new. We are looking for the possibility of a great message, new information – even if its trivial, seeking a diversion from unpleasant tasks or avoiding being left behind or missing out. But this behavior is addicting. Every time we get that new information, the brain floods with dopamine, a pleasure drug, which makes us feel good and seek to repeat the activity (Levitin; Hart and Frejd 63). Neural pathways are entrenched with this compulsion to get a dopamine high from checking our devices, and it becomes an automatic response. As we develop tolerance with repeated overstimulation, the dosage has to be increased to achieve the original high, and we lose our ability to enjoy the simple pleasures in life.

When we’re always “on”, we are controlled by habit rather than conscious decision. We become sleep deprived, our tranquility and ability to enjoy simple things decreases and stress hormones increase. Neural pathways that support calm, linear thought decay.

B. MultiTasking

All our technological devices are supposed to save us time, and give instant access to people and information. However, we rarely find the space to really think about how we pass our time. Pressured to prioritize efficiency, we work with multiple windows open, and audible notifications turned on - so we can attend to e-mails, texts, twitter feeds and social media alerts the minute they come in. Streamed music hums through the computer speakers, and a Bluetooth phone connection hangs on our ear, while we carry on an instant message conversation. How much are we really getting done?

There are myriads of studies done on multitasking (Rosen 106-111, 207; Carr 129-134, 140-142; Rockwell and Singleton; Hembrook and Gay; Bergen et al.; Foerde et al.; Byyny; Hart and Frejd 74-85; UCLA), and we are not as good at it as we think we are. Research shows that multitasking increases errors and decreases the ability to retain information, thus lowering student
performance and decreasing productivity. It also damages our cognitive ability to concentrate and focus.

ERROR: A Michigan State study (Henion et al.) finds that interruptions lasting less than 3 seconds doubles the rate of errors in simple tasks. Just glancing away from what you’re working on dumps the short-term memory. A Florida State University study (Stothart et al.) found that notifications alone were detrimental to attention demanding tasks, even when participants ignored the notification and continued working on the task. “Task-irrelevant thoughts, even in cases when the individual appears to be attending to the task at hand, disrupt performance on a wide range of tasks.”

RETAIN INFO: Research on multitasking shows that performance always goes down with added tasks. Studies have found that student performance decreases by 1/3 while multi-tasking compared with sequential tasking, comparative to drunk drivers (Hart and Frejd 81). E-mail distraction degrades mental functioning equivalent to a 10 point drop in IQ – equivalent to losing a night of sleep or twice the mental impairment of marijuana users (Bregman, “Stop Multitasking”). With so many inputs coming in, our short-term memory is dumped constantly and there is no hope for the slower process of transferring information into long-term memory – i.e. “learning” the material.

PRODUCTIVITY: Workers distracted by email and phone calls usually take ½ hour to get back to their original task. 28% of a typical workers day is taken up by interruptions and recovery time (Jackson, “Your Attention, Please”). Other studies show if we’re juggling 2 tasks, we lose 20% of our time. If juggling 3 tasks, we lose ½ of our time (Hart and Frejd 81-82).

INCREASED DISTRACTABILITY/UNABLE TO FOCUS: The more you multitask, the more distractible you become. Heavy multitasking destroys our will and ability to resist distractions. Researchers at Stanford (Ophir and Wagner) found that heavy multitaskers are not able to filter out what’s relevant to the current goal and are slowed down by irrelevant information. Bombarded with several streams of electronic information they do not pay attention, control their memory or switch from one job to another as well as mon taskers. “Intensive multitaskers are suckers for irrelevancy, everything distracts them” (Carr 142).

Why do we multitask? Some people believe they are good at multi-tasking, but the afore mentioned research refutes this. Multitaskers have built neural pathways that reinforce this behavior, and brain chemistry can contribute to the habit, also. Multi-tasking causes release of adrenaline, a stress hormone that triggers the body’s fight-or-flight mechanism (Levitin). It provides a sudden burst of energy, increased heart rate and blood pressure, and increased metabolism – what we refer to as an adrenaline rush- a physical feeling of intense excitement and stimulation. However, adrenaline is a stress hormone, and excessive amounts can cause long-term health problems and lead to the loss of short-term memory, affecting our ability to learn.

The cost of multitasking is enormous. The consensus from medical, mental health, brain science and academic research (specialties of referenced authors) is multi-tasking causes attention difficulties, poor decision-making, lack of depth of material, information overload, internet addiction, poor sleep habits, overuse of caffeine, impaired thought processes, reduced cognitive ability, weakened memory, and increased stress. Although multitasking has become our new default mode, monotasking is vital for our brain, and by doing less we’re likely to accomplish more.
C. Filling Time

Technology exacts an incongruous toll. Although it is supposed to save us time, it offers many ways to fill that saved time. In this age of perpetual motion, we wear our busyness as a badge of honor. The moment we’re not doing something, we reach for our devices. The Global Web Index reports 39% of people use social media simply to fill time.

Why? To keep us from boredom? Or silence? Or our own thoughts? To keep us from not being productive? Are we mindlessly following deep neural pathways that automatically respond to pings and beeps? You see people interacting with smart phones and tablets while waiting in lines, sitting on busses, working out at gyms, eating in restaurants, listening in church. What do we have to show for all the time spent pointlessly in the digital world?

We fill our time with frivolous knowledge, not giving our brain the downtime it needs for processing - consolidating information, transferring it to long-term memory, reflection, introspection, creative thought. The brain needs down time to learn and for creative thought to occur (Hart and Frejd 67). Moments that are not filled with anything in particular are vital to our lives. This is when we, mostly subconsciously, make sense of our lives, organize our thoughts, talk to ourselves, listen to our creative brain, listen to God’s whispers. The sad thing is we don’t just lose these quiet moments, we actively throw them away by reaching for our media devices. Our digital habits are making it difficult to reflect, contemplate, and ponder profound truths, all of which are required for an authentic relationship with God and formation as spiritual beings.

D. Changing Reading Habits

The internet has made books accessible in unprecedented ways, but most people are reading less than before the availability of digital books. The internet is changing how we are reading and how our brain processes what we read.

SKIMMING: Digital media is used to manage and store our information, rather than retaining it in our brain’s long-term memory. (We used to remember phone numbers, now we just look them up on our portable devices.) Thus reading online has become a habit of skimming- hurriedly and distractedly looking for the particular piece of information we are after, rather than trying to comprehend the topic and understand the context of the content. This is the thrust of Mark Bauerlein’s book, *The Dumbest Generation: How the Digital Age Stupefies Young Americans and Jeopardizes Our Future (Or, Don’t Trust Anyone Under 30)*. We have knowledge at our fingertips, but wisdom evades us.

COGNITIVE OVERLOAD: Not only does online reading encourage cursory reading - a process of elimination rather than deep engagement, it also has the tendency for the cognitive overload we discussed earlier. On-line reading is a concentration-fragmenting interruption system with its tabs, multiple windows and hyperlinks. The torrent of information causes high brain activity (Fig. 1) which detracts from comprehension and restricts transfer to long-term memory. Reading print, on the other hand, under-stimulates the senses, allowing for a calm mind (Fig. 1) and deep thinking. The information comes at you slow enough for your brain to transfer information into long-term memory. Eye movements are different for reading print vs. digital. When reading print, eye movement is left to right, with a careful perusal of words. On a digital page, eyes move in an “F” pattern. Initially they move across the top of the digital page, then move down the page, occasionally following a line partially across. The eyes are scanning quickly to sort & store
bits of information rather than a more complex process of comprehension (Rhodes 22).
Inevitably, through digitization we are losing our ability to learn and retain information, to reflect and think deeply. This is the argument of Carr’s book *The Shallows: What the Internet is Doing to Our Brains*.

The more we train our neural pathways for this type of cursory reading, the more we lose the neural pathways and ability for deep, slow-reading engagement, where we’re trying to understand and engage with the content. If we settle for superficial learning and shallow thinking, how will we ever mine truths from the Bible? How will we hide God’s word in our hearts? It is easy to blindly settle for “the shallows” where we master the art of managing information but fail to experience the joy of discovering truth.

E. Changing Relationships

Relationships have increasingly become mediated through digital technology. Our internet access and social media apps have made it easy to connect with more old friends and family, and make acquaintances we never would have made otherwise. Online relationships are efficient, convenient and we can multi-task our way through them. We respond to messages when it is convenient for us and we don’t have to give our undivided attention to anyone. Unfortunately, this kind of interaction develops shallow relationships. Sherry Turkle at MIT has done foundational research on how our relationships have been effected by our digital technology. Our media-mediated conversations are devoid of emotions, we tend to treat people as units, and we carefully compose and edit who we want to be online.

**DEVOID OF EMOTIONS:** 60 to 90% of our emotions are communicated in non-verbal ways – expressons on our face, eye contact, physical touch, inflections in our voice, body language, …. Written text is devoid of these emotional cues. We use emoticons and caps to try to capture some emotion, but digital engagement is an emotionally sterile structure which doesn’t feed our souls. Communications are superficial and brief. We tend to be careless with our words since we don’t
see the hurt at the receiving end. Our online friends are not the people that attend our family graduations or funerals. It is in-person relationships that share these emotional high and low points in our lives. As our neural circuits adapt to on-line relationships, our people skills diminish and we lose emotional aptitudes like empathy (Lin).

TREAT INDIVIDUALS AS UNITS OR INVISIBLE OR PAUSIBLE: It used to be that we would write a letter to a friend, sharing privileged information, personal reflections and feelings that gave depth to the relationship. We no longer have hierarchies of friends, groups of people that we share more intimate parts of ourselves with. We tweet or post the same information to close friends and barely mere acquaintances. It is hurtful to hear of engagements, weddings, or promotions of good friends and relatives over social media – along with the rest of the world. It robs relationships of the closeness and specialness when you are just lumped in and addressed as a unit. Probably even worse is when we use our technology to treat people as invisible. When people answer their phones in public restrooms and carry on private conversations in hearing of others, they are treating the people around them as invisible, non-existent. We also tend to treat people in our presence as pausible, elevating the presence and attention of absent people above those physically present. Digital interruptions supersede real time conversations.

RECREATE OURSELVES ONLINE: Our online persona is a created image, not our genuine self. When we use our technology to communicate, we are careful how we craft ourselves and our responses. Responses to people are premeditated, thought out, edited and revised to make us look as witty or intelligent as possible. We don’t share gut responses like we are forced to in real person-to-person conversations, where our real selves are revealed. It is also easier to control what people know about you and your short-comings when conversations stay remote. On social media we carefully create our online persona as a performer on a stage. We try to impress and rouse applause (likes, shares, favorites, retweets) and live the fantasy of who we want to be. We don’t form deep, heart-felt connections with people when we are performing.

Why do we resort to these kinds of interactions? Because real, in-person relationships are messy, untidy and inconvenient. Friends have unscheduled and unpleasant needs which don’t fit neatly into our tidy, efficient lives. They have turbulent emotions and need us to listen and spend time. Superficial snippets of information are much easier to deal with than the messy complexities of relating in real time. Online we can be efficient with our time and don’t have to give anyone our undivided attention. It is much easier to post an upbeat encouragement via digital media, then sit quietly with a hurting friend. These cursory, superficial, convenient online connections leave us feeling lonely, though, as these are not the type of relationships that God has designed us for. We are designed to be with people in person, to hear their voice, see their face and know their heart.

III. ELEMENTS OF AN EFFECTIVE SPIRITUAL LIFE

The rise of apps, social media, and ubiquitous digital technology is changing the way many of the world’s two billion Christians practice their Christianity and worship. Our unchallenged social-media habits pose one of the most pressing discipleship challenges in the church today (Reinke). Too much digital engagement keeps us from showing up for life, from being mindful of God and living in the present moment. Digital distractions make us forget that we live in the presence of God, leading to a loss in worldview. Loss of a worldview means it’s harder to see how things are connected to wholes. We experience the world as fragments, rather than from a central worldview that orients our lives to everything else. We need to ponder how the things we do and the way we live actually matters in the grand scheme of things.
So, what does an authentic, vibrant spiritual life look like? - One that is operating from a God-centered worldview? Richard Foster (“Celebration of Discipline”) set forth the following set of spiritual disciplines in 1978 and they have withstood the test of time as his book is still in print. His skeleton of spiritual disciplines was very influential in my life, as I established my worldview and pattern of life for spiritual growth.

Inward Disciplines
- Meditation
- Prayer
- Fasting
- Study

Outward Disciplines
- Simplicity
- Solitude
- Submission
- Service

Corporate Disciplines
- Confession
- Worship
- Guidance
- Celebration

While not wanting to establish these as an exclusive or comprehensive list of disciplines for real spiritual growth, it gives us a starting point to look at our technology use. This list, and probably your list of essential spiritual practices includes disciplines that need uninterrupted time, stillness and focus, comprehension reading skills and relationship skills.

A. Uninterrupted Time, Stillness, Focus

The disciplines of meditation, prayer, fasting, study, solitude and submission are the antithesis of the habits that technology encourages. They require uninterrupted time – instead of our always “on” mentality where we’re always ready and wanting to be disrupted, stillness – instead of always filling our time with frivolous newness so readily available at our fingertips, and focus – the complete opposite of our multitasking culture. Focused intentionality, focusing on God’s word, His laws, statutes, precepts enables us to create “the emotional and spiritual space that allows God to construct an inner sanctuary in the heart” (Foster, “Sanctuary” 26) We need to learn to stop, linger, focus, and reflect in order to “know” God - not merely to know things about Him, such as His character, but also to experience His presence and power, and to be transformed by Him. We also need to stop and listen to hear His whispers amongst the whirlwinds of busyness, the earthquakes of urgent demands and the fires of emergent emergencies (1 Kings 19:11-13). We must practice the habit of resonance - pondering how the things we do and the way we live actually matters in the grand scheme of things. We miss this when cyber-time is our perpetual reality. We must regain the ability to concentrate, to pay attention as we come into God’s presence, and experience the awe of who’s presence we are in – the God and creator of the universe, the creator of our lives and author of our salvation. He should not be treated as another beep or ping on our smartphone, needing a quick multitasked response. This is our God and our salvation – the most important aspect of our lives. And if its important, its worth being uni-tasked. Which means there must be priorities that trump our iPhone push notifications. Maggie Jackson ends her secular book “Distracted: The Erosion of Attention” (266) with a warning of the dire consequences – “We can create a culture of attention, recover the ability to pause, focus, connect, judge and enter deeply into a relationship or an idea, or we can slip into the numb days of easy diffusion and detachment … The choice is ours.”

Should we not aim to uni-task our study of God and our prayer life? Theologian and philosopher David Wells (17-18) suggests that the “affliction of distraction” is the greatest challenge of our age. “How, then, can we receive from Scripture the truth God has for us if we cannot focus long enough, linger long enough, to receive that truth?”
Scripture calls us to a life of single-minded self-reflection that often gets thwarted by the hum of our ever-present digital technology. The Bible calls us to times of stillness and quietness (Eccl. 4:6, Isa. 30:15, Isa. 32:17, 2 Thess. 3:12, Ps. 46:10), and equates trust in God with a calm and quiet soul (Ps. 131:2). Christ Himself retreated from the bustled life to the distractionless wilderness for prayer and spiritual rejuvenation. The Bible calls us to focus, to lay aside distractions and run with endurance the race set before us (Heb. 12:1). And it calls us to meditate on the Law of the Lord day and night (Ps. 1:1-3), not just in 5 minute blocks we’ve carved out of our busy lives for devotions. Scripture also calls us to prayer, and the biggest problem with prayer is the absence of me, with my mind wandering, not the absence of God.

The neural pathways that our technology use have reinforced make it hard to spend any significant time in prayer, reflection on scripture or listening to a deep sermon. Our neural pathways for healthy balance are atrophied due to being increasingly wired for activity, motion and continual distraction. We need discipline, determination and follow-through to change ingrained life patterns. Our ability to interact with God is dependent on dealing with distractions from within as well as without. Research out of Harvard (Killingsworth and Gilbert) shows our minds wander 47% of the time, and when our minds wander, we are unhappy, feel anxious and the brain is overloaded. Interestingly, they point out that “many philosophical and religious traditions teach that happiness is to be found by living in the moment and practitioners are trained to resist mind wandering and ‘to be here now.’” They conclude that a wandering mind comes at an emotional cost and religious traditions have had it right all along. Are we living up to our religious traditions, though? We must regain the ability to concentrate, to pay attention as we come into God’s presence. Single-mindedness is attainable through patience and practice.

The pay-off for reviving those atrophied neural pathways for uni-tasking, stillness and focus are immense. A host of brain-imaging studies during meditation (Rhodes 101) show that deep thinking and quiet reflection make us more socially aware, reduce negative feelings, counter effects of depression, help achieve goals, increase creativity and spatial processing, give fresh perspectives on problems we face, and reduces stress. As we put aside noisy chaos within and without to connect with God, and intentionally allow God’s spirit to direct thoughts, not only is our relationship with God nurtured, but neural pathways from the prefrontal cortices to the amygdala are strengthened also, enhancing our emotional state.

Resolve yourself to embark on a journey in solitude, submission, meditation, prayer, fasting and study. Strive to enter God’s rest (Heb. 4:10-11), knowing that resting means wasting time on God Himself.

B. Comprehension Reading Skills

The spiritual discipline of study requires the old comprehension reading skills that allowed calm linear thought to form an accurate, composite picture of God, so we can compile a full picture of what God requires of us and how He wants us to interact with our world. The spiritual disciplines of worship and celebration require these focused reading skills also – in order to understand Who our worship is directed towards and what we are celebrating.

The body of Christ shares a collective story, across continents, through centuries, passed down primarily through printed word. Although 9 out of 10 Americans own a Bible, only 80% consider it sacred literature. 58% believe it is the inspired word of God, but only 13% of Americans read it daily. Of those that do read the Bible, only half do so to connect with God, the
rest read it for personal comfort or practical trips – for self-interest. (Barna, “State of the Bible”). The most popular Bible verses bookmarked or highlighted digitally and shared on social media – deal with personal struggles or dealing with anxiety, rather than promoting the glory of God (Stokel-Walker). Most of our scripture interaction is not centered on trying to comprehend the breadth, width, height and depth of our spiritual story. Scripture tells us to “study to show thyself approved unto God” (2 Tim. 2:15). When we read just for knowledge, direction, or inspiration, we are displaying “a form of godliness, but denying the power thereof. From such turn away” (2 Tim. 3:5).

Unfortunately, our digital life can encourage “a form of godliness” without the power of studying “to show thyself approved unto God.” We can be fooled into thinking we are absorbing the word of God. 81% of Christian millennials post scripture on social media (Barna, “Millennials”). But for many, the extent of theological reflection springs from scriptural slogans or Biblical tips from social media apps, YouTube videos or websites. We can nibble around the edges of the many on-line Christian resources, overtaken by the vastness of what is available. Dr. Rhodes in her book “The Wired Soul” (61) speaks of the feeling of being dropped in the middle of a grand amusement park when she went into her church’s on-line media library. Everything seemed so enticing she ended up hopscotching around, reading a snippet here, watching a minute or two there, trying to settle on one amazing lesson over another. Spending so much time grazing around the edges of the choices and feeling spiritually sated while never communing with God in meaningful ways through His word. As our mobile phone Bible is now replacing the paper version of the Bible, Reverend Pete Phillips, from Durham University (Stokel-Walker) warns of interacting with the Bible in bite-sized nuggets. “If you go to the Bible as a paper book it’s quite large and complicated and you’ve got to thumb through it. But you know that Revelations is the last book and Genesis is the first and Psalms is in between. With a digital version you don’t get any of that, you don’t get the boundaries. You don’t flick through: you just go to where you’ve asked it to go to, and you’ve no sense of what came before or after. … When you’re on a screen, you tend to miss out [on] all the feeling stuff and go straight for the information. It’s a flat kind of reading, which the Bible wasn’t written for. You end up reading the text as though it was Wikipedia, rather than it being a sacred text in itself.” We need to carefully consider what contribution our spiritual activity online is making to our relationship with God.

For spiritual growth, it is best to stick to the simplicity of sitting quietly before our Maker with only our Bible open, reading, listening and hearing God’s voice. We need to read for comprehension – pausing and pondering the words. We need to read reflectively – reading slowly to be more aware, listening for God to speak to us through His word. We need to participate in our reading – allowing what we read to change us, to change our lives. We need to read for retention – so God’s word can abide and dwell in us (John 15:7-8, Col. 3:16), and be bound on our hearts (Ps. 1:1-6, Ps. 37:21, Ps. 40:8, Ps. 119:11,16, Pr. 6:21-22, Matt. 4:4), which is not the same as carrying it with us on our smartphone. To accomplish these in our reading of Scripture, we need to be thoughtful, disciplined, and deliberate, which requires focus, consistent practice, reflection and depth. We need to realize that God Himself is speaking the words to us.

Remember that our brains are malleable and will respond to build stronger neural pathways while we establish better spiritual reading habits. “A person doing sacred reading has to resolve to waste time, a terribly countercultural, counterproductive move in this media and web-saturated culture.” (Lichtmann 22). It is essential for our spiritual lives, as God admonishes us to be
diligent about keeping our souls (Deut. 4:9, Prov. 4:23) and tells us that keeping, meditating, and observing scripture brings life to our souls (Josh. 1:8).

C. Relationship Skills

Richard Foster (“Celebration”) set forth a whole group of spiritual disciplines that are corporate in nature. Spiritual formation can never be relegated to a solo endeavor. Community and relationships are the very currency of spiritual growth. The Father, Son and Holy Spirit created man in their own image, establishing a pattern of communal life. God created companionship because it is “not good for man to be alone” (Gen. 2:18), and we see that with babies that fail to thrive when denied human interaction. Then, the Word became flesh and dwelt among us (John 1:14) – the ultimate in sacrificial relationship. Throughout the Bible, human relationships are modelled as the way God wants us to live. The Israelites lived together in tribes. Their punishment was dispersal, but God’s plan was to gather them together (Micah 2:12). Christ gathered close friends around Him – the 12 disciples and Mary, Martha and Lazarus. Fellowship was important to the early church (Acts 2:42), and they were admonished to love one another with brotherly affection (Rom. 12:10). Paul, many times in his epistles, expressed his desire to see others face-to-face (1 Thess. 2:17; 3:10). John, exiled on the isle of Patmos, hoped to see his family of faith in person (2 John 1:12). The culmination of our spiritual sojourn is all about relationship, when Christ will gather His elect (Matt. 24:31). Our spiritual journey is about relationship with God and relationship with man – both individually and communally.

RELATIONSHIP WITH GOD: Our whole spiritual life is about relationship with God, and submission to Him. Deeply meaningful times alone with God, loving conversations with Him and study of His word, result in greater consecration and are an indispensable component of formation in His Image.

RELATIONSHIP WITH MAN - INDIVIDUALLY: We are commanded to encourage one another (Heb. 10:25) and carry one another’s burdens (Gal. 6:2) - to interact with each other on an emotional level. We are to rejoice with those who rejoice and weep with those that weep (Rom. 12:15), to be tenderhearted towards each other (Eph. 4:32) and to love our fellow man (Lk. 10:25). When 60 to 90% of feelings are expressed in non-verbal ways, God’s mandates indicate face to face, person to person interactions. In our digital worlds, we think we’ve shown compassion when we comment with an inspirational quote or verse or post a “like.” We think we’re interacting with others when we post pictures on social media but are too busy to visit our neighbor, when we place our cell phone on the table while dining with a friend. Instead, we are having a private expression of faith between us and our screen and destroying the intimacy of our personal interactions. Is God’s image in us is slowly being extinguished as we rely more and more on technology and less on the gentle whisper of His voice wooing us to reach out and really touch each other? What might it mean to go deeper in relationships to be more present personally and share more vulnerably in order to give and receive encouragement in our journey?

Therefore, encourage one another and build each other up (1 Thess. 5:11). This admonition ranges from the simple – a smile or hug, to the sacrificial - sabotaging schedules or billfolds to meet other’s needs.

RELATIONSHIP WITH MAN - COMMUNALLY: We are also called to be in community with each other – “not forsaking the assembling of ourselves together” (Heb. 10:25). However, a separate strand of Christian practice is booming – the belief that it is no longer necessary to set foot in church. The Pew Research Center (Religious Landscape Study) reports that 1/5 of
Catholics and ¼ of protestants seldom or never attend organized services. Online spiritual content is substituted that seems relational but actually takes place in isolation. Church services via the computer or TV cater to a personalized religious experience – you can pick and choose to fashion an individualized faith that perfectly caters to all your preferences. It is about us, not community. On-line we choose friends, news sources, and create playlists that fit our worldview and our preferences. If someone disagrees with us, we hide, block, unfollow, unfriend, delete. We create a digital world that caters to our views and preferences. DiSalvo (55) warns that “the danger is that technology could limit the perspective of its users and breed insular thinking, turning us into a society of myopic cliques.” The same danger applies to on-line church. The offline Church is diverse with different preferences in music and preaching, different ethnicities, cultures, spiritual languages, ages, spiritual maturities and burdens for service and outreach. Not everyone gets along. “Learning to do community with such different people, in the flesh, shapes me into a much better person than one who does community solely in front of a screen” (Pierce). When people come and worship in spirit and in truth there is also the presence and dynamic of the Holy Spirit that can’t be repeated through a group skype call. We are called to be with each other and to worship together. But beware that you don’t show up for church and fiddle with your phone – looking for something more promising, more entertaining than the joy of God offered in embodied fellowship.

While web-saturated existences can reduce relationships to instant messages and images on social media, living contemplatively calls for ever deepening connections both with God and others. We need to preserve and repair our neural pathways that support in-person, deep, engaged relationships so that we can relate to God. Digital engagement can augment interpersonal connections but its sterile structure is dangerous to the well-being of our soul. Human relations are difficult and messy, and the internet makes it easy to hide from this. We need to develop the discipline of presence, freed from the tedium of incessant interruption, to experience the power and beauty in relationship, to honor and attend to the people around us. We need to build the depth of relationship where we are comfortable confessing our “faults to one another” (James 5:16), receiving constructive criticism (Prov. 27:17) and seeking guidance and encouragement from fellow believers. This is the depth of relationship that God has created us for. We also need to open ourselves to the wonder of spiritual community, rather than participate solely in a world of our own preferences.

IV. The Way Back

Unfortunately, most of us have just wandered blindly into using digital media technology without honestly assessing how our engagement is affecting our lives, allowing each upgrade to invade further. We’ve allowed ourselves to be caught up in the swift-moving current of digital culture that waits for no one. We move mindlessly through our days, while life slips through our fingers, pulled along at technology’s relentless pace. We don’t stop to assess how the digital tsunami is affecting our quality of life, our relationships, our productivity, much less our spiritual lives.

The Bible has outlined the emptiness of inanimate technology long ago in Ps. 115:4-8: “But their idols are silver and gold, made by human hands. They have mouths, but cannot speak, eyes, but cannot see. They have ears, but cannot hear, noses, but cannot smell. They have hands, but cannot feel, feet, but cannot walk, nor can they utter a sound with their throats. Those who make them will be like them, and so will all who trust in them.”
We become like what we behold. To worship an idol is to become like the idol; to worship Christ is to become like Christ (Ps. 115:4-8; Rom. 1:18-27; 12:1-2; Col. 3:10; 2 Cor. 3:18) What we spend our time beholding shapes our hearts and molds us into the people we are. Gazing at a screen, endlessly enmeshed with digital devices develops dependencies which gives access to our hearts. We lose our freedom to rely on the Holy Spirit to shape our choices and it is hard to hear God’s voice or see His hand or grasp His heart for those all around us.

We must override these unhealthy patterns of digital dependency by establishing new, healthier habits of life. We are able to do this, with God’s help, due to the malleability of our brain. We need to create healthy neural pathways and keep using them until they become habit. Summarized below are potential steps to rewire your brain to replace harmful patterns with better neural pathways - neural pathways for a vibrant spiritual life.

1. **Mindfulness** – Becoming aware of your thoughts and decisions is essential for helping the brain to create new pathways. You must be observant of your inner experiences and convicted you need change. Ask God for spiritual revelation regarding the amount of time you are beholding digital screens, the ways you are seeking to satisfy your soul in that space, and how you are falling short of the glory for which He created us for.

2. **Set new goals** - Establish rules to set boundaries on online hours, curb interaction with smart phones and establish a protected “Godspace” – free of interruptions. Set basic parameters for when, where and how you will use technology and spend quality time with God and others. Rules turn intentions into specific commitments, commitments into actions, actions into habits, habits into a way of life. Rules can become cold legalism, but rules acknowledge that to live the way we want to live, humans need something with more backbone than in-the-moment willpower can provide (Medefind).

3. **Make a conscious decision for new behavior** - Use filters, apps and accountability to limit your technology consumption. Recognize triggers that regress to old patterns. Own up to your finiteness and the fact that you have to say ‘no’ to some things.

4. **Seek pleasure from healthy pursuit of reward** – Realize that our technology use causes dopamine releases, pleasure hormones, which is part of the addicting behavior. In order for the brain create new neural pathways, we need to substitute heathier rewards and regain our ability to enjoy the simple things in life. Might I suggest that a walk in nature, without your technology, will do double duty. It will provide healthy pleasure and, according to research at the University of Michigan (Kaplan), will restore the focus that technology can steal from us.

5. **Practice, practice, practice** - New neural pathways need to be strengthened until they become the default mode. Peter Bregman (“Eighteen Minutes”) recommends stopping for 1 minute at top of every hour to evaluate if you’re doing what most needs to be done right now, and being who you most want to be right now. Realize that you are going to fail because you are fighting well cultivated neural pathways and a pleasure reward that is well established. Cognitive neuroscientists say that recognizing when you get derailed and deciding to return to the new goal helps alter the brain circuitry (Rhodes 79). It is
imperative that you persist in fighting to secure time and focus to allow God’s voice to break through your busyness and pierce your heart.

6. **New healthy habit formed** – Habits of operating from a God-saturated worldview while using technology, and exercising dominion over technology (Gen. 1:26-28)

Digital media technology has immensely expanded how we find information, how we do our work, what we’re able to accomplish, and how we communicate. It has immense benefits – which is why we scramble to get each new update! But just like any new tool, responsible use means learning how to use it and knowing its limitations. Our culture has become so bedazzled and enmeshed by the expanse of its use that most haven’t had time to reflect on its limitations. As Christians, the consequences of this passive approach are dire, as digital media technology can stealthily steal our time, our focus and our relationship with God. We must live a more cognizant, mindful life, carefully choosing how we’re going to live our lives for God’s glory. Paul tells us that a life well lived is a life lived carefully (Eph. 5:15-16, Col. 4:5). Be vigilant with your technology, using it as a tool to enhance lives, relationships, and spiritual life, rather than letting the tool control us. As admonished in Christ’s parable of the sower (Mark 4:13-20), keep a protected patch of “good ground” to cultivate your relationship with God, uncluttered by the stones of distraction and the thorns of technology.

As engineers, we are both designers and users of modern technology. We should be on the forefront of knowing the limitations of our technology and its appropriate utilization in our lives. We should lead by example, reflecting a peaceful presence from meaningful communion with God in our harried world. Challenge those around you to not mindlessly follow the cultural response to digital media technology. We do have control over the balance of technology and the life God wants us to live.
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Exploring Divine Providence through the Engineering of a Microscale Niche to Test a Novel Anti-Cancer Agent

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Abstract

Cutting-edge biomedical research often relies on innovative tools from the field of engineering. Some of these tools are designed to investigate or probe a niche, analyzing its characteristics and affordances. Other devices are engineered to create a niche in which a specific, unique interaction can take place, while the outcomes are carefully monitored. This paper will focus on the latter and, more specifically, the affordance structure behind production of a niche designed for cancer research that suggests a divine engineer behind the whole of creation and provides evidence of God. Preliminary research suggests that when maintained in close proximity to breast cancer cells, mushroom mycelia secrete compounds which trigger the programmed cell death of the cancer cells. Experiments are currently being conducted to assist in the development of an appropriate scaffold to facilitate this interaction. This experiment’s use of affordances will serve as a template to understand complex interactions and to display an ingenuity that points to God.

Since niche construction can be viewed as the perception, utilization, destruction and creation of affordances, it is proposed that affordance-based design and reverse engineering techniques will prove advantageous in this work. The specific design question being asked is: “What set of affordances is necessary to achieve a high success in the organism interactions, as well as ease of experimentation and repeatability?” As with all new innovations, there has been much trial and error. The process for engineering this device was to first create a setup that would allow for the most basic affordances, i.e. allows for both the mushroom and cancer cells to survive, and then to add on more unique affordances. At this point, a prototype has been fully constructed and the physical parameters are being adjusted to allow for ease and accuracy of analysis.

Affordance-based design allows for a more holistic understanding of the process and the created niche. The utilization of affordances in the understanding of any niche or system would allow for a greater interchange of information between disciplines, including Christian theology. As scientists continue to discover interdependent affordances at all levels of the natural realm, a picture of divine providence and exquisite engineering expertise comes into clear focus. While an individual affordance does not necessarily serve as an indicator of purpose or teleology, layers of interdependent affordances in both space and time point to the work of an engineer. This interconnectivity can be applied to understand how known cosmological constants afford the known universe and those who inhabit it; in essence, pointing towards an intelligent and loving creator. Thus, this concept of affordances can be used to understand such things as a biblical creation, or can potentially be helpful in describing how a Christian worldview is consistent with the fields of science and engineering.

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Introduction

In the world of biomedical engineering, there are many facets and avenues that are able to be explored. Each day, there are advances being made in medical technologies, making them smaller, smarter, and faster; however, in the area of medical research, biomedical engineering is seemingly often left out of the foreground. Medical research is soon approaching the point where not only are scientists being required to apply an immense amount of ingenuity, but the supporting engineering must also do the same in order to facilitate scientific advancements that are limited by existing equipment and technology.

A strong approach to the understanding of a theoretical biological niche that is to be facilitated by way of engineering is gained from an affordance-based analysis. An affordance is defined as a relationship that has the potential to result in an outcome for an end user. Affordances also have the ability to be nested in space and time. In more complex multi-part systems, intermediate, or part-to-part affordances may lead to an end-user affordance.² By the use of an affordance-based analysis, an understanding of the parameters necessary for the biological niche to be designed is achieved. In the current paper, this approach will be discussed in regards to understanding the necessary design to create a niche for mushrooms and cancer cells to destructively interact.

From a Christian perspective, a valuable feature of using an affordance-based analysis is the fact that the terminology is teleologically neutral and is acceptable in both Christian and scientific circles. No secular scientist will use terminology that would imply that something has a purpose or has been designed; however, with the use of affordance terminology, it is only implied that it has an ability, which is not necessarily its purpose.³ This is an important step to showing the interconnectivity of all aspects of life, and through an in-depth analysis there is strong evidence of a transcendental intelligence in the universe.⁴

Creating a biological niche by understanding the necessary parameters through an affordance-based analysis provides an avenue for Christian engineers and scientists to celebrate the divine ingenuity of God. Through the process of determining the necessary scaffold of a biological niche for mushrooms and cancer cells to interact, the creativity and brilliance of the Creator is apparent. This paper will discuss the method of affordance-based analysis used in this specific instance and how this analysis leads to a fruitful interaction between science and theology.

Understanding the Problem

Mushrooms themselves are extremely resilient and are able to survive in some of the harshest environments on the planet; however, like all living things, there are necessary parameters in order for life to be sustained. Parameters such as food source, space to grow, surface area for gas diffusion, etc. are taken into account.⁵ Cancer cells are more easily adapted to a lab environment by the submersion of the cells in a nutrient rich solution; while the provision of life affording parameters it straight forward, there are additional parameters that must be considered to avoid their unintended death or apoptosis. These parameters take into consideration such things as light, floating particles, air pollution, etc.⁶ The crux of the problem...
being faced is how to afford the survival of mushrooms while in the presence of cancer cells, and still affording the ability for them to interact. Thus, the primary focus of the analysis is:

“What biological environment needs to be engineered that would afford the ability for mushrooms and cancer cells to simultaneously survive and interact?”

Research into the subject of cancer cells and mushrooms sheds some light on what affordances are necessary for a successful and repeatable interaction. The primary problem set that was uncovered centers around the physical proximity necessary for an interaction to occur; however, this physical proximity threatens entanglement and death of the mushroom. Due to the nutrient solution that the cells are submerged in, the mushroom must be afforded the ability to grow into the solution to interact while maintaining a sufficient surface area outside of the solution to allow for gas diffusion. This same engineered part must also afford an ease of separation when removing the mushroom from the cancerous environment. The secondary problem set centers around the necessity of data collection and monitoring. The engineered environment, by definition, is a closed system, thus any type of data collection and monitoring is going to be intrusive. This problem set begs the question of what design will afford the ability to collect data and monitor with the least amount of intrusions.

Engineering Process

The engineering process began by creating an affordance matrix of what parameters were needing to be met or built through the construction of niche. This matrix allowed for the visualization of the necessary affordances needing to be established, as well as displaying the part-to-part and nested affordances that would be built into the experimental scaffold of the niche. The benefit of having this affordance matrix is that the initial design could be more efficiently and thoughtfully planned, which saves on both cost and timing. After the matrix and initial design was created on paper, SolidWorks software was utilized to create the prototype design.

SolidWorks software affords the ability to do a vast amount of technical visualizations and experimentations; however, the software is not sufficient to completely understand the biological niche that was created by the design in order to adjust and improve the affordances. To this end, an XYZ printer was initially utilized to establish a proof of concept; however, the XYZ was printing with PLA filament and thus not able to be used in biological experimentation. The PLA filament is technically biologically active and could interfere with the organisms utilizing the design. While this could be compensated for by the binding of proteins to the outer layer of the PLA, the PLA filament does not provide sufficient affordances beyond that of ABS that would make an argument for more extensive biological meddling of the design before experimentation. Through this 3D printing process with the XYZ printer, the affordances became tangible and the part-to-part affordances were able to be manipulated and tested.

Once the proof of concept was established, the 3D printing was being done by an Object24 printer printing with ABS Verawhite material and supporting structures. This printer affords a more precise print that is also usable in biological experimentation due to the material; however, there was an unexpected limitation to this print. The film and supporting structures that
are needing to be removed before use left small particles that were seen in the electron microscope when viewing the cells. This is just one example of many where a new affordance had to be created when there was an unexpected consequence of the design or experiment process.

Currently, all aspects of the project are being restricted as proprietary knowledge due to the experimental process being in the patent process; and so, specifics and results are not available to be discussed at the current time. What can be stated, however, is that the design and experimental process has been quantifiable as highly successful and are proceeding forward with the current results.

Design Concept

The definition of completeness for this project is: To engineer an artificial niche that affords the ability to successfully force an evolutionary adaptation of the mushroom in order for it to kill and feed off of cancer cells in order to survive. The key for this to be successfully is the interface and niche in which the two interact. The end-user affordances that are essential to this successful interface are close proximity, ability to grow, and ease of mushroom manipulation. The end-user affordances that are essential to this successful niche are being a closed system, compatibility with other lab equipment, and being repeatable. In this case, the end-user is the scientist as well as the mushroom; while this may seem slightly odd, both are actively using the parts based upon their provided affordances. The mushroom, cancer cells, and design are all combined in multiple part-to-part affordances to produce the ultimate affordance of the release of an anti-cancer agent by the mushroom.

Affordances from a Christian Perspective

Christians hold the belief that God is in everything and it’s one of their goals to display this fact in as many facets as is possible. The ingenuity of the Creator is displayed clearly by the recognition of the lengthy string of nested affordances to create a niche for a single interaction to take place, let alone the large number of niches that occur within nature. An affordance-based analysis of this biological interaction also reveals the divine thought involved in the creation of the mushrooms, and possibly cancer cells, depending on one’s theological perspective of cancer. The mushroom mycelium affords a foundation for rapid growth and expansion of the organism that is necessary for the interaction to take place, while also having a biological makeup that affords the ability to break down its surroundings into a food source. Both of these affordances are fascinating; while Christians are able to point towards a design and Creator, secular scientists require the neutrality that the affordance terminology allows in order to discuss said abilities in regards to what permits them to be actualized in nature or a synthetic niche.

The affordances being discussed in regards to the experimental niche construction are all fairly straightforward; however, when combined into a product, the collective part-to-part affordances and end-user affordances provide a design concept that affords a successful interaction and repeatability. Each time the term affordance is utilized, as engineers, the terminology is visualized as indicating a purpose and design. This same interpretation can be applied as Christians to areas of knowledge such as cosmology, ecology, and biology. The same
terminology can be used by secular scientists in the same areas of knowledge without the teleological implications. Due to this, a neutral foundation established that affords the ability to exchange conclusions and data without compromising scientific integrity nor compromise on one’s personal convictions.

An example of an affordance outside of strictly engineering, albeit rather broad, is the existence of life as it is currently known that is afforded by the four fundamental forces in physics. There is a common uncertainty in science as to why the fundamental forces seem to have “frozen” and became distinct mathematical forces. The use of affordances in discussing a topic such as the frozen nature of fundamental forces becomes valuable due to a lack any solid reasoning or understanding as to why they “froze” when they did. With this use of affordances, Christians are able to articulate the evidence for a divine intelligence behind the existence and static nature of the forces, and the secular realm can agree that the forces are seen to provide the ability for life to exist as it currently does and not having to rely on any true supporting arguments to make an assertion. The caution that must be stated is that the terminology must remain consistent throughout any discussion in order to maintain the integrity of the science and neutrality of the discussion.

One clarification that is needing to be made is that this paper does not hold the purpose of furthering the fine-tuning argument, or any creation argument for that matter. The transcendental implications from the use of affordance terminology are derived by the ability to display the web of part-to-part and nested affordances that exist in niches. This display of interconnectivity allows for conclusions of divine providence to be asserted by the Christian perspective.

Conclusion

An affordance-based analysis is able to provide a unique framework for the understanding of complex biological interactions and the engineered designs that create the necessary niche for the interactions to take place. These affordances that have been used to understand the way in which the parts interact to provide a unique end-user affordance open the door for a discussion into the ingenuity of the artificial niche, which would consequently lead into the ingenuity found in all of nature. While Christians unveil the purposes of God through science, it is imperative to remember that this terminology can be a barrier to other scientists. Due to this, it is proposed that affordance terminology is used so that Christians can keep their spiritual integrity while also conversing in an academic and teleologically neutral discussion of science. While evangelism is not the goal of technical exchanges, Christian engineers and scientists can strive to lay bare the data and present the science in a way that will lead others to the divinity behind it all.

References


