Proceedings of the 2019 Christian Engineering Conference

DORDT UNIVERSITY
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Forward

Welcome to the 2019 Christian Engineering Conference! The Christian Engineering Conference is the flagship event of the Christian Engineering Society, and in this volume of proceedings you will find the eighteen papers from the conference in the order they were presented. The associated slide presentations are also available on the Christian Engineering Society website. Many thanks are due to the authors who did such a fine job preparing them. The conference also featured: a keynote address by Mike Adams, CEO of Adams Thermal Systems and president of Adams Thermal Foundation; panel discussions on ABET, leadership in engineering, and engineering ethics (which was eligible for PDH); a poster session; and numerous informal discussions with colleagues.

The Christian Engineering Conference (CEC) continues to serve as a resource and forum for Christian engineers in both Christian and secular universities and for Christian engineers in industry, government, and other non-academic settings. In total, conference attendees represented thirty-six different organizations: eighteen Christian universities from a range of faith perspectives, four secular universities, and fourteen missions and industry organizations. For the first time, the conference included a Friday-only option, which included the engineering ethics training and which was attended by engineers representing nine industry organizations.

The next Christian Engineering Society gathering will be in 2020 in Montreal, Canada, for dinner during the ASEE Annual Conference. The next Christian Engineering Conference will be in 2021 at Azusa Pacific University, in conjunction with the Association of Christians in Mathematical Sciences, and just before the ASEE Annual Conference in Long Beach, CA. See the Christian Engineering Society website for full details as they become available.

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

Special thanks to Justin Vander Werff (the conference General Chair) and steering committee members Ethan Brue, Kevin Timmer, and Nolan Van Galen for their excellent planning and execution. Thanks also to the many reviewers who reviewed abstracts and papers for the conference and to the other volunteers who led as session moderators and in worship, prayer, and devotions.

Randal S. Schwindt
CEC 2019 Program Chair
Program Educational Objectives (PEOs), Student Outcomes (SOs) and Institutional Mission: A Comparison

Gayle E. Ermer

Abstract

The Christian Engineering Conference has a strong history of stimulating reflection on the impact of Christian perspectives on professional engineering work and technology development. This reflection has resulted in the articulation of general concepts that would typically be included in a distinctively Christian approach to engineering (e.g. service focus, ethical framework, and normativity). Less consideration, however, has been given to studying how these foundational principles are implemented in various engineering curricula and how the distinctiveness of a Christian approach is communicated to various audiences. This presentation will summarize the results of a research project focused on the following questions: What is distinctive about the engineering programs offered at Christian colleges or universities (compared to those at secular institutions) and what aspects of Christian faith are emphasized in different programs?

The methods used for this study included qualitative analysis of program educational objectives (PEOs) and student outcomes (SOs) for a variety of engineering programs. The engineering programs reviewed included Christian institutions, as well as a sample of secular institutions. Because all accredited engineering programs are required to make public a list of PEOs and SOs, these statements provide an accessible and concise reservoir of data for evaluation. Several coding and analysis techniques were used to identify common themes among programs, as well as those that differed between programs. The results of this investigation provide a framework for Christian engineering educators as they endeavor to more effectively integrate Christian worldview concepts into their own programs and to emphasize the distinctiveness of a faith-based approach to accreditors and prospective students.

Introduction

Christians who pursue engineering work are faced with a number of questions pertaining to the relationship between their faith and professional activities: What Christian values impact technology development? What does it mean for engineering to be done in a distinctively Christian way? How should daily work in engineering design reflect God’s will for human flourishing?

Colleges and universities who claim to teach from a Christian perspective must face these questions as well, and have a strong incentive to work towards answers that can be incorporated into program curricula. As the chair of a department at a college with an explicitly Christian mission, I am not only interested in identifying the impact of Christian principles and perspectives on program goals, but also in how the distinctiveness of these program goals is communicated to prospective students and their families. Parents sometimes question the

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1Calvin University, Grand Rapids, MI
difference between engineering programs offered at secular and Christian schools. Unlike with science, where parents may come in with concerns about potential conflicts between Christian and secular theories (e.g. evolution), there seems to be a perception that Christian faith has much less bearing on how engineering is taught or practiced.

The Christian Engineering Conference has a strong history of stimulating reflection on the impact of Christian perspectives on professional engineering work and technology development. This reflection has resulted in the articulation of general concepts that would typically be included in a distinctively Christian approach to engineering (e.g. service focus, ethical framework, and normativity). Less consideration, however, has been given to studying how these foundational principles are implemented in various engineering curricula and how the distinctiveness of a Christian approach is communicated to various audiences. This paper will summarize the results of a research project focused on the following questions: What is distinctive about the engineering programs offered at Christian colleges or universities (compared to those at secular institutions) and what aspects of Christian faith are emphasized in different programs? The attempts to answer this question focus on consideration of the connections between first principles and program implementation as reflected in guiding institutional statements, particularly an exploratory analysis of program educational objectives (PEOs) and student learning outcomes (SOs).

Models for Faith Integration

This research was undertaken under the assumption (compatible with the expectations of ABET for accredited programs) that institutions might follow a process for curriculum development similar to what is shown in Figure 1. For Christian institutions, the expectation would be for Christian principles or perspectives to guide the institutional mission in distinctive ways. The engineering program mission is presumably a subset of the institutional mission (also impacted by Christian values). This program mission is what should then guide the content of the PEOs. The goals for students (SOs) must include the set specified by ABET, but could also be augmented with SOs that serve the PEOs in a particular way. The SOs would then guide the courses and other elements that make up the curriculum. The motivation for this research project was curiosity about how the Christian principles at the beginning of this process are actually reflected in the later stages (particularly in the PEOs and SOs). In particular, this research hopes to see evidence of Christian principles represented in both the SOs and PEOs of Christian engineering programs. The analysis will therefore focus on the connections signified by the darker, heavier arrows in the curriculum design model of Figure 1.

Another way to think about these connections could be from the perspective of an engineering graduate who is working in industry. Figure 2 reflects the idea that both Christian principles and secular principles would typically influence the life of a Christian engineer. A “separate spheres” approach might see Christian principles reflected only in personal characteristics or expectations, while secular principles influence professional expectations (the pale boxes and grey arrows of the diagram). Both of these streams of knowledge would then need to be integrated into engineering work by a particular Christian engineer. This model of engineering work would imply that engineering program goals and implementations might not reflect a great deal that is
specifically Christian (i.e., good engineering is good engineering, no matter what your faith background). If this model is reflective of reality, then we might expect the professional goals established for engineering programs to be essentially the same, with differences only reflecting the personal nature of Christian faith commitments (which would not be significantly different from Christian commitments expressed relative to any other profession).

![Figure 1. Conceptual Model of Engineering Program Development](image)

While it is true that analytical techniques and experimental work within an engineering curriculum might look very much the same in a secular or a Christian classroom, the purpose of this paper is to explore how Christian principles might be reflected in not just the personal, but also the professional expectations of an engineering program (the darker, heavier arrow in the diagram).

**Project Goals**

The goal of this paper is to present a summary analysis of themes identified in the PEOs and SOs of a variety of engineering programs. The institutions included in the analysis represented a range of Christian traditions, as well as sampling of secular institutions. This project consisted of a qualitative discovery exercise to separate out themes or ideas that are common to programs offered at Christian institutions, themes that are common to programs offered at secular institutions, and difference in themes between the two groups. Some basic textual analysis methods and coding schemes were used. The intention is to provide a framework that can help Christian engineering programs (and perhaps Christians teaching in secular engineering programs) to enrich their thinking about the implications of Christian perspective and also as a benchmarking study that might help faith-based engineering programs to improve the integration of Christian themes into their own institutional identity statements and curricula.
Approach and Methods

The methods used for this study included qualitative analysis of engineering PEOs and SOs for a variety of engineering programs. The engineering programs reviewed include those provided at Christian institutions, as well as a sampling of those provided at secular institutions. Because all accredited engineering programs are required to make public a list of PEOs and SOs, these statements provide an accessible and concise reservoir of textual data for evaluation. Several coding techniques were used to identify common themes among programs, as well as those that differed between programs.

The analysis was based on two data sets. The first included Council for Christian Colleges and Universities (CCCU) institutions and secular institutions, whose PEOs were studied both separately and as a whole. The second included a broader range of Christian institutions whose SOs were analyzed to determine whether and how differences were expressed relative to the specific SOs required by ABET. This study was intended as a bottom-up effort to determine what aspects of engineering education are being influenced by Christian principles and which principles in particular are most often appropriated into Christian engineering program goals.

Definitions: PEOs and SOs (ABET)

The goal of this research project was to find evidence of faith integration themes in program statements that are generated by each program and are made available to the public. Although program or departmental mission statements can reveal a great deal about fundamental commitments and goals for Christian engineering programs, not all programs have mission statements, and if they do, they vary significantly in length and complexity, making them hard to compare to each other.

PEOs and SOs, as representative program statements, were chosen for analysis for the following reasons: all ABET-accredited programs are required to have them (consistency) and to make them accessible to the public, typically on the world wide web (accessibility). This provides the
means for efficient access to program information without the need to contact people
individually or implement surveys that might have low response rates. Also, as someone who has
had significant experience with ABET as a program evaluator and who has seen a range of
programs, both Christian and secular, I am familiar with their requirements and format.

The Engineering Accreditation Commission of ABET includes in Criterion 2 the following
requirement: each accredited engineering program must have “published PEOs that are
consistent with the mission of the institution, the needs of the program’s various constituencies,
and these criteria. There must be a documented, systematically utilized, and effective process,
including program constituencies, for the periodic review of these program educational
objectives that ensures they remain consistent with the institutional mission, the program’s
constituents’ needs, and these criteria.” According to ABET, PEOs are “broad statements that
describe what graduates are expected to attain within a few years after graduation.” In practice,
PEOs tend to be relatively short (a single paragraph of text). For analysis purposes, there is
therefore a reasonable amount of text to consider, making for an efficient study. Because PEOs
are not lengthy, they tend to be focused on high priority program goals, rather than on general
program marketing. PEOs are supposed to represent the perspectives of multiple constituencies,
as opposed to those of a single faculty member or marketing person. Since the same definition
applies to all programs, PEO analysis provides for an “apples to apples” comparison of program
goals. Thoughtfully constructed PEOs are dense texts, capturing a variety of goals in relatively
few words. On the other hand, the brevity of PEOs may limit the amount of complexity that can
be reflected. Also, it is not clear that all programs take them seriously. They can easily be
perceived as just a paperwork checkbox to satisfy ABET.

The EAC includes in Criterion 3 the following requirement: “The program must have
documented student outcomes that support the program educational objectives. Attainment of
these outcomes prepares graduates to enter the professional practice of engineering.” According
to ABET, SOs “describe what students are expected to know and be able to do by the time of
graduation. These relate to the knowledge, skills, and behaviors that students acquire as they
progress through the program.” ABET specifies the outcomes that every program must include
for its graduates, along with an option to add outcomes that are program specific. Until the 2018-
2019 accreditation cycle, these outcomes were (a) – (k), which I will refer to as the old SOs.
Starting with the 2019-2020 accreditation cycle, the ABET outcomes are 1-7, which I will refer
to as the new SOs. Table 1 lists the SOs, with the first column including the new version, and the
second including a reordered version of the old SOs. When the SOs were updated, ABET
indicated that the goal was not to substantially change the content of the SOs, but rather to
reorganize them in such a way that they would be simplified and easier to assess. Table 1
illustrates that all of the old SOs can be mapped to the new ones, except for the old (k) “an
ability to use the techniques, skills, and modern engineering tools necessary for engineering
practice”, which is now reflected in a different criterion.
Table 1. ABET EAC SOs

<table>
<thead>
<tr>
<th>New (2019/20) SOs</th>
<th>Old (pre-2019/20) SOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics</td>
<td>(a) an ability to apply knowledge of mathematics, science, and engineering</td>
</tr>
<tr>
<td></td>
<td>(e) an ability to identify, formulate, and solve engineering problems</td>
</tr>
<tr>
<td>2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors</td>
<td>(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability</td>
</tr>
<tr>
<td>3. an ability to communicate effectively with a range of audiences</td>
<td>(g) an ability to communicate effectively</td>
</tr>
<tr>
<td>4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts</td>
<td>(f) an understanding of professional and ethical responsibility</td>
</tr>
<tr>
<td></td>
<td>(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context</td>
</tr>
<tr>
<td></td>
<td>(j) a knowledge of contemporary issues</td>
</tr>
<tr>
<td>5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives</td>
<td>(d) an ability to function on multidisciplinary teams</td>
</tr>
<tr>
<td>6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions</td>
<td>(b) an ability to design and conduct experiments, as well as to analyze and interpret data</td>
</tr>
<tr>
<td>7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.</td>
<td>(i) a recognition of the need for, and an ability to engage in life-long learning</td>
</tr>
</tbody>
</table>

When the concept of SOs was originally adopted as part of Criteria 2000, institutions were encouraged to develop program-specific SOs from scratch that integrated the themes of (a) – (k), rather than using (a) – (k) verbatim. Although this seemed like a natural way to honor the variety of PEOs that programs were designed to meet, in practice, SOs that were organized differently from (a) – (k) were cumbersome to audit, since PEVs were required to make sure that (a) – (k) were met by every program. This required yet another layer of mapping from program-specific SOs to ABET SOs. Over time, it has become much more common for institutions to adopt (a) – (k) (and the new 1-7) verbatim, which greatly simplifies the auditing process for evaluators.

**PEO Analysis**

*Data Set.* For PEO analysis, the first data set included CCCU schools with accredited engineering programs, a total of 16 institutions. This list is maintained by the office of the dean of the school of engineering and computer science at Cedarville University, which compiles and publishes it yearly. There are a few CCCU schools on this list with programs that are not accredited, are 3-2 programs that rely on a secular school for the accredited degree, or are in the
process of obtaining accreditation. These programs were not included in the analysis. For comparison, data from a sampling of engineering programs at secular schools was assembled and added to the data set. The sample included a range of institutions in size and classification, from small, liberal-arts based programs to large research universities. Table 2 lists the institutions included. Many smaller schools only offer a single engineering program, accredited under the general criteria. When this was the case, the PEOs for that single program were used. For institutions with multiple programs, if a general engineering option was available, the general program PEOs were used, if not, the PEOs for the mechanical engineering option (with which the author has the most familiarity) were used.

Table 2. Institutions for PEO Analysis

<table>
<thead>
<tr>
<th>Christian Institutions</th>
<th>Secular Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bob Jones University</td>
<td>Grand Valley State University</td>
</tr>
<tr>
<td>2 California Baptist University</td>
<td>Western Michigan University</td>
</tr>
<tr>
<td>3 Calvin College</td>
<td>Michigan Tech</td>
</tr>
<tr>
<td>4 Cedarville University</td>
<td>University of Wisconsin - Milwaukee</td>
</tr>
<tr>
<td>5 Dordt College</td>
<td>Illinois Institute of Technology</td>
</tr>
<tr>
<td>6 Geneva College</td>
<td>Cal Poly San Luis Obispo</td>
</tr>
<tr>
<td>7 Grove City College</td>
<td>Rose-Hulman University</td>
</tr>
<tr>
<td>8 John Brown University</td>
<td>Swarthmore</td>
</tr>
<tr>
<td>9 LeTourneau University</td>
<td>Dartmouth</td>
</tr>
<tr>
<td>10 Liberty University</td>
<td>Olin College</td>
</tr>
<tr>
<td>11 Lipscomb University</td>
<td>Harvey Mudd College</td>
</tr>
<tr>
<td>12 Messiah College</td>
<td>Georgia Tech</td>
</tr>
<tr>
<td>13 Oklahoma Christian University</td>
<td>University of Wisconsin - Madison</td>
</tr>
<tr>
<td>14 Oral Roberts University</td>
<td>Stanford</td>
</tr>
<tr>
<td>15 Pensacola Christian College</td>
<td>University of Illinois</td>
</tr>
<tr>
<td>16 Seattle Pacific University</td>
<td>University of Michigan</td>
</tr>
</tbody>
</table>

Analytical Methods. As an engineering faculty member, I did not have much experience with textual analysis methods prior to this project. Several possible techniques were identified in Ryan and Bernard’s article “Techniques to Identify Themes.” For this initial exploratory phase of research, inductive methods were deemed to be appropriate. Inductive methods focus on the attempt to organically determine themes from text, rather than assuming previously defined categories for coding of information.

In reality, every researcher already has previously defined categories and expectations when approaching a text. Mine have been influenced by a variety of past CEEC/CEC papers that have described Christian principles related to engineering and technology. A brief survey of past presentations yields the following distinctively Christian themes: service to society, humanitarian engineering/appropriate technology, holistic view of technology incorporating value-ladenness, stewardship, and integrity/ethics. However, in this case I tried not to impose prior categories or
concepts, but rather to let categories and concepts emerge from careful reading and comparison of the texts themselves.

This inductive process was based on the following definitions: 1) themes are the categories, codes, or labels that help to group concepts based on similar meaning, and 2) expressions are the incidents, words, phrases, text segments, or chunks that serve as illustrations of a theme. Observational techniques for inductive analysis involve line-by-line scrutinizing of the text to discover similarities and differences and to note commonalities or repetitions. The particular processing technique used for PEO analysis consisted of 1) assembly of the PEOs into one document for each data set, 2) identification of expressions, essentially a chunking of the text into independent phrases, 3) printing each expression on a separate slip of paper, and 4) rearranging the slips of paper into piles where commonalities were observed. For this study, the PEOs from all the Christian engineering programs were placed in a single document (after removing common introductory or explanatory material) and treated as a single text. The PEOs from all of the secular engineering programs were treated similarly. After this inductive coding process was used to identify themes, incidences of some themes within specific program PEOs were counted and compared.

Word clouds were another technique explored for determining theme occurrence. Word cloud software works by identifying all unique words in a text and counting the number of times they occur. However, the word cloud technique did not reveal much useful information about themes in the PEO texts. The variety of words/phrases used within the PEOs to refer to similar themes made a straight word count ineffective as a grouping strategy.

**Results.** Prior to textual coding, the word count for each set of PEOs was determined, including any introductory or concluding information (e.g. phrases like “Graduates of the program are expected within a few years of graduation to…”). For the CCCU programs, word counts ranged from a low of 37 to a high of 292, with a median of 95 and a mean of 116. The distribution of words counts is shown in Figure 3. In comparison, the word counts for secular programs were found to be generally smaller, from a low of 30 to high of 137, with a median of 83 and a mean of 78 (distribution shown in Figure 4). This gives some indication that Christian programs may be adding Christian content to professional goals that are shared by most institutions in order to make their PEOs distinctively Christian. For programs with particularly long PEOs, there tended to be more framing commentary related to Christian perspective, rather than an increase in the length of the achievement goals themselves. Within the secular programs, some of the shortest PEOs reflected very basic expectations for graduates (e.g. be employed or successful in graduate school), with very little explanatory text or framing context provided to indicate distinctiveness of mission.

The results of the inductive analysis for Christian program PEOs is summarized in the first column of Table 3. The table identifies 6 major themes, along with subthemes. The results of the inductive analysis for secular program PEOs is summarized in the second column of Table 3. Text in bold italics in the second column indicates differences in themes observed between the two texts. I was not surprised to find that many themes and sub-themes were shared between Christian and secular institutions, e.g. a focus on career and professional productivity (we all aim
to produce engineers that are employable) and an emphasis on continued learning. Also, many of
the attributes that programs desire for their graduates are shared by all programs. Perhaps less
expected was the common emphasis on social responsibility, service, and ethics/integrity, which
are themes that have been presented as somewhat distinctively Christian. Clearly, both secular
and Christian programs value these aspects of engineering professional work (although not all to
the same extent).

Figure 3. Christian Program PEO Word Counts

Figure 4. Secular Program PEO Word Counts
There were some significant thematic differences observed between the two data sets. Perhaps most strikingly, none of the secular program PEOs included any framing assumptions (except for one with a sustainability emphasis) or emphasis on aspects of life beyond professional work. Secular programs tended to have successful employment defined in employer terms (which was not the case for Christian programs) and did not include attributes similar to perseverance and well-roundedness, instead emphasizing initiative/resourcefulness and entrepreneurship.

Table 3. PEO Themes

<table>
<thead>
<tr>
<th>Christian Program Themes</th>
<th>Secular Program Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Career/Professional Productivity</td>
<td>1) Career/Professional Productivity</td>
</tr>
<tr>
<td>• Analysis/application of technical knowledge</td>
<td>• Analysis/application of technical knowledge</td>
</tr>
<tr>
<td>• Problem solving/design (real-world/complex)</td>
<td>• Problem solving/design (real-world/complex)</td>
</tr>
<tr>
<td>• Successful employment/excellence</td>
<td>• Successful employment/excellence (employer focus)</td>
</tr>
<tr>
<td>• Leadership</td>
<td>• Leadership</td>
</tr>
<tr>
<td>• Social responsibility</td>
<td>• Social responsibility</td>
</tr>
<tr>
<td>2) Continued Learning</td>
<td>2) Continued Learning</td>
</tr>
<tr>
<td>3) Service</td>
<td>3) Service</td>
</tr>
<tr>
<td>4) Attributes Displayed</td>
<td>4) Attributes Displayed</td>
</tr>
<tr>
<td>• Perseverance</td>
<td>• Initiative/resourcefulness</td>
</tr>
<tr>
<td>• Creativity</td>
<td>• Creativity</td>
</tr>
<tr>
<td>• Teamwork</td>
<td>• Teamwork</td>
</tr>
<tr>
<td>• Cultural competency</td>
<td>• Cultural competency</td>
</tr>
<tr>
<td>• Communication</td>
<td>• Communication</td>
</tr>
<tr>
<td>• Well-rounded</td>
<td>• Entrepreneurial/Financial implications</td>
</tr>
<tr>
<td>• Ethical/integrity</td>
<td>• Ethical/Integrity</td>
</tr>
<tr>
<td>5) Framing Assumptions</td>
<td></td>
</tr>
<tr>
<td>• Christian Worldview/philosophy</td>
<td></td>
</tr>
<tr>
<td>• Vocation</td>
<td></td>
</tr>
<tr>
<td>• Stewardship/sustainability</td>
<td>• Sustainability</td>
</tr>
<tr>
<td>6) Beyond Career</td>
<td></td>
</tr>
<tr>
<td>• Balance</td>
<td></td>
</tr>
<tr>
<td>• Church participation</td>
<td></td>
</tr>
</tbody>
</table>

A final level of analysis included a comparison of the prevalence of themes within each of the data sets for certain themes of interest. Table 4 presents the results. As might be expected, more CCCU program PEOs included expressions of the service theme than did secular program PEOs. Secular programs included more expressions of the leadership theme than did Christian programs (although 2 additional instances of the word leadership appeared in Christian programs in the context of servant leadership, which I did not count as matching the more general leadership theme). Finally, only one secular program had an expression of the sustainability theme, while almost a quarter of Christian programs referenced that theme in the context of stewardship.
Table 4. Prevalence of Themes

<table>
<thead>
<tr>
<th>Christian Programs</th>
<th>Secular Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theme: Service</strong></td>
<td></td>
</tr>
<tr>
<td>9/16 (56%)</td>
<td>4/16 (25%)</td>
</tr>
<tr>
<td><strong>Theme: Leadership</strong></td>
<td></td>
</tr>
<tr>
<td>4/16 (25%)</td>
<td>9/16 (56%)</td>
</tr>
<tr>
<td><strong>Theme: Stewardship/Sustainability</strong></td>
<td></td>
</tr>
<tr>
<td>4/16 (25%)</td>
<td>1/16 (16%)</td>
</tr>
</tbody>
</table>

SO Analysis Results

*Data Set.* The SO analysis was focused exclusively on Christian institutions. The list (62 institutions in total) was obtained from the Christian Engineering Society website. The subset of institutions with ABET-accredited engineering programs on this list totaled 37. SOs for each of these programs were copied from institution websites.

*Analysis.* The complexity of the SO comparison was increased to some extent due to the fact that, as of April 2019, many institutions had not yet updated their SOs to match the new ones issued by ABET. Table 5 reports the percentages of programs using the old and new outcomes in the top two rows. However, since the old SOs can be mapped onto the new ones (as shown earlier in Table 1) it was still possible to identify common themes over the entire data set. The first level of analysis was a simple count of which institutions used the ABET outcomes directly, versus those institutions who had modified the ABET outcomes by revising or adding content. Just under half of the programs had modified the outcomes in some way (see the “Modification” section of Table 5). Table 5 also shows the proportions of old and new SOs for which the institutions in the data set have left the SOs unmodified, revised particular SOs within the ABET set, added one or more SOs to the ABET set, or have both revised and added to the ABET SO set.

Where institutions had added to the ABET SOs, themes were identified, some of which were secular in nature, i.e. values/goals which, in my judgement, would likely be embraced by institutions with secular as well as Christian missions (similar to the themes that were common to both data sets in the previous analysis). The themes identified as Christian included expressions that would be more likely to be associated with distinctively Christian principles. Table 6 lists the themes associated with each of the ABET SOs (1 – 7). Added SO themes of a secular nature are listed in Table 7, in language copied directly from the added SOs. Finally, added SO themes that are more explicitly Christian have been listed in Table 8. These have been organized into larger theme categories which align well with the themes identified in the PEO analysis.
Table 5. SO Analysis Summary

<table>
<thead>
<tr>
<th>Version</th>
<th>Old</th>
<th>26</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>11</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>37</td>
<td>100%</td>
</tr>
</tbody>
</table>

| Modification | Unmodified | 20 | 54% |
|              | Modified   | 17 | 46% |
|              | Total      | 37 | 100% |

| Old - Modification | Unmodified | 13 | 50% |
|                   | Revised    | 1  | 4%  |
|                   | Added      | 6  | 23% |
|                   | Revised and added | 6 | 23% |
|                   | Total      | 26 | 100% |

| New - Modification | Unmodified | 7  | 64% |
|                   | Revised    | 1  | 9%  |
|                   | Added      | 2  | 18% |
|                   | Revised and added | 1 | 9%  |
|                   | Total      | 11 | 100% |

Table 6. ABET SO Added Themes

<table>
<thead>
<tr>
<th>SO</th>
<th>Common/General</th>
<th>Specifically Christian</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (a) (e)</td>
<td>Specialty knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fundamental principles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critically evaluate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specify, document</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normativity/aspects</td>
<td></td>
</tr>
<tr>
<td>2 (c)</td>
<td>Produce prototype</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Holistically</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specialty areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Responsible technology</td>
<td></td>
</tr>
<tr>
<td>3 (d)</td>
<td>Software/tools</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Active member/mentor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Openness/honesty</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Servant leadership</td>
<td></td>
</tr>
<tr>
<td>4 (f) (h) (j)</td>
<td>Appreciation for ethics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local community</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Holistic perspective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Christian stewardship</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Christian faith/worldview/principles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ecclesiastical/missionary context</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Articulate faith</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cultural mandate</td>
<td></td>
</tr>
<tr>
<td>5 (g)</td>
<td>Value other viewpoints</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oral/written/visual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Various audiences</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technical/non-technical content</td>
<td></td>
</tr>
<tr>
<td>6 (b)</td>
<td>Extract meaning</td>
<td></td>
</tr>
<tr>
<td>7 (i)</td>
<td>Teachable disposition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work independently</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insights, skills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proactively set and pursue personal goals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Faithful stewards</td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Added SOs – Common/General

<table>
<thead>
<tr>
<th>Knowledge/Understanding</th>
<th>Exposure to Profession</th>
</tr>
</thead>
<tbody>
<tr>
<td>an understanding of the basic concepts in leadership</td>
<td></td>
</tr>
<tr>
<td>strong liberal arts background</td>
<td>8) biology, 9) statistics</td>
</tr>
<tr>
<td>An ability to pass the Fundamentals of Engineering (FE) examination</td>
<td></td>
</tr>
<tr>
<td>An understanding of the inter-relationship between Engineering Analysis and Engineering Design and the ability to approach a problem from an integrated Design/Analysis perspective</td>
<td></td>
</tr>
<tr>
<td>an understanding of project management techniques</td>
<td></td>
</tr>
<tr>
<td>completed a broad-based education in the humanities and general studies</td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Added SOs – Specifically Christian

<table>
<thead>
<tr>
<th>Knowledge – articulate apply Christian principles or worldview</th>
<th>Character</th>
<th>Service</th>
<th>Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>an ability to articulate a Christian worldview on personal, professional, technical, and societal issues</td>
<td>Christian character. Views all of life including engineering from a consistent biblical worldview</td>
<td>Fully equipped to do every good work (II Timothy 3:17) serving Christ in all aspects of their lives</td>
<td>An appreciation for a balanced life emphasizing leadership, spiritual, social, and professional roles</td>
</tr>
<tr>
<td>an understanding of the relationship between science, technology, and a Christian world view</td>
<td>A solid Christian character expressed in service to church, campus, and community</td>
<td>demonstrated service to campus and community and responsibility to self, profession, and society</td>
<td>an integration of Christian faith, learning, and professional life</td>
</tr>
<tr>
<td>strong liberal arts background including religious studies</td>
<td>Faithfulness and Responsibility. An ability to articulate and faithfully practice responsible engineering that grows out of Christ’s all-encompassing work as Creator, Sustainer, and Redeemer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>An understanding of the Christian world view</td>
<td></td>
<td>Faithfulness and Responsibility. An ability to articulate and faithfully practice responsible engineering that grows out of Christ’s all-encompassing work as Creator, Sustainer, and Redeemer</td>
<td></td>
</tr>
<tr>
<td>Students are able to apply Christian principles of stewardship.</td>
<td>an understanding of the role of Christian ideals in professional and personal life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>an understanding of the relationship between science, technology, and a Christian world view</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faithfulness and Responsibility. An ability to articulate and faithfully practice responsible engineering that grows out of Christ’s all-encompassing work as Creator, Sustainer, and Redeemer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>an understanding of the Biblical concept of calling, particularly of the calling to be an engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions and Future Work

This analysis confirmed that for many Christian engineering programs, Christian principles influence not just expectations related to the personal behavior and faith life of students, but also the professional expectations of students as reflected in PEOs and SOs. For the SOs, a little over half of Christian engineering programs have chosen not to modify the ABET SOs in any way. Although this could be interpreted as a failure to emphasize the integration of Christian values into professional expectations, I suspect instead that these programs have chosen to integrate in different venues, perhaps relying on PEOs to carry the burden of expressing distinctively Christian goals, or relying on performance indicators (statements intended to identify measurable goals for evaluating SO attainment) to integrate Christian content. It should be noted that institutions who add content to the ABET SOs must commit to assessing the extent to which students are attaining those extra outcomes. Future work to identify the assessment mechanisms used by various programs to accomplish this could be a valuable resource for institutions that are new to assessment or struggling to construct reliable methods for assessing “soft” outcomes.

The study results also emphasize that Christian principles can result in goals for engineering work that are similar in nature to those expressed by secular institutions. The summary of PEO themes included in Table 3 could be used as a benchmarking tool for Christian institutions as they consider revising their own PEOs and SOs for the purpose of establishing comprehensive standards for graduates that reflect professional as well as faith-based expectations. Although each Christian institution may prefer to emphasize some values over others, and not every program should feel compelled to address every theme identified in this study, using these themes as a yardstick could help Christian institutions to reflectively and explicitly consider what best fits with their institutional mission and tradition. Additional insights might be gained by comparing PEOs and SOs within the Christian and non-Christian categories, to see what other factors contribute to the inclusion of various themes.

Finally, it would be interesting to compare the PEO and SO themes to mission statements and other marketing messages used to promote Christian engineering programs. It could be the case that the distinctiveness of a Christian approach comes through much more at the mission statement and marketing level than it does in PEOs/SOs. Since SOs in particular provide accountability for emphasizing certain content within the curriculum and course structure, careful consideration of SOs within the context of the themes revealed in this research could be helpful in encouraging concrete manifestations of faith-based intentions. All Christian institutions can be challenged to make sure that messages reaching prospective students and constituents are being faithfully actualized in our classrooms.


\(^{2}\) http://www.christianengineering.org/resources-career-opportunities/christian-engineering-education-programs (referenced 4/24/2019)
Would It Naturally Happen?
– Faith and Engineering Integration at a Christian University

Jianghong (Esther) Tian*

Abstract

In 2016, at Eastern Mennonite University, we started a new Engineering program. We emphasize service-learning experiences in our program. Students are also required to take core curriculum courses in areas such as Christian faith in our university. With the help of these built-in curricular elements, does faith animating learning (Davis 2017) in engineering happen on its own, or do we need to do something more deliberately to achieve it? This is a particularly important question for us to address when developing and implementing our engineering curriculum.

To that end, I have conducted surveys and interviews with students in the Engineers for a Sustainable World (ESW) club to learn about how they have experienced faith and learning in the engineering program at Eastern Mennonite University (EMU), with a goal of a systematic approach to integrating faith into our engineering curriculum. From this study, I found that students understood the importance of serving others and recognized the importance of Biblical morality in engineering study and practice. However, they are less sure about using Biblical illustrations and presenting Biblical truth to address issues in engineering. Students would like to see examples of faith in action in real-world situations and desire systematically organized discussions about faith and engineering. They noted that the service projects in the ESW club have helped them gain knowledge of faith applied in engineering.

This study has helped us decide to include a unit on faith and engineering integration in the Engineering Ethics course. Students also expressed that they would appreciate group discussions with various topics and different group sizes.

Keywords: service-learning, faith and engineering integration, curriculum

Introduction

We started our Engineering program (with two concentrations: mechanical and computer engineering) in 2016. What would the uniqueness of our engineering program be? What would an engineering program in a Christian liberal arts university entail? We asked these questions at the conception of the program, and we continue to address them today.

Choi (2015) provided views for the question, how Christian higher education in engineering may be directed, in six aspects. The author suggested, “we need to raise our future engineers with visions and callings from God, […] and] should help students to cultivate characters and attitudes that are suitable for mature and responsible Christian engineers who are not of the world but are still actively living in the world in order that they may transform the world.” Brue

*Eastern Mennonite University, Harrisonburg, VA
(2015) suggested sowing seeds of grace in an engineering profession and preparing the soil for grace via an engineering curriculum. Jordan (2015) observed that Christian worldview construction is the liberal arts component of a curriculum such as literature and philosophy, while disciplines such as physics and engineering might be considered minimally worldview oriented.

In the process of developing our engineering program, we have considered collaborations with various departments in the university as well as organizations outside of the university concerning the integration of engineering education and faith. For example, we consider collaborating with the Bible and Religion Department in the development of our new Engineering Ethics course, where they offer Ethics in the Way of Jesus course. Also, the cross-cultural study is an integral part of students’ experience at EMU. We plan to develop and implement a cross-cultural program via collaborations with the Mennonite Central Committee, a worldwide ministry of Anabaptist churches, for humanitarian projects.

While exploring the best practice of and a systematic approach to integrating faith into our engineering curriculum, I, further, turned my learning to my students. I conducted a research study titled “The course of faith animating learning in engineering at EMU.” The goals of this study were (1) to learn about the current status of faith integration in engineering at EMU; (2) to determine the path we should take to implement faith integration in our engineering curriculum.

Methods

I conducted surveys and interviews with students in the Engineers for a Sustainable World (ESW) club at EMU to first learn about how the students have been experiencing faith and learning in our engineering program. The ESW @ EMU club is a project-orientated club that promotes sustainability around campus and beyond. Some non-engineering students are members of the club in addition to the many engineering students. The reason that I chose this group of students for the study was that they experienced service-orientated learning opportunities through team projects in addition to their regular course work.

The survey and interview questions were listed in Table 1 (a) and (b), respectively. The first eight questions were adapted from Halsmer et al. (2016). The first six questions used a Likert-type scale listed under Question 1. The responses were analyzed using Excel.

Table 1 (a) Survey questions

1. I have knowledge and understanding of how Christianity and a Biblical worldview relates to engineering.
   - Strongly Disagree  - Disagree  - Neutral  - Agree  - Strongly Agree
   - 1 2 3 4 5

2. I understand the relevancy of Christianity and the Bible to learning engineering, and vice versa.

3. I can use Biblical illustrations and examples to shed light on academic issues in engineering.
4. I can present Biblical truths and principles to address current issues in engineering.
5. I understand how Biblical morality and ethics are important in the study and practice of engineering.
6. I understand how knowledge of engineering is important for serving others, both materially and spiritually.
7. Please provide further details on any of the above statements:
8. What suggestions would you give for improving faith and engineering integration?
9. I gain my knowledge of faith applied in engineering through (circle all that apply)
   Experience in ESW through service learning
   Engineering classes
   Math and sciences classes
   Humanities classes
   Church, family, and friends
   Others (please specify):
10. Would you like to see a course (maybe one credit including assigned reading, in-class discussion, and reflective writing, for example) dedicated to faith and engineering integration? (circle one)
    YES
    NO

(b) Interview questions
1. What and how does ESW experience help you grow in faith?
2. How does your faith motivate your learning in engineering?
3. How important is it to you to integrate faith and engineering?
4. What do you like that is happening at EMU in regard to faith and engineering integration?
5. What would you like to see happening at EMU in regard to faith and engineering integration?

Results

The project is a baseline study, through which I seek to learn about students’ perception of the topic of faith-animated learning in engineering. This will help us plan and implement faith integration in our engineering curriculum.

The survey results of the first six rating questions were summarized from responses of fifteen engineering students and shown in Figure 1. I graphed the responses to the first two questions in Figure 1(a), questions 3 and 4 in (b), and questions 5 and 6 in (c). Students felt they somewhat understood the relevancy of Christianity and the Bible to engineering (Figure 1(a)). However, they were less confident about using and presenting Biblical truth in engineering (Figure 1(b)). They were very positive about the importance of Biblical morality and serving others (Figure 1(c)).

Many students provided further details regarding their responses to the six rating questions. For example, Student 1 said, “I think that anything can be integrated with faith and you should do all that you can with faith as a foundation.” Student 2 commented, “I feel like I have a strong moral compass and have some understanding of the relationship between responsible
engineering and faith, but I don’t know that I have experienced the faith being emphasized in classes.” Student 3 suggested, “I would agree most strongly with the last question about using engineering as a tool to serve others. However, I am not sure that this is best done by viewing the work of engineering through a Christian or faith-based lens. I think the work of helping others through engineering can be carried out in many different ways.” Student 4 said, “Stewardship is an important element of Christianity, and it is highly prioritized in ESW.”

Q1: I have knowledge and understanding of how Christianity and a Biblical worldview relates to engineering.
Q2: I understand the relevancy of Christianity and the Bible to learning engineering, and vice versa.

Q3: I can use Biblical illustrations and examples to shed light on academic issues in engineering
Q4: I can present Biblical truths and principles to address current issues in engineering

Q5: I understand how Biblical morality and ethics are important in the study and practice of engineering
Q6: I understand how knowledge of engineering is important for serving others, both materially and spiritually

Figure 1. Survey responses to the six Likert scale questions.
When students were asked where they had gained their knowledge of faith applied in engineering, the category “Church, family, and friends” scored the highest (13/15) followed by “Experience in ESW through service learning” (9/15), and “Engineering classes” (8/15), then “Humanities classes” (7/15). I was a bit surprised by this result. I thought we had not given ample time and space for the faith and engineering discussions in our engineering curriculum, yet students were able to pick up the information.

Students offered suggestions for improvement of faith and engineering integration. Some of the responses were: “Having more discussions about ethics and faith in our engineering classes”; “Look at more current issues in engineering and analyze how they relate to faith”; “Perhaps by suggesting or requiring other courses here at EMU focused in this area, not only the core Bible credit”; “Maybe a class examining engineering in the Bible, and how the Bible ‘tells’ us to engineer”; “Also with ESW doing service events and talking about faith”.

I certainly saw students desire more learning in this area. Out of the engineering students, eleven of the fifteen wanted to have a suggested 1-credit course dedicated to faith and engineering integration. I also asked the non-engineering major students in the ESW club their opinions on this topic. Eight of the nine students embraced the idea of a new course. They wanted to make sure that other majors would be welcomed in the proposed course. “If such a 1-credit course is in fact offered, it may be beneficial to make it include CS (or even math) as well, as both will encounter similar issues regarding faith and technology.”, one student said.

I also interviewed eleven of the students to further the discussion. I found that students appreciated the community we built around the Engineers for a Sustainable World club. They recognized that the projects they did in the club were beneficial to the environment as well as encouraged stewardship. They all believed that faith and engineering integration was important. They talked about how their faith motivated them to help others, to be diligent, and to have a purpose in life. Some of them felt the calling of studying engineering. Speaking about the future, they all expressed the desire to have more discussions about faith and engineering either in a designated course or embedded in different courses. One student observed that faith meant different things for different people and hoped that would be taken into account in a class discussion.

Discussions

In this study, I learned that an engineering program in a Christian liberal arts university needed to emphasize faith-animated learning intentionally. One of the areas in EMU’s core curriculum is Christian faith with the goal for students to be able to “articulate Christian approaches, explain Anabaptist faith traditions and recognize expressions of these approaches and traditions in contemporary life” (EMU Core Curriculum, 2019). However, the connection between faith and engineering may not naturally happen for students. They, in fact, would like to have more discussions and see real-world examples as one student suggested, “we could get other people’s perspectives and how they integrate their faith into their job.”

Students have recognized community building and service learning in the Engineers for a Sustainable World club. However, we have not intentionally talked about faith while working on
our projects. This club presents a venue where we can have discussions at our club meetings and invite speakers in the field of engineering to talk to the club about their faith journeys.

Ultimately we would like to incorporate faith-animated learning in our curriculum. Our program is new. We have not established a thorough approach as Sikkema and Vander Werff (2015) did, where they had a set of five distinctively Christian guiding principles for engineering that they implemented and evaluated in their civil engineering curriculum. Che (2017) focused on “the development of a system of thinking that related engineering with theology”. Nonetheless, we have decided to have a faith and engineering integration unit in the Engineering Ethics course that we will offer in the next academic year for the first time. We plan to have assigned readings and reflective writings, in-depth in-class discussions, case studies, and invited talks. This is a starting point. We will determine the best practice of and a systematic approach to integrating faith into our engineering curriculum.

In addition, I am continuing the interviews with students who have completed their cross-cultural learning, which is another core requirement at EMU with a goal for students to “develop a critical awareness of themselves and others in local and global contexts” (EMU Core Curriculum, 2019). I want to do a comparative study of their views on faith and engineering before and after the cross-cultural experience. Also, I have been selected into the Lilly Faculty Fellows program engaging the intersections of Christian thought and practice with the academic vocation. This will provide an excellent opportunity to further my learning and to help advance the integration of Christian faith and academic practice at EMU. My hope is to instill faith into students’ learning at EMU and thus better prepare them to serve each other and to serve God.

Acknowledgment
The study is supported by the Scholarship of Teaching and Learning program via an NSF grant titled Faculty-Led Institutional Transformation for Teaching Diverse Learners in STEM (NSF Award #1611713).

References


Opportunities for Faith & Learning Integration in a Mechanical Engineering Instrumentation & Measurement Course

Joseph B. Tipton Jr.*

Abstract

How might a Christian worldview affect an instrumentation and measurement course both in content and practice? This paper attempts to answer this question and then utilize the answers at a Christian university to improve such a course.

Approaching the question of worldview begins with an attempt to understand some of the tacit assumptions and ideologies present in the “default” engineering curriculum as inherited from secular institutions. Among them is the fact/value dichotomy which views empirical data as (hard, disembodied) fact while other forms of knowing are demoted to (soft, personal) opinion. This stands in direct contrast to the Christian worldview and – if left unchecked – fosters a form of “knowledge snobbery” among engineering students situated in a liberal arts university.

These revelations are used to suggest improvements in an instrumentation and measurement course. One area in particular is measurement uncertainty. The adage of Segal’s law – “A man with a watch knows what time it is. A man with two watches is never sure.” – captures the difficulties and “messiness” involved when embodied minds attempt to make empirical measurements in the physical world. Students are confronted with this in repeated measurement labs. Lab report deliverables encourage students to evaluate measurement comparisons and reflect on epistemological connections with their coursework across campus as they consider what “counts” as knowledge.

Results after two course cycles of implementation reveal the challenge of putting faith into action in the vocation of teaching as well as the challenge of reintegrating disciplines that have become siloed by the prevailing worldview in higher education. Sustained and voluntary discussion group meetings yielded fruitful outcomes which points to the beneficial role of historical Christian practices in the classroom.

1. Introduction

1.1. Background/Motivation

This author has worked in engineering education for almost a decade and found himself surprised to have only recently felt a challenge to address the question, “What is the purpose of a University?” Wendell Berry provides an answer that speaks to the holistic aspirations of higher education:

"The thing being made in a university is humanity. Given the current influence of universities, this is merely inevitable. But what universities, at least the public-supported ones, are mandated to make or to help to make is human beings in the fullest sense of those words – not just trained workers or knowledgeable citizens but responsible heirs and members of human culture. If the proper work of the university is only to equip people to fulfill private ambitions, then how do we justify public support? If it is only to prepare citizens to fulfill public responsibilities, then how do we justify the teaching of arts and sciences? The common denominator has to be larger than either career preparation or preparation for citizenship. Underlying the idea of a university – the

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bringing together, the combining into one, of all the disciplines – is the idea that good work and good citizenship are the inevitable by-products of the making of a good – that is, a fully developed – human being. This, as I understand it, is the definition of the name university." [1]

The next question for the author at his institution is, "What is the purpose of a Christian University?" Or put another way, "What is the purpose of a Christian University education?" It seems like this is important to Christianity for, as Wilkens observes:

"Wherever Christianity has taken root, one of the first things Christians have done is found, fund, and staff schools of all types. The universality of this practice would indicate to most observers that Christians believe that education is central to our identity." [2]

Indeed, God's Word has much to say about the "life of the mind":

- "Love the Lord your God with all your heart and with all your soul and with all your mind and with all your strength." [3, Mark 12:30]
- "Finally, brothers and sisters, whatever is true, whatever is noble, whatever is right, whatever is pure, whatever is lovely, whatever is admirable—if anything is excellent or praiseworthy—think about such things." [3, Philippians 4:8]
- "Do not conform to the pattern of this world, but be transformed by the renewing of your mind. Then you will be able to test and approve what God’s will is—his good, pleasing and perfect will." [3, Romans 12:2]
- "And whatever you do, whether in word or deed, do it all in the name of the Lord Jesus, giving thanks to God the Father through him." [3, Colossians 3:17]
- "The Son is the image of the invisible God, the firstborn over all creation. For in him all things were created: things in heaven and on earth, visible and invisible, whether thrones or powers or rulers or authorities; all things have been created through him and for him. He is before all things, and in him all things hold together." [3, Colossians 1:15-17]

Upon reflection of these passages, it has slowly dawned on the author (albeit quite belatedly) that Jesus Christ should affect the entire educational process (both formal and informal) including why one learns, what one learns, and how one learns. And in the special role of a university professor this corresponds with why one teaches, what one teaches, and how one teaches.

Wilkens summarizes the call to action thusly:

"The Christian confession calls us to faith, a faith that shapes all that we see, think, and do. Thus, for those whose vocation is to minister through education, the way we understand the relationship between faith and reason is not a peripheral matter. Instead, it is at the center of the way we engage in our ministry.” [2]

As an engineering educator placed in a Christian university, the author reads this as more than a value-added proposition and more of a weighty, fundamental challenge. For one, Christians are called to be "in the world but not of it." This requires serious contemplation and work especially with a degree as world-oriented as engineering. Furthermore, James reminds us through Scripture that "Not many of you should become teachers, my brothers, for you know that we who teach will be judged with greater strictness." [3, James 3:1]

1.2. The Current Default and the Christian Challenge
Whether we know it or not, we all approach our life in the world with a worldview or a lens through which we filter and interpret information.

"A worldview provides a discrete picture of reality based upon reasonable faith and observation. . . . A worldview provides a framework for interconnecting the diverse components of reality. It also provides direction for inquiry. . . . Specifically, a Christian worldview is developed by organizing knowledge gathered from the world around us (general revelation) and knowledge from beyond our natural boundaries, such as the sacred Scripture (special revelation). Ultimately, though, all philosophical presuppositions that construct any worldview are based upon faith." [4]

Several scholars have observed that most faculty in Christian academic programs have received their training at secular universities. We have - probably unknowingly - continued to operate in a worldview that is foreign to Christ:

"American Christian higher education is currently focusing on the recovery of integrating a Christian worldview with 'secular' discovery. . . . This intentional re-integration of all truth ('sacred' and 'secular') distinguishes the experiences of Christian college students. Ultimately, the process of integrating faith and learning must be done intentionally. To be intentional, one must understand it.

"The formal training of most university educators, including Christian college educators, was completed at a secular university. At these institutions, a variety of worldviews . . . have more often than not replaced Christian theism as the guiding philosophy underlying the study of a particular discipline. In addition, the increased specialization within the academy has 'bred fragmentation, rather than integration, of knowledge.'" [4]

Also,

"Christian faculty members, having been trained in such institutions, have typically received little or no guidance in relating their graduate training to their Christian faith. As they begin their professional careers, then, they are in fact confronted with two 'separate and disjoint bodies of knowledge and belief.'" . [5]

And,

"... even in institutions committed to faith, the fact/value dichotomy, which dismissed from the beginning the possibility of faith-learning integration, had made deep inroads even into Christian education. Perhaps more significant is that this bifurcation of fact and value was never explicitly advocated. Neither was it examined. I was never taught this view; I was taught through the filter of this view. By the end of my formal education, it seemed self-evident that this was how education should work." [2]

If the quoted authors are correct, this is much more of a deep and systemic problem than many realize. To drive home the depth of the challenge, the list below compiles examples from the literature that are deemed NOT sufficient modes of faith-learning integration:

- praying in class [6]
- sharing devotional thoughts, stories, readings, or spiritual quotations [6]
- offering spiritual input [6]
• quoting the Bible to "prove" an academic idea [6]
• being a Godly person [6]
• striving for personal and professional excellence [6]
• spiritual formation programming within the curriculum and co-curriculum [4]
• encouraging personal relationships between the educator and student [4]
• an auxiliary or preparatory activity [like prayer before class] [4]
• having biblical or theological courses as a graduation requirement [4]
• addition of biblical or Christian theological precepts as illustrative examples within any particular discipline [4]
• protective atmosphere [7]
• cultivation of personal Christian living on the part of the faculty member [5]
• using academic disciplines as a source of illustrations for spiritual truths [5]

As Beers explains:

"These programs and activities are important for equipping the saints and challenging the seeker. But in themselves they fall short of the basic task of integrating faith and learning, which is the acquisition, organization, and presentation of knowledge informed by a Christian worldview." [4]

So what does the Christian Worldview look like in a university in general and an engineering program in particular?

1.3. Recovering (or Nurturing) the Christian Worldview

1.3.1. Attitudes toward Work and People

First, the Christian worldview should affect the attitude of Christians in their lives and vocations. Holmes says, "The most important single factor in the teacher is the attitude toward learning" [7]. This is echoed by Hughes who argues that teaching from a Christian perspective means teaching with wonder and teaching with passion [8]. In this case, what we do may not be that different, but how we do it or approach it should look different.

1.3.2. University-Wide Impact

Moving toward increasing specialization, the Christian worldview should affect the university as a whole. The default mode of operation in many higher education institutions could be deemed a multiversity. The Christian worldview offers a vision of a true uni-versity with theology as a uniting core. Hughes sources Paul Tillich in arguing that the principal task of religion is to provide answers to our ultimate questions including:

• "How can I cope with the inevitability of death?"
• "Am I an acceptable human being?"
• "Is there any meaning in life, and if there is, what is it?" [8]

No matter their academic discipline, students at a Christian university should be actively wrestling with these questions. Furthermore, Hughes sources Sawatsky who "... argues that in addition to integrating learning with faith understood as a noun, Christian scholars should also integrate learning with hope and love..." [8].
Another area of impact by the Christian worldview is with the teaching/research dichotomy. The secular world is very focused on university rankings according to the Carnegie classification system whereby the R1 institution stands as the epitome of educational excellence. In their book, *Faith and Learning*, Allen and Badley argue instead that "[t]he scholarship most valued at a T1 institution should be scholarship that engages, involves, and shapes students. . . . The three essential aspects of faculty work at a T1 institution are: to teach, to shape, and to send . . ." [9, pp. 209].

1.3.3. Engineering College-Level Impact

"The level to which the subject matter of any discipline's body of knowledge differs, when seen through different worldviews, is a matter of degree" [4]. At a Christian university, it is easy to expect philosophy and theology courses to look quite different from similar courses at the secular, state university. The differences in engineering coursework appear to be less evident and more nuanced. In a way this will take more effort and determination on the part of engineering faculty. We expect our students to take their liberal arts courses seriously and be lifelong learners. Similarly, the engineering "[f]aculty members must be encouraged to read, study, and teach across the engineering curriculum in areas such as philosophy, biblical foundations, aesthetics, economics, ethics, history, communication, and leadership" [10].

The "faith in action" paradigm also applies to engineering education from a Christian worldview. As Beers observes, "He [Mannoia] argues that Christian colleges have a special niche to fill - one where reintegrating the discipline is the standard. He also challenges Christian college professors to conduct research that utilizes real world problems, thus putting their 'faith into action'" [4]. This connects nicely with Boyer's Scholarship of Application/Engagement for faculty development [9, pp. 135-141]. On the part of students, this translates to the dichotomy of "taking" engineering versus "doing" engineering as described below:

"A Creating People: One of the most important grammatical corrections we can communicate to our students is that they do not “take” engineering, math, and science, rather they “do” engineering, math, and science. This is a countercultural grammatical change. The “do” in our curriculum, emphasizes the “art” of learning. We make math, we generate science, and we fashion as engineers. It is a naming process that started in the Garden of Eden. It is human and thus fallible and finite. It is also God-ordained. In it we have both a freedom and a responsibility. Our secular counterparts might encourage free-thinking innovation in hopes of creating the next Apple computer company or cure for a deadly disease. We, on the other hand, encourage free-thinking because God invites it. Do we encourage this radical creativity in our classes? Is playful engineering not outside the bounds of the Christ follower whose inspiration is the God who created the penguin?" [10]

Indeed, engineering professors can be agents of God's redeeming work through our vocations as both engineers and engineering educators:

"The process by which portions of God’s creation are opened up to be used in new, increasingly complex functions will continue to occur regardless of whether Christians are involved or not. Without Christian involvement, the current trend of secular culture-making seems to indicate a continuing movement toward assumptions and motivations that are humanistic (e.g., saving the world through our engineering abilities) or
naturalistic (e.g., preserving the non-human creation in a form uninfluenced by humans). As Christian engineers, we have been tasked as agents in Christ’s reconciliatory work.

"Based on the biblical mandate that God has established in using and caring for his creation, we believe that an engineering curriculum seeking to be distinctively Christian must acknowledge the unique responsibility engineers have to engage creation while recognizing the God-given cultural mandate to unfold creation for his glory and Christ’s reconciliatory work in both the human and non-human creation. Such engagement will recognize the all-encompassing, cosmonomic nature of creation and the CFR [Creation-Fall-Redemption] framework. As such, it cannot be limited to traditional engineering disciplines or missions-based engineering. Instead, the responsibility to unfold and preserve in recognition of God’s creational work and Christ’s reconciliatory work must be deliberate and holistic." [10]

1.3.4. Guiding Principles

The engineering faculty at Dordt College have articulated how a Christian worldview might fundamentally influence engineering education. The guiding question posed by Vander Werff et al. is, "[How can we] . . . structure an engineering curriculum to equip and disciple students to have such an understanding of their profession and calling and to be able to serve obediently and effectively in the tasks God places before them?" [10] There is no universally agreed-upon approach to the integration of faith and learning. Several authors propose approaches as listed below.

- Four Approaches to the Integration of Faith and Learning [4]
- Four Approaches to the Integration of Faith and Learning [7]
- Strategies for Integration [5]
- Dimensions of Integration in the Applied Disciplines [5]
- Models of Faith and Reason: Marginalization, Coexistence, or Integration [2]

The disparate models presented above can easily leave one confused. Two sources, given below, offer guiding questions instead. This may indeed be the best place to start with the practice of integration in engineering courses. The Azusa Pacific University Faith Integration Faculty Guidebook lists the following guiding questions [6]:

- *How are my students "transformed" after being touched by my instruction and scholarship? How do they make both academic and spiritual progress after being touched by my instruction and scholarship?*
- *What are the academic implications within the teachings, experience, history, interpretations, and practices of the Christian faith?*
- *How does knowledge gleaned from _______ deepen the student’s understanding of faith?*
- *How does Christian faith challenge and clarify matters within _______?*
- *What will these ideas mean for my students as they relate with their neighbors?*
- *What benefit do I expect if I continue upon this course of investigation or creative production?*
- *Will sharing this "knowledge" be an expression of love to my students?*
- *Is this beneficial for others and me?*
• Will this limit, or support, my capacity to be led by God?

Beers & Beers provide a list of complementary questions to guide the integration of faith and learning [4]:

• What does my field say about what is and is not real, about what is true and what is false, and how do I understand that as a Christian?
• What does my field say about the nature and limits of knowledge?
• What methodology for gathering data does my field require before someone is able to assert their view about something?
• How can what I know and teach in my field point to God's existence and presence in everyday life and nurture a hunger to understand and know him?
• What are the ethical issues involved in my field of learning, and how do they relate to my ethical beliefs as a Christian? How does my faith promote principles of justice, charity, and concern for others within my field?
• Is Christian scholarship in my particular vocational, implicit, explicit, or a combination of the three?

2. Application to an Instrumentation & Measurement Course

2.1. Course Background

ME-3703 “Instrumentation and Measurement” is a Junior-level course in the Mechanical Engineering curriculum at Lipscomb University in Nashville, TN. This course was created by the author at another institution and has been taught in various forms over 8 times. At Lipscomb it is a 3 credit hour course offered every Spring semester that includes a 1 hour lecture on Mondays and Wednesdays with 1.5 hour lab sections on Tuesdays and Thursdays. The course covers common measurement systems, extensive hands-on use of transducers, digital data acquisition, and uncertainty analysis. Approximately two-thirds of the course consists of weekly lab assignments including load cells, strain gages, RC filters, beam vibration, temperature measurement, and flow measurement. The last third of the course is devoted to team-based, open-ended instrumentation and measurement projects. The deliverable for every assignment is an infographic slide-deck that encourages visual communication of technical information.

2.2. Knowledge Claims

Several of the guiding questions listed previously deal with knowledge claims. This author would argue that engineering education often suffers from the fact/value dichotomy which views empirical data as (hard, disembodied) fact while other forms of knowing are demoted to (soft, personal) opinion. This stands in direct contrast to the Christian worldview and – if left unchecked – fosters a form of “knowledge snobbery” among engineering students situated in a liberal arts university.

If indeed engineering students (and faculty) tend toward this distortion, an instrumentation and measurement course provides opportunity for cognitive dissonance through measurement uncertainty. The adage of Segal’s law – “A man with a watch knows what time it is. A man with two watches is never sure.” – captures the difficulties and “messiness” involved when embodied minds attempt to make empirical measurements in the physical world. Students are supposedly confronted with this in repeated measurement labs. And so the author embarked upon a journey
to encourage students to evaluate measurement comparisons and reflect on epistemological connections with their coursework across campus as they consider what “counts” as knowledge.

2.3. Phase I - Spring 2018

2.3.1. Course Modifications

In 2018, only a slight modification was made to the course assignment deliverables. The following instructions were provided to the students for the discussion and conclusions slides for each assignment:

- This should be 1-2 slides total.
- Compare your results. What do they indicate? Do your results agree within uncertainty ranges? If not, what have you missed and why?
- Suggest ways to improve the experimental apparatus if needed. Use uncertainty analysis to drive your conclusions. What contributed most to your error and why?
- This should also be dominated by visual communication. Remember, a picture is worth 1,000 words!
- What did you learn? What do you know well? What questions do you still have? (*I encourage you to consider these questions from a broader perspective. You can move beyond this specific assignment and think about how this lab assignment fits into what we have been doing thus far this semester. You can back out further and try to make connections with your other engineering coursework. You can back out even further and try to make connections with your liberal arts education... maybe even epistemology!*)

The words in italics were the new addition. Previous iterations of the course had requested student self-reflection (What did you learn? What do you know well? What questions do you still have?), but this seemed to be the first thing submissions left-off. It was hoped the added text would provide more guidance for students.

2.3.2. Assessment

The results were few. In the first lab assignment, two teams (out of ten) provided statements beyond basic reflection:

- “This experiment definitely makes us think more about uncertainty in everyday lives and the technology we rely on to be correct. For example, what is the uncertainty on a car's speedometer?”
- “This experiment really helps us to gauge our trust in products and precision of measurements throughout the world. This not only hinders our trust in some products but also bolsters our awe at some of the truly precise measurements/accomplishments that have been achieved thus far.”

In the following 6 lab assignments and open-ended project, no further attempts to make epistemological connections were made.

2.4. Phase II - Spring 2019

2.4.1. Course Modifications
In 2019, the author invited the students to an informal weekly discussion on Friday mornings. Since the lecture portion of the course met on Monday and Wednesday mornings, the students had the corresponding Friday time slot available. An e-mail announcement to all students in the course encouraged them to come if they were interested in questions such as “What is knowledge?” and “How does Instrumentation & Measurement (or even Mechanical Engineering) connect with the rest of my University education?”

Of a course enrolment of 32 students, about 10 students consistently attended the informal Friday gatherings over 11 weeks. The meetings were roughly structured over group readings and guided questions from Part 1 of Meek’s *A Little Manual for Knowing* [11]. This included chapters on Love, Pledge, Invitation, and Indwelling and also introduced the concept of tacit knowledge along with subsidiary focal integration.

### 2.4.2. Assessment

Some modest gains were made in assignment deliverables. In the first lab assignment, three teams (out of sixteen) provided self-reflective feedback. One team included a comic illustration taken from an online article dealing with science and knowledge claims as shown in Figure 1.

![Figure 1: A comic illustration from an online article dealing with science and knowledge claims [12]. This image was used in the discussion section of a student slide submission.](image)

A second team provided the following statement:

“Overall, what was learned most in this lab experiment is that we as humans truly know nothing for certain! We have many ways to analyze things that we believe to be a "sure science", but we are continuing to learn throughout the
weeks of this course that what we thought we knew to be true, we most certainly do not.”

A third team provided a truly unique and visual connection to epistemology:

![Diagram of epistemology concept]

Figure 2: A student slide submission for the discussion and conclusions portion of the first lab assignment. Used with permission.

In the following 6 lab assignments and open-ended project, one further attempt to make epistemological connections was made. A student submission included a reflection on a discussion slide saying, “Multiple measurements made in different ways provide for better results. What else can be evaluated in different ways for better results? Art, Science, Religion”

In addition, the last informal Friday meeting was a review of the semester. The students were told about this conference paper and asked how the discussions on epistemology impacted their outlook in engineering. Examples (reconstructed from shorthand notes) included:

- The idea of a “uni”-versity. We’re cocky to think only we engineers have the answers. I’m learning to take a more humble approach to seeking knowledge.
- Why are we seeking to know in the first place? We forget we’re in school to learn and not just to get a job. We’re here to grow as a person. This is not just an obligation to fulfill to get a job.
- Messing with the Arduino. [This was a student who needed to use an Arduino microcontroller to complete their open-ended project.] My first reaction is I’m not built for it. I’m not an EE. Now I’m willing to try. You can only plan so much. Eventually you have to be willing to start and try and it takes guts.
• The Friday meetings make me notice more – be more aware. I think about tacit knowledge. You know by doing.
• Uncertainty makes me question what do we know well? Life is like that. The more you know the less you know.
• Epistemology – on Fridays we talk about ideas of knowing and then we’ve been doing it in labs to see how it applies.

3. Discussion/Conclusions

Results after two course cycles of implementation reveal the challenge of putting faith into action in the vocation of teaching as well as the challenge of reintegrating disciplines that have become siloed by the prevailing worldview in higher education. Attempts to encourage self-reflection on lab assignment deliverables shows promise on the first assignment and then all but disappears in succeeding submissions. This is most likely an issue with a challenging workload more than anything else. The students are already being cognitively tasked with completing an instrumentation lab, debugging, data gathering, uncertainty analysis, and then visual reporting through slide submissions. Workload is admittedly high in this course, and it is probably unreasonable to add more material to an assignment, even if it is fundamental in nature.

Feedback (both informal from the voluntary weekly meetings and formal from course evaluations) was surprisingly positive. It is apparent that the students who attended the informal Friday gatherings continued to self-reflect on epistemological connections in the course throughout the semester and even applied what they were learning when approaching new, open-ended, design projects at the end. Thus what began as a tool to help motivate reflection on lab slide submissions became itself the primary vehicle for self-reflection in epistemology. In retrospect, Smith and Smith’s *Teaching and Christian Practices* provides a vocabulary for what occurred. “A community of practice . . . is shaped out of certain forms of participation, an ongoing process of reification that turns intentions into stable objects, the growth of a shared repertoire of meanings and behaviors, and the development of a shared imagination concerning what the group is really aiming for” [13].

Applied here, the author seems to have (inadvertently!) practiced hospitality and opened a space for contemplation, several students chose to consistently attend, and a community of practice was established. David I. Smith also suggests that, “The path that we are exploring . . . requires . . . both a continuing attentiveness to classroom repertoire . . . and an equally ongoing attentiveness to how our actions together are being framed and understood . . . Teaching in a manner shaped by Christian practices involves not only requiring behaviors but recruiting imaginations” [14]. In this course, requiring behaviors in terms of epistemological reflection on assignment deliverables was not very successful. In contrast, the informal Friday discussions were able to successfully recruit imaginations and encourage students to “see” their education and interaction with the world differently. This, in turn, gave birth to beneficial behaviors in the course.

Only about a third of the class chose to participate in the informal Friday discussions. If this is truly beneficial, then it would be good to try to increase involvement without losing the spirit of voluntary participation. In future course offerings, the author hopes to increase student participation by further exploring and purposefully applying the traditions of Christian hospitality.
Acknowledgements

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References

[NOTE – Statements from student assignment submissions have been used with permission.]

6. Faith Integration Faculty Guidebook, Version 1.1, Azusa Pacific University, https://www.apu.edu/faithintegration/resources/.
A Christ-Centered Dominion Mandate - Reflections on Integration of Faith and Engineering

David C. Che*

Overview

This is the 3rd paper documenting the author’s work on integration of faith and engineering that began at Geneva College. The other two papers appeared in the proceedings of the CES conferences in 2013 and 2017 (Che, 2013, 2017). This paper starts with a brief review of the dominion mandate as it applies to engineering and analyzes its challenges after men’s fall. Some discussions on sin and its effect on engineering followed. The benefits of God’s common grace and special grace and how these could be applied to engineering are discussed. It was concluded that a Christian higher education is of value to both believers and non-believers. For believers, it is a discerning process of a calling from God that he/she should serve God in the engineering profession. A metaphor from the Old Testament is used to illustrate this calling. For non-believers, it is a gift from God according to His common grace so that men can continue to prosper and flourish in this world. The picture of a Spirit-filled engineer is painted to point to a role model of a Christian engineer. A Christ-centered dominion mandate is proposed that would provide a structure to unite the teachings from both the Old and New Testament on the integration of faith and engineering.

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The Dominion Mandate and Its Challenges

Why do Christians pursue an engineering career? Why do more and more Christian colleges start to add engineering to their degree offerings? It comes down to a calling from God. *Dominion mandate* is one of the most foundational doctrines of the Church as it relates to the world we live in. In Genesis 1:28, the first recorded words of God to men were,

“And God blessed them, and God said unto them, Be fruitful, and multiple, and replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth.” (KJV)

In order for us to carry out this dominion mandate (sometimes referred to as *cultural mandate* or *creation mandate*), several things must be included (Slick, 2019),

1. Men and women must work together and have children who are then trained in a godly, Christian fashion to carry out the *dominion mandate*.

2. We must learn how the world operates, which requires expertise in all areas of knowledge including *engineering*, mathematics, physics, aerodynamics, agriculture, etc. This way we can better fulfill God's command. Our offspring must then be involved in all these areas.

3. The exercise of dominion must be done with wisdom, as *stewards* who are carefully and reverently acting in responsible ways with what God has entrusted to us in the world. We are not to destroy the land, overfish the seas, deplete the soil via farming, etc.

Obviously the dominion mandate is for Adam and all his descendants, which naturally include both Christians and non-Christians. After the fall, however, sin entered the world and the human race was met with significant challenges in fulfilling this God-ordained dominion mandate. As it is eloquently stated in the Foundational Concepts of Christian Education (Geneva College, 1996),

“By our relationship to Adam, as representative of the human race, we are fallen creatures. By moral revolt against God, we lost both our position of communion with God and our ability to consciously reflect God's glory, and instead became devoted to the worship and aggrandizement of self. Our fall into sin affected not only our *moral* nature but also our *intellect*, making us prone to error, and requiring divine revelation to determine ultimate standards and values in all fields. The *moral* and *intellectual* effects of sin are such that we are incapable of removing them by our own effort.” (Emphasis added)
Engineering is not only affected by sins of individuals, but also sins of institutions, as often is referred to as “institutional sins” (Bouwers, 2009). Richard Harwood also recognized the fallen nature of engineering individuals, industrial organizations, production processes, and the engineering marketplace (Harwood, 2002). “Institutional sins” are related to policies and practices of groups of people, whether the group is a company, a government, or a society. Members in a group may feel pressured to commit unethical conduct. This is different from personal sin. Examples from the Scriptures include the pressure exerted by the Israelites on Aaron to make a golden calf (Exodus 32), and the pressure exerted by the Jews on Pontius Pilate to hang Jesus on the cross (Luke 23).

The 2010 oil spill in the Gulf of Mexico is one example of an engineering failure that occurred both at a personal level and at a corporate level. According to results of a government-led investigation (Reuters, 2011):

> “In its final report on the causes of the largest offshore oil spill in US history, the commission said BP and its collaborators on the doomed Macondo well had lacked a system to ensure their actions were safe. ‘Whether purposeful or not, many of the decisions that BP, Halliburton, and Transocean made that increased the risk of the Macondo blowout clearly saved those companies significant time (and money),’ the report said.”

Individual engineers were also charged (Fowler, 2012):

> “A former engineer for BP PLC has been arrested and accused of deleting text messages detailing how much oil was gushing into the Gulf of Mexico as BP tried to staunch the Deepwater Horizon spill in the spring of 2010.”

In essence, it is the brokenness of men that leads to the brokenness of human institutions and society. To fix it, we need to address the problem at its root – the heart of fallen men. We also need to look at the bigger picture and see if there are things Christians can get involved in “fixing” the culture we live in. Richard Niebuhr in his classic Christ and Culture analyzed the various models of relationship between Christianity and civilization (Niebuhr, 2001). It gives some formal thought into the involvement of Church in the society.

It is also important to point out here that not all engineering failures are a result of men’s sins. “Human finitude,” i.e., men’s limitedness in knowledge and power (whether that is brain power
or physical strength), could be the culprit for some of the engineering failures. As it is eloquently stated (Ermer, 2008),

“The category of human finitude can easily be overlooked as a primary contributor to the risk of failure in today’s technological systems. ... While it can often easily be seen how poor ethical choices or the temptation of cutting corners for economic reasons contribute to engineering failures, the fact that we are limited by our own capabilities is not often acknowledged, especially under the influence of modernist thinking which assumes that human nature and society can be never-endingly improved by applying our scientific knowledge.”

**Christ’s Redemptive Work and Its Impact on Engineering**

Even though sin continues to taint the engineering profession both at a personal level and institution level, we still have hope. God’s saving grace continues to work its way into many people’s hearts. Once men experience a heart change, their worldview, ethics, and eventually behavior, will all change.

It was emphasized in the first two papers of this series that the doctrine of common grace is important in our understanding of roles that both Christians and non-Christians would play in engineering in order to fulfill the dominion mandate (Che, 2013, 2017). The Christian Reformed Church (CRC) in 1924 adopted the doctrine of common grace at the Synod of Kalamazoo (Michigan) and formulated what is now known as the “three points of common grace” (CRC Church, 1924):

1. The first point pertains to the favorable attitude of God toward all His creatures, not only toward the elect.
2. The second point is the restraint of sin in the life of the individual and in society.
3. The third point pertains to “civic righteousness by the unregenerate.” This means that God, without renewing the heart, exercises such influence that even the unsaved man is enabled to perform good deeds toward his fellow man.

On the first point, this “favorable attitude of God toward all His creatures,” is rooted in Christ’s redemptive work, albeit not directly. With *Common Grace* being the title of the first chapter for the section “The Doctrine of the Application of Redemption” in Wayne Grudem’s book
Systematic Theology, he noted that common grace flows indirectly from Christ’s redemptive work, “because the fact that God did not judge the world at once when sin entered it was primarily or perhaps exclusively due to the fact that He planned eventually to save some sinners through the death of His Son.” (Grudem, 1994, 2000)

Genesis 8:20-9:17 recorded the Noahic covenant that God will not destroy the earth with flood again:

And Noah built an altar unto the LORD; and … offered burnt offerings on the altar. (Gen. 8:20)

And the LORD smelled a sweet savour; and the LORD said in his heart, I will not again curse the ground any more for man’s sake; … neither will I again smite any more every thing living, as I have done. (Gen. 8:21)

While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease. (Gen. 8:22)

This covenant was made between God and all living creatures, plus Noah and his descendants, of whom we all are. In this important covenant, God extended to the human race once again the common grace that was briefly interrupted by the flood. After the flood, the dominion mandate was reiterated by God,

"And God blessed Noah and his sons, and said unto them, 'Be fruitful, and multiply, and replenish the earth. And the fear of you and the dread of you shall be upon every beast of the earth, and upon every fowl of the air, upon all that that moveth upon the earth, and upon all the fishes of the sea; into your hand are they delivered. Every moving thing that liveth shall be meat for you; even as the green herb have I given you all things.'" (Genesis 9:1-3, KJV, emphasis added).

And it is so fitting that in offering this common grace, God also re-issued the dominion mandate to men. We see that common grace and dominion mandate go hand-in-hand. It is an enabler for all men to carry out the dominion mandate.

This “enabling” can also be seen from the second and the third points in the CRC’s three-point common grace statement. God’s common grace restrain sins of individuals and society. It also enables unsaved man to perform good deeds toward his fellow man. This viewpoint also finds its
support from the Scripture, for example, in II Thessalonians 2:7, and Christian literatures (CRC Church, 1924) (Stewart, 2019). According to a Reformed scholar (Berkhof, 1979),

“[Common grace] curbs the destructive power of sin, maintains in a measure the moral order of the universe, thus making an orderly life possible, distributes in varying degrees gifts and talents among men, promotes the development of science and art, and showers untold blessings upon the children of men.”

It is widely accepted that the saving of the Noah family is a foreshadowing of God’s saving of His Church through Christ’s redemptive work on the cross. This again confirms Wayne Grudem’s earlier assertion that common grace flows indirectly from Christ’s redemptive work, “because the fact that God did not judge the world at once when sin entered it was primarily or perhaps exclusively due to the fact that He planned eventually to save some sinners through the death of His Son.” (Grudem, 1994, 2000)

**Examples of Redeeming Work**

In the context of engineering, it might be helpful to expand the meaning of the word “redeem.” According to the Random House Dictionary (Random House, 2013), “redeem” is wider in its application than “ransom” and means to “buy back, regain possession of, or exchange for money, goods, etc.” One example of the act of “redeeming” something in life is, let’s say you are taking a walk around the neighborhood, you see a nail on the road, and you stop and bend over to pick it up. You see that the nail is not rusted, so you take it home and put it in your toolbox. What you just did to the nail is you redeemed it. You recovered its value. In the process you paid a price, albeit a small one in that you took some time and effort by stopping in the middle of a walk and bend over to pick up a nail that others would simply ignore and walk right by. You took the trouble to clean it up and put it in your toolbox. You not only redeemed the nail, you also saved a potential driver’s tires from getting punctured by this very nail. You did some good.

Another example might be that you see a pop can or a drink bottle thrown away on a public parking lot. You pick it up, you can’t find a recycling bin nearby. You take it home and put it in your recycling bin. You were a good steward of the earth. You recovered the value of the can/bottle. You redeemed it. The recycled can or bottle will be put to good use -- maybe it is eventually turned into a metal can that contains food to relieve hunger in a disaster relief
operation. Your actions might not be spectacular, but they are significant in God’s eyes nonetheless, as you faithfully obeyed His commands to be a good steward of the earth He put in your care.

One more example: let’s say as an engineer you were involved in an engineering project. Due to your Christian conviction, you convinced your unbelieving coworkers and/or your unbelieving boss not to cut corners in a particular design. Years later you found out that a competitor’s product got recalled due to a similar design where they did cut corners in order to save a few bucks. And now this competitor is paying millions on recalls. What you did at your company was simply participating in Christ’s redeeming work in the world. You saved your company millions of dollars by putting your Christian faith and ethics into your engineering practice. You have been faithful in the work He called you to do. You have allowed Christ to work through you in witnessing to the world His good deeds and marvelous character.

Two Balancing Pairs

Some philosophers of technology such as Ellul (Society, 2019) painted a pretty bleak picture of the technological world. As quoted by Ferre,

“Ellul and his followers tend to assert that the problems of modern technology are too heavy to bear. As Christians they think that modern technology is an autonomous, demonic power. In The Technological Society – but also in later books such as The Ethics of Freedom and The New Demons – Ellul seems to argue that man is not the master of technology, but its slave and its victim. Man is the victim of a universal, artificial, monistic, self-directing power.” (Ferre, 1995)

As Egbert Schuurman, a Dutch philosopher of technology, noted however, this despair is not biblical since it “does not leave open the possibility of deliverance.” (Schuurman, 1984)

According to Ferre, Schuurman’s view of history from a biblical perspective had “four major elements, presented in two pairs of principles that collide with and balance one another.” The first balancing pair is,

(1) **Cultural mandate** from Genesis – “Man has received the calling to dress or to build the creation, and to keep it (Genesis 2:15)”
(2) **Fall** – “Man forsook his original task” – after which the culture mandate was no longer possible for human efforts, history ceased to be wholesome, and nature became threatening, and human technology was distorted by sin.

The second balancing pair is:

(3) **Redemption** – “God himself provides redemption” and breaks the power of sin over history decisively through the coming of Jesus Christ

(4) **Disobedience and secularization** – “not everyone lives within the dynamic power of the creation, which is in Christ the power of the Kingdom of God.”

“Ellul runs the danger, Schuurman warns, of taking (2) and (4) without the good news of (1) and (3). The dangers of sinful disobedience have indeed been greatly reinforced by the powers of modern techno-science, but despite its intimidating face, contemporary technological secularization cannot finally force the meaning of history against the will of God.” (Ferre, 1995)

The debate boils down to this question – who rules the world? Satan or God? We have to admit that according to 1 John 5:19 “the whole world lies under the sway of the wicked one.” It seems Satan is in control of the affairs of the earth. It seems man has lost the dominion of the earth to Satan once and for all since the fall. If this is all that is to it, then Ellul would be right – the problems of modern technologies would be too heavy to bear. Actually we would all eventually not only be enslaved by technology but also killed by it, according to this theory, because it has been Satan’s wish all along to “kill, steal and destroy.” (John 10:10)

But the good news of the gospel is, “And Jesus came and spoke to them, saying, ‘All authority has been given to Me in heaven and on earth.’” (Matthew 28:18) Ephesians 1:20-22 pointed out that God “raised Him [Christ] from the dead and seated Him at his right hand in the heavenly places, far above all principality and power and might and dominion, and every name that is named, not only in this age but also in that which is to come. And He put all things under His feet.” We need to acknowledge that fallen men cannot have dominion over God’s creation on their own. Men need Christ. Whether it is enabled through common grace or special grace, men need Christ. True dominion belongs to Christ, as it is said in 1 Peter 5:11,
“To Him be the glory and the dominion forever and ever. Amen.”

The solution of sin problems rests with the gospel, whether directly or indirectly, as has been analyzed above. The whole world needs Christ’s redemption whether they acknowledge it or not. We need to have a balanced approach - on the one hand we fully recognize the effect of sin in all areas of life and would want to be fully prepared for the worst to happen; on the other hand we also are fully aware of the excellency of Christ’s redeeming work and know that God is still sovereign over all His creation. We hope for the best and prepare for the worst. We know the best is yet to come. We know our hope will not be in vain. We can rest in God’s goodness and benevolence.

“These things I have spoken to you, that in Me you may have peace. In the world you will have tribulation; but be of good cheer, I have overcome the world.” (John 16:33)

**Engineering as a Calling - A Metaphor from the Old Testament**

When Joshua led the Israelites to conquer Jericho, God instructed the Israelites to kill every living thing including the animals, but all the precious metals (silver and gold) and vessels of bronze and iron were allowed to be kept,

> “Now the city shall be doomed by the LORD to destruction, it and all who are in it. Only Rahab the harlot shall live, she and all who are with her in the house, because she hid the messengers that we sent. And you, by all means abstain from the accursed things, lest you become accursed when you take of the accursed things, and make the camp of Israel a curse, and trouble it. But all the silver and gold, and vessels of bronze and iron, are consecrated to the LORD; they shall come into the treasury of the LORD.” (Joshua 6:17-19, emphasis added)

> And they utterly destroyed all that was in the city, both man and woman, young and old, ox and sheep and donkey, with the edge of the sword. … But they burned the city and all that was in it with fire. Only the silver and gold, and the vessels of bronze and iron, they put into the treasury of the house of the LORD.” (Joshua 6:21, 6:24, emphasis added)

This is proof that at least the engineering materials are not accursed. Note that these are “engineered” materials, not raw materials from nature. In other words, these metals were extracted from ores and processed by the hands of these sinful people whom the LORD ordered destroyed. But the LORD allowed the metals to come into the treasury of the LORD, after they
were consecrated to the LORD. If this is a picture of our own salvation, Rahab represents our soul (that was saved), and the other city dwellers represent our sinful desires and flesh (that were all killed, as stated in Galatians 5:24, *And they that are Christ’s have crucified the flesh with the affections and lusts*), and the precious metals and metal vessels represent our career and training (consecrated to God and preserved). Some of us got our engineering education and training when we were not yet saved. If we give ourselves to the Lord, He is pleased to accept us as His adopted son and servant, and He will allow us to continue to use our engineering training and skills to serve him. As Paul said in I Corinthians 7:17 (KJV),

_But as God hath distributed to every man, as the Lord hath called every one, so let him walk._

Later on, he wrote in I Corinthians 7:20 (KJV) again,

_Let every man abide in the same calling wherein he was called._

The context of this was Paul’s instruction to those who were servants. In today’s society, since there are no servants any more, the application of this verse is that we are to stay in the same career/status after we are saved. God did not call us all to abandon our profession/career to pursue the so-called “fulltime Christian ministry.” Our service in our professional careers is pleasing to Him and acceptable to Him after it has been consecrated to Him. A corollary would be that in the new heaven and new earth the management and engineering skills we acquired today would still be useful. This is because the new heaven and new earth still are made of materials, so engineering should still apply in some form. Even if it completely changed, we would still have all the time in the world to learn and figure it out.

Our learning today counts in His Kingdom. This is the Reformed view of calling and vocation. It is biblical. Engineering students like and need to hear this, as this motivates them to continue to work hard in their studies in engineering. It gives them incentives to do well in their chosen professional fields. The following is a quote that is fitting to conclude this section,

“When our primary sense of identity is that of belonging to a God whose mission is the redemption and healing of this world, our other sources of self-identity are not erased but re-purposed. Rather than serving to define us, they now serve to bring about healing and wholeness to a world in desperate need of both. When our true identity is found in God, those things that
previously identified us are redemptively aimed toward ends we never would have previously thought possible.” (Shawna and Tim Gaines, 2012, emphasis added)

The Spirit-Filled Engineer and the “New” Dominion Mandate

Another approach to the integration of faith and engineering is devotional. As Christian engineers, we ask the Lord to fill us with His Spirit each and every day. We devote ourselves to His service each day. A role model of this approach can be found in Exodus 31. His name is Bezalel, the son of Uri. He was called by God to be an engineer (Exodus 31:2). He was filled with the Spirit of God, in wisdom, and in understanding, and in knowledge, and in all manner of workmanship (Exodus 31:3). He was empowered by God to engage in engineering design, to work with various precious metals, stones and timber, in order to build the tabernacle of the congregation, ark of the testimony, and the utensils and furniture, etc. in it. God also sent him fellow coworkers to help him. In Exodus 31:6b, it revealed God’s double blessing on him and other Christian workers: “… and I have put wisdom in the hearts of all the gifted artisans, that they may make all that I have commanded you.”

According to the Jewish tradition, the older brother inherits a double portion. Jesus is our older brother (Hebrews 1:6, 2:10-12, etc.). For those of us who are in Christ, we receive a double blessing as well. We have both common grace and special grace. It is grace upon grace (John 1:16). We should be grateful to Him not only for this life, but also for eternity.

To demonstrate how to live a Spirit-filled life in the engineering profession, let’s look at another example. A Christian engineer was working in a routine job for years. The line of work was not very challenging and sometimes there were politics involved. One day, after he saw the film “Thereses” (Defilippis, 2006), he was touched by the central character of the movie – Saint Thérèse of Lisieux (Flower, 2013). Her faithfulness to the Lord in little things of daily life deeply convicted him. He repented of his sins and went back to work with a renewed faithfulness. He would follow up with coworkers on things he was supposed to do more faithfully. This is another manifestation of Christ’s redemption at work in a saint’s life. Nothing spectacular – he was simply doing what the Lord called him to do in life. It is a testimony of Christ’s great love and saving grace, and a testimony of the engineer’s response to that great love, as it is beautifully said in Ephesians 2:10,
For we are His workmanship, created in Christ Jesus for good works, which God prepared beforehand that we should walk in them.

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. This is the true essence of a “new” dominion mandate – a Christ-centered dominion mandate. The reason there is a quotation mark on “new” is that it is not really new – in the Old Testament there were already craftsmen being filled with the Holy Spirit carrying out God’s work (Exodus 31:2-6) - Spirit-filled engineer is indeed Christ-centered engineer, is it not?

Even for non-believers, as God’s image-bearers, they have a need to depend on God, as all his strength, wisdom and creativity are gifted by God. “For of him, and through him, and to him, are all things: to whom be glory forever. Amen.” (Romans 11:36)

Other Scriptures that support the Christ-centeredness in fulfilling the dominion mandate are I Peter 4:11 and Colossians 3:17.

Monsma et al said it well in the opening paragraph of chapter five of the edited classic Responsible Technology,

“If we are to find our way as exiles in a secularized culture, foreign to the Christian’s beliefs and commitments, we need a guide. We cannot go by our own lights. The spirit of this age is too strong and the way back home too long for us to find our way without assistance.” (Monsma, 1986)

It went on to say that the only true guide is “God’s will and his norms for our lives.” And the overarching principle of all the normative principles is the norm of love. (Monsma, 1986)

Chapter 4 of Monsma et al’s book is an excellent essay on Christians’ call to participate in the cultural mandate. There is a tension for Christians, as mentioned in page 55-56 of this book,

“As Christians we are to be doers of technology seeking to fulfill their God-given mandate to shape and mold culture in keeping with God’s normative will. But in fulfilling the cultural mandate, we take part in the line of creation and redemption, while the prevailing line of our culture is that of the Fall and secularization. Thus we are exiles in our own culture – exiles in
Babylon. To be an exile is to be caught in the tension of being redeemed from sin, yet still being sinful and still living in a world of sin.”

The “new” dominion mandate ties the cultural mandate in the Old Testament to the gospel in the New Testament. The finished work of Jesus Christ enables all Christian engineers to live fully before God in all we do. It makes it possible to do technology “wholly.” We will not be perfect on this side of heaven, but at least we can start to taste what a holistic “heavenly engineering” will look like. As Christian engineers, we are each empowered by the Holy Spirit to do God’s will. It won’t be easy. It is the way of the cross ahead of us. As testified by the Flint water crisis “hero” Marc Edwards (Teaching Ethics in Light of Flint and Volkswagen, 2016)

“They (students) are taught that if you follow the rules, things will work out for you. That’s not true. Ethical dilemmas in the real world are gut-wrenching, life-altering experiences.”

There will be sacrifices and persecutions if we wholly follow God’s leading. But we know by faith that it is worthwhile and there is an eternal reward waiting for us. The way of the cross opens new doors for Christians to serve God in engineering like never before. But this new way is hidden from the world - it can only be seen through eyes of faith.

In Chapter 5 of the Monsma book, it mentioned a “wholeness” that is unique to a Christian approach to technology,

“Essential to a Christian approach, therefore, is the confession that there is only one true God and that all things are from him, unto him, and through him. Accordingly, there is a wholeness that marks his creation and the service that his creatures are to render to him. And although this wholeness was broken by sin, the possibility for wholeness has been restored through the redemptive work of Jesus Christ. Although technology is only one means of culture-forming, it is a means that has remarkable power to affect virtually all aspects of culture. Retention or restoration of wholeness is thus crucial to our perspective on technology. It is all the more crucial because human beings have too often forgotten to take the demands of wholeness into account in their technological activities, and consequently they have concentrated their attention and powers on one part of their existence to the exclusion of others.”
The Role of Christian Engineering Education

A Biblical worldview is incomplete unless it encompasses a view of the world to come. Until a man is equipped with an eye of faith, he cannot see the unseen and the world to come. Before conversion happens, a Christian’s ethics is involuntary and tainted. Therefore faith, either Reformed or non-Reformed, is foundational to Christian engineering education. Without a saving faith and the regenerative work of the Holy Spirit, there is no ground on which to build other things, such as a Biblical worldview. Though worldview education might help lead one to the saving faith, until a person is born again, his/her worldview is flawed as he/she is still spiritually blind and cannot see the Kingdom of God (John 3:3). One might have some head knowledge and be able to pass some Bible classes, but it will likely have no effect on his/her behavior.

James Gidley argues that even unbelievers can benefit from a Christian education due to God’s common grace:

“If it is true that God has given more common grace to a Protestant America than the Communist North Korea and China, one of the reasons seems to be that for a number of generations, many people who were not personally believers still looked at the world in a way that was deeply influenced by the Bible and to a large extent conformed their outward behavior to biblical norms. The work ethic that Max Weber (Weber, 2002) wrote about is an example of this. I don’t think we could make the case that it was only the truly born-again believers who exhibited this work ethic. In my opinion, an education from a Christian perspective is one of the ways in which God provides to unbelievers the capacity to behave in an outwardly moral way, which in turn produces great benefits to society. The education that we aim primarily at the true believers does have a benefit to the unbelievers at a Christian College – but it is not so much a personal benefit to them as a common-grace benefit to the society in which they will live and work.” (Gidley, 2013)

There is no denying that some nonbelievers are good engineers. You can see God's image in them, even though it might have been severely broken – much like a broken mirror. This can certainly be explained by God's common grace. The challenge is how one can put this broken mirror back together so it will reflect God’s glory again. We know this is not a job anyone can do except God Himself.
On the flip side of the coin, a born-again Christian, even though he/she might be a devout Christian, can sometimes act like a fool. Without continued sanctification and growth in the knowledge and grace of Jesus Christ, he/she still might not be able to reflect God's glory in words and deeds more fully. This is where a solid Christian education can help. Education can help us gain wisdom, in addition to knowledge. Christian education can help equip one to more fully use his/her potential for the Kingdom of God.

Intellectual challenge is needed to develop a mind that can think critically. With the lens of Scripture as a guide, one can put everything into its proper perspective. We need a living faith; we also need a functioning mind, and skillful hands. One might emphasize one more than another at a certain time and place, but a balanced act is what we need in the end. We may never be able to fully put our acts together this side of heaven, but that is the goal for which we need to strive.

One of the ways to help students understand God’s will for engineers is to have them read about Biblical engineering design norms (Monsma, 1986).

**Implementation in the Engineering Curriculum**

In three consecutive years (spring semesters of 2017, 2018 and 2019), the author incorporated integration of faith reading assignments in key engineering courses at Mount Vernon Nazarene University (MVNU). In addition to the “a” through “k” student outcomes stipulated by ABET, the engineering department added a student outcome “l” to capture some Christian content:

> A commendable character based on biblical principles and a Christian worldview and expressed through a life of service.

In spring of 2017, a one credit hour *Engineering Ethics* course was offered at MVNU and all engineering students were required to take it. The course covered a range of topics on the integration of faith and engineering, which included dominion mandate, common grace, responsible technology, and God’s creation from an engineering point of view. The course readings and discussions were structured around the following three resources:
1. The author’s own integration paper *Engineering through the Eyes of Faith* (Che, 2014)

Prior to each discussion session, students were expected to read and answer questions on a section of the book or paper. See Appendices A, B and C for sample discussion/quiz questions for each of the three resources mentioned above. The discussion-format of the course allows the students to explore the material together, which had been effective for increasing their engagement and interest. Course outcomes as listed in the syllabus were:

1. *Students will be able to study and reflect upon modern technology and its implications for the Christian life.*
2. *Students will recognize that doing technology is not a neutral activity but one that involves valuing of a profound, fundamental nature. The value-ladenness and the pervasiveness of technology in modern societies make it clear that all Christians, whether as consumers, citizens, and formers of culture, or as engineers/designers, need to confront the issues raised by the nature of modern technology.*
3. *Students will be able to understand that technology, as one form of human cultural activity, must be done under the Lordship of Jesus Christ.*

The course outline is as follows:

1. *Common Grace and Engineering*
2. *Integration of Faith and Engineering*
3. *Relationship between Biology and Engineering*
4. *Understanding Technology*
5. *Technology Examined: Definitions and Distinctions*
6. *Is Technology Neutral*
7. *The Cultural Mandate and Modern Technology*
8. *A Guide to Responsible Technology*

The reflection/response paper requirements and grading rubrics were:
After reading assigned sections/chapter(s) of the book or paper, students are required to write a response/reflection paper. Each paper should be in general two or more typed pages in length, and answers questions supplied by the instructor. It should also include critical evaluation of the materials read and offer comments on the viewpoints the student agrees with the author, and some push-backs on viewpoints that the student might not totally agree with the author. Grading is based on depth of analysis and quality of writing (structure/style and grammatical/spelling correctness, etc.).

Performance indicator used was average score of the six reading assignments. A Likert scale of 1-4 were used in assessing the student outcome. If the grade is 90% or above, it is designated as Excellent. If it is between 75% and 90%, it is Adequate. If it is between 60% and 75% it is Minimal. Finally, if it is less than 60%, it is Unsatisfactory. For the eight students (all juniors), 4 were excellent, 4 acceptable, 0 minimum and 0 unacceptable. An average score of 3.5 is thus achieved, as shown in the table below. Seven of the eight students were previously exposed to engineering ethics teaching in an engineering economy class. This partly explains the high score.

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In spring of 2018, a new group of students were assigned to read the author’s integration paper (Che, 2014) in the Thermodynamics course. Students were asked to answer some discussion and quiz questions (see Appendix B) after reading the paper. For the 21 students (a combination of juniors and sophomores), 10 were excellent, 6 acceptable, 5 minimum. An average score of 3.24 is thus achieved, as shown in the table below. Compared to the previous year’s group, this group had a lower score. Part of the reason was that no classroom discussions were conducted. It was only assigned as a take-home reading assignment. Some of the students obviously did not put enough effort into the reading of the paper and answering of questions.

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In spring of 2019, students in the *Engineering Materials and Processes* class were assigned to read Laurel Dovich’s integration paper (Dovich, 2002). They were asked to answer seven reflection questions (see Appendix C). The grading rubrics were:

- Accuracy of knowledge
- Depth of thought
- Style of writing including the correct use of grammar and sentence structure
- Critical thinking and applications to your own life.

Again, those who scored 90% or above would be classified as “Excellent,” and those who score 75% or above would be counted as “Acceptable,” etc. The average score for this student outcome is 3.69 which is higher than that from the previous year. One explanation is that some of these students were already exposed to a biblical view of engineering the previous year in the *Thermodynamics* class. Another explanation is that the instructor did cover some of the materials of the paper in his classroom lectures.

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Monsma’s book, *Responsible Technology*, was found to have a strong philosophy flavor and is a hard read for engineers. Even though the authors of the book had every intention to write in plainer languages for the general readers, the language in the book is more suitable for audiences with a philosophy of science or technology background. Some of the definitions are foreign to engineering students and sometimes confusing. For example, the definition of “Technology” given in chapter two (top of page 19), is closer to the definition of “engineering” as engineering students mostly understand it. A more streamlined book is probably more desirable, so students can quickly get to the key chapters of cultural mandate (chapter 4) and normative design principles (chapter 9).
Another book that potentially could be used is Rudi Volti’s *Society and Technological Change* (Volti, 2017). It is much easier to read and covers more contemporary issues that would be convenient to assess ABET outcomes f, h, i and j. The author used an earlier version of this book in a hybrid *Service Engineering* course at Anderson University in 2016 (Che, 2018). The downside is this book is not written for the Christian audience and occasionally you would encounter non-biblical views. The author has been looking for such a book written from a Christian perspective and he has not found one yet.

**Summary**

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,” commonly referred to as “dominion mandate” or “cultural mandate.” However, due to the fallen nature of man, engineering will also be corrupted by sin. And this sin can appear in various forms, two of the common ones are personal and corporate (institutional) sins. 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 this “new” dominion mandate – a Christ-centered dominion mandate. The difference between Christians and non-Christians is that Christians can obtain the help of the Holy Spirit so they can fulfill a Christ-centered dominion mandate. One can participate with more insight in Christ’s work by abiding in His Word, walking in His Spirit, and being a bold witness of His saving grace in our everyday lives. With His help, a Christian can become a Spirit-filled engineer.

In conclusion, this paper series attempt to establish a unified theological framework and biblical grounding for engineering students – a worldview grounded on biblical truth and principles. There are many ways to implement the teachings of these topics in the engineering curriculum. One way is to have a designated course or courses to cover these integration topics, like what the author had done in spring of 2017 at MVNU. Another way of doing this is spreading the coverage of these topics in several required engineering classes, like what the author had done in
the spring semesters of 2018 and 2019 at MVNU. Both approaches seemed to have achieved satisfactory results, based on assessing the relevant student learning outcomes.

Acknowledgement

Fruitful discussions with many faculty colleagues at Geneva College are deeply appreciated. In particular, I’d like to thank Dr. James Gidley, for his general guidance and specific suggestions of readings. Institutional support from Geneva College in the form of summer faculty development grant for integration work is also acknowledged. I want to thank Rev. Scott E. Sharpes at the Lakeholm Nazarene Church in Mount Vernon, Ohio, for his sermon messages which gave me inspirations and ideas. I’d also like to thank the two anonymous CEC reviewers, who provided valuable feedback and editorial help.

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Appendix A  Discussion Questions for the First Four Chapters of Responsible Technology – A Christian Perspective (Monsma, 1986)

Chapter 1  Understanding Technology

1. Can technology be both good and evil at the same time? If it does, does this conflict with the teachings in the bible (James 3:11)? Give examples.
2. Does technology have anything to do with faith? (or engineering has anything to do with Christianity) Why or why not?
3. Can technology affect culture? Give examples.
4. Give four reasons why understanding technology is crucial.
5. Which three right relationships does shalom consist according to philosopher Nicholas Wolterstorff? Give two to three examples of technology each in keeping with shalom and not in keeping with shalom.
6. Is technology neutral in value? Why or why not?

Chapter 2  Technology Examined: Definitions and Distinctions

1. Briefly describe the history of the word “technology.”
2. What are the three approaches underlying the many struggles to acquire an adequate definition of technology? Briefly describe the strength and weakness of each approach.
3. Who is Jacques Ellul? What are his views of technology?
4. Who is Carl Mitcham? What are his views of technology?
5. What is the new definition of technology given by the authors of this book? Delineate the five key elements in this definition.
6. What are the three criteria that a definition of technology should meet?
7. What are the two elements of discontinuity between pre-modern and modern technology?
8. What are the common elements that undergird the technology of the past and that of the present? In other words, what are the two elements of continuity between pre-modern and modern technology?

Chapter 3 Is Technology Neutral?

1. What is an emotive view of values? What does the book argue as grounding for valuing?
2. Why valuing is an activity both common and unique to human experience?
3. Why is the supposed “neutrality of means” inaccurate or wrong?
4. Why is the supposed neutrality of science a fallacy?
5. Demonstrate at least in three ways that doing technology can never be neutral but inevitably involves presuppositions, valuing, and normative principles.
6. What is the basic source of one’s structure of preconceptions?
7. What are “control beliefs”? Which philosopher is the proponent of this concept? Give one example of its application.
8. Why do control beliefs have to comport well with the religious base or, broadly speaking, with the heart commitments of their holders?
9. What are the two objections (on page 30) that the doing of technology has been treated as too explicitly a cognitive act? How to answer these two objections?
10. Why do the authors claim that non-neutrality and value-ladenness of technology are two sides of the same coin?
11. There are people who argue that technology is value-laden because it is intertwined with various social structures. What is the weakness in this argument?
12. What’s wrong with the assertion that we should pursue all sorts of technology because technology broadens our range of choices? Give some examples.

Chapter 4 The Cultural Mandate and Modern Technology

1. It was stated in this chapter, “Beavers dam up streams to create ponds, then build safe and secure lodges on those ponds. Birds … build intricate nests. Bees build hives and organize their work by a clear division of labor.” What is the main difference between humans and animals?
2. What is the cultural mandate? Why doing technology is one way humankind fulfills the cultural mandate?
3. Lynn White, Jr. published an article in the 1967 issue of Science and claimed that Christianity is to be blamed for all the technological evils present in the Western society. What are the four main contentions he had? Are there any merit to his claims? What are some refutations to his claims?
4. The following quote was from a famous book written by a noted Christian. Name the author and the book.

   “Christianity is the story of how a rightful king has landed ... and is calling us all to take part in a great campaign of sabotage.”
5. To understand the forces that have shaped the broad trends in human cultural activity in general and in technological activity in particular, it is helpful to examine four basic lines running through human history. What are the four basic lines?

6. What is technicism? What are the key characteristics or beliefs of technicism?

7. Why do the authors state that technicism constitutes a faith, a new religion?

8. In this chapter, what is “a culture of Babylon” and “the spirit of Babylon”? When was it started?

9. List five dominant impulses or driving motives in Western culture that mark it as a Babylonian culture.

10. Why can’t it be said that modern Western culture and all Western societies are purely and totally Babylonian?

11. What are the three possible solutions/approaches/attitudes for Christians who live in such a culture? Which approach should Christians adopt?

Appendix B  Discussion and Quiz Questions for the Author’s Integration Paper (Che, 2014)

1. What is common grace? Give at least three Bible verses each, from the Old and New Testaments, respectively, which support the doctrine of common grace.

2. Why was common grace given?

3. What is dominion mandate? Do non-Christians have a part in it?

4. What is the “new” dominion mandate proposed by the author?

5. Fill in the blanks:

   For common grace:

   ![Blank Fill-Ins](image)

6. True/False question:

   (True/False) By His death Christ secured the delay of the full penalty of death for sin for all men.

7. Multiple choice question: Which of the following are benefits of God’s common grace to men (circle all correct answers)?

   a) It curbs the destructive power of sin

   b) It maintains in a measure the moral order of the universe, thus making an orderly life possible

   c) It distributes in varying degrees gifts and talents among men

   d) It promotes the development of science and art, and showers untold blessings upon the children of men
8. Short answer question: Why are some non-Christians as successful, if not more successful, than Christians in the professional fields?

Appendix C  Discussion Questions for the Integration Paper Our Creator – The Master Engineer (Dovich, 2002)

I. INTRODUCTION
   1. According to the author, what is the reason that not much reflection has been done on creation from the perspective of engineering?
   2. According to the author, there is a dichotomy between engineering and biology in the classrooms. Do you agree with the author? Why or why not?

II. STRUCTURAL ENGINEERING EXAMPLES IN NATURE
   3. Which structural engineering example in nature is most inspiring to you? Why?

III. GOD THE ENGINEER
   4. 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.

IV. ENGINEERING PRINCIPLES LEARNED
   5. What engineering principles can be learned from nature?

V. IN THE CLASSROOM
   6. What spiritual benefits can be gained by learning from God’s creation in an engineering classroom?

VI. CONCLUSIONS
   7. The author shared that “Exploring the wonders and mysteries of nature in the classroom also sets up an anticipation for the life to come, where our queries will be answered, our perplexities solved, our understanding enlarged, and our engineering education completed at the feet of the Master Engineer.” What is your view on this?
Friedrich Dessauer: Biomedical Engineering Pioneer and Model for Involvement in Science, Engineering, Philosophy and Politics

Karl Heinz Kienitz

Abstract: Within an aspirational approach to engineering practice and ethics, the paradigm of learning from example is particularly well suited. In this contribution, learning from biography – a variant of this paradigm – drives a review of the biography and thought of Friedrich Dessauer (1881-1963), a devoted Christian who became one of the pioneers of biomedical engineering and philosophy of technology, leaving to posterity also a remarkable case for learning from biography.

Introduction

This text is about Friedrich Dessauer, a pioneer of biomedical engineering and of philosophy of technology. In this contribution a variant of the learning from example paradigm – learning from biography – drives a review of the biography and writings of Friedrich Dessauer (1881-1963), a Germany born devoted Christian who, though physicist by study, became one of the pioneers of biomedical engineering. The difference between the “scientist-only” and the “engineer” is here understood as implicitly put forward by Einstein: “And here I will say that the scientist finds his reward in what Henri Poincare calls the joy of comprehension, and not in the possibilities of application to which any discovery of his may lead.” [1] The engineer, on the other hand, focuses on discovery and application, with a clear striding towards the second. Dessauer's ground breaking contributions to the development of radiotherapy – he was the inventor of deep-penetration X-ray therapy – and radiotherapeutic equipment follow this pattern.

As a Christian, Dessauer maintained that every invention is a discovery of preformed ideas for finding an optimal technical solution. Thinking in this direction we are able to establish a fundamental relation between technology and God. Moral questions concerning biotechniques, automatization, ecology, internet, etc. lead us to this relation, inviting us to find optimal solutions compatible with Christianity. Dessauer stated that “Christianity knows of need and misery, but it also knows of salvation ... As a result, the Christian tackles life, he does not withdraw from it ... Basically, the ideal of the Christian is a heroic overcoming of all that degrades, ... not only on his own, of course, which is not enough, but with the help of grace.” [2] He thus implied that technology for itself is not a stand-alone tool to solve humanity's problems.

This article is organized as follows. In the next section a brief biographical sketch is given, based on [3]-[7]. Then several of Dessauer's considerations on science, engineering, philosophy, politics and Christian life are put into perspective. Application remarks and conclusions are found in the last section of the text.

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A summary of biography, contribution and impact

Dessauer was born 1881 in Aschaffenburg, close to Frankfurt, Germany, to a catholic industrialist family. He was the youngest of eleven siblings. As a teenager he read about Conrad Röntgen's (1845-1923) discovery of a new radiation, and – still in high school – started his own experiments on the topic. A manuscript with his results was submitted to his Physics teacher, who decided to forward it to Röntgen. Röntgen encouraged the young student to continue researching. After secondary school, Dessauer started his studies of Physics and Electrical Engineering in Munich and Darmstadt. But because of the early death of his father in 1901, he left the university to secure the support of his (actually wealthy) family. With the support of his brother-in-law, a medical doctor, Dessauer established the Elektrotechnisches Laboratorium in Aschaffenburg. The company built X-ray equipment for medical use. Although Dessauer travelled widely to promote his equipment, his main interest lay in research directed at the cure of cancer patients. In 1907 the company expanded to Frankfurt and in 1914 had 500 employees. During this time as industrial entrepreneur, more precisely in 1909, Dessauer married Elisabeth Elshorst. They had three sons and one daughter.

In 1914, Dessauer resumed his studies in Frankfurt. That same year his first skin problems appeared. They were consequences of his experiments and demonstrations with X-rays, many of them performed on his own body. This was the start of a constant, unceasing fight against an issue that would ultimately lead to his death in 1963.

Dessauer concluded his studies in Frankfurt in 1917, earning a doctorate with his thesis “On a high-voltage transformer for the generation of penetrating X-rays.” While he was involved in many entrepreneurial and scientific activities, Dessauer's concern with the social problems of his employees grew, specially after the end of World War I. He decided to become politically active as a member of the Catholic Centrum Party, where he expected to best realize his Christian ideals. He right away became a member of the board and was elected a Frankfurt city councilor. His main political concerns were related to social and economic policies.

In 1920 he became a honorary professor at the University of Frankfurt. To support his activities, the university created the Institute for the Physical Foundations of Medicine (which today is the Max Planck Institute for Biophysics). Because the university had not enough resources to support all the scientific staff he needed, Dessauer sold his company and with the yield established a research supporting foundation. Although most of the foundation's assets were lost to inflation in 1929, the institute survived thanks to the loyalty and dedication of its staff.

In 1922, Dessauer became a full professor. That same year the newspaper “Frankfurter Volkszeitung” came into serious financial trouble. Dessauer, who was one of the shareholders, proposed a recovery concept and personally financed the necessary capital increase. The newspaper was merged with another newspaper in financial difficulty, and for 10 years the new “Rhein-Mainische Volkszeitung,” with Dessauer as chairman of the board, gave superregional voice to the young representatives of German socially engaged Catholic Christianity. Dessauer expanded his political engagement, being elected as member of the Reichstag (national parliament) in 1924. There he led the centrum's proposal of guidelines for the economy,
advocating for a cooperative economy consistent with the solidarity principle of Catholic social teaching. He later became one of the main advisors to Chancellor Heinrich Brüning (in office from March 1930 to May 1932).

After the National Socialist German Workers' Party (NSDAP) came to power in 1933, Dessauer was temporarily imprisoned and accused of embezzlement in the context of his involvement in establishing the NSDAP-critical “Rhein-Mainische Volkszeitung.” He was acquitted in court in December 1933. Nevertheless, further activity at the university was prohibited to him and, in the aftermath, he was discredited and had his home attacked in one of several nationwide hate campaigns.

In 1934 Dessauer emigrated to Turkey with his wife and two younger children. There he had been appointed a professor at the University of Istanbul, with the task to establish a new radiological institute for physical therapy. The institute was integrated into the department of medicine, and its interdisciplinarity resulted in a difficult standing at the university, mainly because Dessauer – though an expert in radiology and radiotherapy – was not a medical doctor. He already knew this challenge from Frankfurt.

In 1937, mainly for health reasons, Dessauer accepted an invitation of the University of Fribourg, Switzerland. During the time of his exile in Switzerland, his estate was confiscated in Germany and his German citizenship canceled.

Dessauer's German citizenship was reinstated in 1949. The following year he returned to Frankfurt for a first lecture. In 1951 he resumed his lecturing activity in Frankfurt on biophysics and natural philosophy, in spite of University of Fribourg's generous offer of increased long term research funding. Dessauer returned to his former residence in Frankfurt and until 1960 lectured to sizable audiences, which usually overcrowded the university's largest lecture hall.

After his return to Germany, Dessauer was widely honored, e.g. with honorary doctorates in medicine, theology and engineering, and the honorary citizenships of Frankfurt and Aschaffenburg,

Dessauer's manufacturing interests never interfered with his theoretical studies and research. In the earlier years he mainly contributed advances to X-ray generation technology. Later, contributions to radiotherapic practice were added. He recognized the importance of homogeneous irradiation to deliver effective subcutaneous doses of radiation without burning the skin and other interposed tissues. His chief principles were summarized in what sometimes has been called “Dessauer's laws of homogeneous irradiation.” These were widely spread, being also presented before the American Roentgen Ray Society in 1921. Furthermore he emphasized the advantages of using hard, well-filtered radiations to guarantee adequate radiosensitivity safety margins between normal and malignant tissues. Dessauer's biophysical theory of the effects of radiation on living tissues found mixed response and stimulated research on a world wide scale.

Dessauer's social concerns ultimately led him to involvement in politics, but already in 1908 he wrote on technological culture [8]. From 1926 to 1928, his concern with the course of German society and hostile views of technology lead him to publish on the philosophy of
technology [9]. Later, in 1956, he revisited, deepened, expanded and improved the consolidation and contextualization of his findings in his magnum opus “Streit um die Technik” [10] (Quarrel on technology), which was to be recognized by authors such as Monmsa et al. [11], and Mitcham [12]. Dessauer's book on cooperative economy [13] was also well received by more than one generation, having been reprinted posthumously.

Right after World War II, people throughout Europe reflected on the future of the West in the wake of such debacle that left much of the people and their continent in graves and ashes. Dessauer contributed actively to the discussions. On at least two occasions he was a speaker on the radio about “Inheritance and destiny of the West”, the first one as early as 1948 with Studio Radio Bern, Switzerland, and years later on the same topic with Radio Bremen, Germany. Both radio talks have been printed ([2] and [14]). Therein Dessauer gave a cultural and historical portrait that acknowledged Christianity's role in the making of the Occident. His conclusion in Bremen was: “We are Westerners. We know how we became Westerners. We want to preserve our inheritance. We do not want to sacrifice it to the skepticism of our time, to a nihilistic, desperate mindset, to the loss of meaning. The danger of the West is not so much its outward wreckage, but its inner ambiguity.” He then commented on technology and its relevance in shaping human destiny, pointing out that much of it happened in distance from God and that keeping such distance would not be sustainable. Talking about continuity, he called for renewal: “Being human means to strive, every day, to become human. Being a Christian means to start anew every day in the quest to become one. Every evening the past day dies away from us. And we must let go what has been called off, and daily the new flows towards us, and we must grasp it whenever it leads us up; this demands strength. And such strength is called trusting faith.” This faith was the ground for Dessauer's remarkable resilience and legacy.

A brief on Dessauer's thought

Dessauer saw technology as an instrument of general improvement of mankind's standing. He saw it providing liberty, time, improved resources for culture, and making these available to masses who previously had no access to them. Technology takes the human environment from the survival challenges set by nature to an ever-higher sphere of the mind, and – in principle – gives all people access to culture, entailing humanization through technology. But, thus far, too much of it happened in disconnection from God.

Although Dessauer in his writings touched specific ethical issues entailed by technology, such as those related to the environment or the development of atomic weapons, he avoided discussing them extensively. This did not come out of a lack of concern, but rather from his focus on a framework to consider transdisciplinary issues (without actually coining this post-Dessauer term) related to technology, culture, Christian faith, society and nature. Such framework would then enable the grasp and tackling of specific ethical issues.

Dessauer proposes his own definition of technology, with the goal to capture its essence. “Technology is real being out of ideas / through final design and processing / from natural resources.” [10] The first part establishes an ontological definition of technology that acknowledges human creativity and imagination as originators. The second part refers to the
means of realizing technology. The third part acknowledges technology's connection to and limitations due to nature.

He wrote in defense of technology, contesting those who condemn technology because of their lack of understanding or out of an (alleged) legitimacy obtained from misunderstandings. He also pointed out that the Christian longing for redemption has been distorted by men of technology of modern times into a passionate endeavor towards self redemption. Technical innovation and activity can thus often be observed as a religious endeavor, even if the agent – the technical men of modern times – is not explicitly aware of it as such.

As is not surprising, Dessauer devoted a chapter of Quarrel on Technology to the religious and theological aspects of technology. There he points out that technology shows the universe, i.e. creation, as being infinitely richer than anyone had ever imagined. Furthermore, technology, the bigger it gets, the more it points beyond itself towards its background, thus fostering natural science. Dessauer then points out Bible passages that encourage technology (such as Genesis 1:28 and Genesis 6) as well as passages that warn against idolatrous faith in technology, and against self redemption efforts (which may include technology). He also endorses Emil Brunner's understanding of Genesis as “Magna Charta of Technology,” and points out that our Lord incarnated, as a carpenter, was seen in his time also as a man of his technical profession (Mark 6:3) and thus of technology. The life and example of our Lord Himself, as a person of technology and of concern with His “kingdom that is not from this world” (John 18:36), can therefore be seen as endorsement and encouragement of the Christians' professional of technology. He summarized: “The Christ-believing professional of technology takes his commission from Genesis' creation account and finds his distinction, example, consolation and support in Christ's technical career.”

Dessauer then proceeds to analyze the impact of “Erblast” (literally burden of heritage, meaning the inherited consequences of the fall and sin) on technology. “Man has fallen from the nearness to God into the tendency to rebellion and thus to abuse, and it is harder for him – and possible only with the help of grace – to succeed in the positive, constructive.” This of course fully applies to technology, because technology, like all human activity, is open to the abuse that follows from human freedom and hence theologically has the “Erblast” at its root.

In the last part of this chapter in Quarrel on Technology, Dessauer discusses relations of “pastoral care” to technology, addressing a mix of several issues he deemed of relevance to priests / pastors involved with people in the technical professions. He recalls that the Great Commission is “go... and teach...” He stresses that going means “not remaining” in one's own familiar circle of thought and life, but reaching out to others, to their “place of residence.” As the intellectual place of residence, to a large extent, he sees one's profession, in the engineer's case the technical profession. There the person lives, has his attitude shaped, daily receives substance and horizon definitions for his mindset, for his behavior towards fellow human beings, the environment, etc. The challenge, thus, is to show – within “technological reality” - how to see the Creator, the Father, to whom Christ always points anew. It is true that God the Creator is mentioned in the first sentence of the Christian creeds. But then He disappears from sight. No day in the sequence of Christian festivals is consecrated to Him, who can be (but most often is

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2 A term coined by Brunner during ETH Zürich-jubilee commemorations [15].
met daily within creation by the researcher and engineer. It was not always like this. Joule and Maxwell felt Him, proclaimed Him; Nicholas of Cusa, Giordano Bruno, Kepler and Augustine did the same much before them. If – for historical reasons – the Creator appears so little in Christian thinking of modern times, it is understandable that professionals involved in research and technology fell into the distance from God in their “secular professions.” With their growth and multiplication this expanded to society. Dessauer identified an “external re-approximation” throughout the first decades of the 20th century, but still saw need for recovery. His closing of the chapter is: “How far are we away from the old demand to look uno aspectu – in one glance – through nature and society at the divine background.”

Dessauer also tackles epistemological issues, though with less emphasis. Technology can contribute to epistemology, and Dessauer stresses that none of the famous schools of epistemology until the 20th century has taken this seriously into account. Natural science and technology always accepted the intelligibility of the universe, initially for theological reasons, and one cannot deny that they did very well with such presupposition. Objections to this “naive realism” of researchers and engineers have been widely spread, and Dessauer's work has been criticized on such grounds as well [16].

Application remarks and conclusions

An understanding of technology similar to Dessauer's is found in a belletristic and self-contained form in Herbert Hoover's memoirs (not mentioned by Dessauer). More specifically on engineering, Hoover writes:

“It is a great profession. There is the 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. That is the engineer's high privilege… 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.” [17]

Dessauer's understanding of engineering – or more generally technology – along these lines has been called “optimistic” (e.g. in [18]). However, it is difficult to see how such (mis)reading can be reconciled with a rational approach to Dessauer's contextualized writings (i.e., without taking individual phrases out of context). Possible abuse of technology is clearly acknowledged by Dessauer. Roots for it, as well as for any other abuse, he finds in the sinful nature of men. Needed response lies in the realm of the individual's and the society's responsibilities. Proper practice and regulation are expected to succeed whenever they are informed by case specific application of Christian principles, although such application may not be straightforward. Hence, the ethical foundation needed for technology is not found within technology. Dessauer finds it within Christian theology and philosophy.
On a more motivational level, Dessauer endorses that a commission for work in the technical professions can be taken from Genesis' creation account, and that in Christ the professional of technology can find distinction, example, consolation and support. This understanding drives his integration of faith, profession and personal life. Dessauer's broad, courageous and selfless engagement for and within society underscores his insights and teaching with powerful testimony and has enduring example value.

Finally and fortunately, it remains to be said that Desauer's pioneering engagement for a much needed philosophy of technology has found expert continuators (e.g. in [19] and [20]). He started by reviewing what had been said on technology, and captured the essence and foundations of the methods of technology. On such grounds he built his contributions. This brings to mind the remark of Karl Popper at the end of his notable paper “What is dialectic?” [21]. Popper addresses the philosophers of science stating: “The whole development of dialectic should be a warning against speculative philosophy. It should remind us that philosophy must not be made a basis for any sort of scientific system and that philosophers should be much more modest in their claims. For their task, which they can fulfill quite usefully, is the study of the methods of science.” Not surprisingly, the methods of technology Dessauer so competently used in professional practice lay at the foundation of his successful push towards a philosophy of technology.

References


Biophysicist and Reichstag Deputy Friedrich Dessauer, in German


An Engineer’s Two-fold Call

Jose Oommen Kochalumnoottill* and Pheba George*

Abstract

The paper introduces the two-fold call of a Christian Engineer – as a developing professional engineer and a developing Christian in Christ likeness. The investigation is guided by instances of the two-fold call in the life of Old and New testament saints, where the Lord uses double salutations to get their undivided attention to His heart’s most yearning request to manifest His purpose in the life of His choosing. The first call could be a call of attention, but the second call is definitely a compelling call of His commission to us. This rather unpredicted and unplanned event for some might come at a time that they least expect it. It might alter the well-planned dreams of one’s mind; nevertheless, it happens by the perfect will of God at His perfect time that changes the direction in life of the person receiving the call and the people around. The double call always comes at a time of utmost importance, substance and exigency, and the recipients of the double call of God in the Bible, fulfilled the great commission with intense passion and fervor. This paper starts by taking a look at what the authors mean by the two-fold call, and brings in perspectives of faith, and faithfulness that are essential to fulfilling the call through examples in the life of Old and New Testament saints. The paper presents several ways in which engineers can fulfill the calling in their secular and spiritual work and concludes by emphasizing that the two-fold call is applicable to all Christians who want to fulfill God’s ultimate purpose in life by bringing people to God and God to the people. The goal of the paper is two-fold:

a) To reflect upon the great commission that we are all saddled with, to bring out people under spiritual darkness into His marvelous light.

b) To encourage Christ-likeness, with faith and faithfulness being the embodiments.

The paper also reflects on the authors’ personal experiences, and a fervent call to all engineering educators and professionals to run the race that has been marked out for us, and to pass on the baton to our succeeding generations so that they may also be able to have the same zeal for God.

Introduction

We as engineers, hold on to a divine calling to be God’s spokesperson on this earth. This is akin to the two-fold call in the life of Old Testament saints like Samuel, Moses, and Abraham, and exemplified by Paul in the New Testament. A believer’s personal engagement with the gospel and steadfastness to upholding the tenets in the midst of personal, professional, and worldly turmoil is the heartbeat of every mission undertaking and contributes to the struggles associated with this two-fold calling – A Christian Engineer.

Calling is personal, and the calling of an engineer is no different from the call to be a child of God. In my advising roles and my interaction with prospective engineering students, I often come across numerous individuals who claim to have a deep passion to be in this dual role as Christian engineers and be missionaries for the furtherment of God’s kingdom. Christian educators thus have an additional responsibility to nourish, and encourage the students, and be a role model for these kids as they leapfrog into the chaotic real world where they are supposed to light up the darkness as LED (Light Emitting Disciples).

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Many engineers in Canada wear an iron ring to remind themselves of the obligations and commitment to not only the profession but to society in general. The ritual of the calling of an engineer has been a century old tradition and is a private ceremony with no obligation to attend. The ritual’s origin can be traced to Professor H.E.T. Haultain of the University of Toronto, who conceived the ritual, and requested Rudyard Kipling to create it in 1922. The Iron ring ceremony is exclusively Canadian and consists of 26 camps across Canada, usually situated near an engineering university (Wikipedia). The ring embodies the pride which engineers have in their profession, while reminding them to be humble at the same time. The ring serves as a constant reminder to the engineer and others of the engineer’s obligation to live by and exhibit a high standard of professional conduct.

The goal of the ritual of the calling of an engineer is aimed at directing the young engineer towards an understanding of the profession and its significance, and furthermore, indicating to the older engineers, their responsibilities in receiving, welcoming and supporting the young engineers in their beginnings - Rudyard Kipling, from notes by Dr. J. Jeswiet.

The ring is a symbol of being in the family of engineers who have toiled just like them, burning midnight oil, to achieve the dream. In Luke 15:13-32, we read that upon the return of the prodigal son, the father asked his servants to clothe the son with a robe and presented him with a ring – which symbolizes sonship. While the world focuses on tangible things to symbolize like the iron ring, spiritual calling focuses on things that are not visible to the common man, and hence requires faith – even as small as a mustard seed that can move mountains. 2nd Corinthians 4:18 states: “The things which are seen are temporal; but the things which are not seen are eternal.” This is exactly what faith is. Faith is the divinely endowed capacity to trust in the superior being, and an unwavering belief that God is in control in all circumstances, and He works in amazing ways, but in His time. Faith that is simple, but strong and takes a lifetime to master is equivalent to a mustard seed that requires arid climates to germinate but evolves to deal with difficult environmental conditions like little moisture and extreme heat. It is said that a mustard seed grows best when planted in full sun, under direct exposure to sunlight (McMullen). Jesus 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.” (Mathew 17:20, NIV).

Romans 10:13 (KJV) says, “So then faith cometh by hearing, and hearing by the word of God.” Thus, while God is light, His word is also light. Just as continuous exposure to sunlight helps in the germination of the mustard seed to bloom into the plant that it deserves to be, daily reading of the word (Light), meditating, understanding and practicing it in our lives will enable us to walk in the light, keeping us out of darkness, nurture and establish our faith, resulting in our lives reflecting the brilliance of God’s glory.

As the former US President and mining engineer Herbert Hoover wrote, “Engineering is a great profession. There is the 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… Then it elevates the standards of living and adds to the comforts of life. That is the engineer’s high privilege.” (On Engineering – Herbert Hoover).
This is so true, for as per the world, an engineer’s high privilege is to add to the quality of life through inventions and discoveries, but as spiritual Christians, we need to focus on another important matter – the greater calling as a disciple of Christ.

**Calling of Old Testament saints**

There are numerous examples in the Scripture where the Lord has called his saints by repeating their name twice. Whenever He called their names repeatedly, it was always at a moment of great significance and urgency.

The first time God called in this fashion was the name of Abraham, who had left his father’s household to sojourn in the land of Canaan. When the time came, he was subjected to a test of obedience about his son who was born when Abraham was hundred years old. God promised Abraham that He will make him into a great nation, but here He was asking Abraham to sacrifice the God given promise, which was his only son, to which Abraham unflinchingly agreed. “And the angel of the LORD called unto him from heaven, and said, Abraham, Abraham: and he said, Here am I.” (Genesis 22:11). Abraham passed God’s challenge, whereby which he received the fulfillment of the divine promise, resulting in him being called as the Father of many nations.

While his faith was being tested, he did not slack in his faithfulness, thus preserving his faith. Hence, Abraham was called a friend of God. It truly speaks volumes about his closeness to God, and as a result, the great promise regarding the blessing on his seed came to pass. Furthermore, because of Abraham obeying the laws and ordinances of God, all his future generations were blessed through him. “I will make you into a great nation, and I will bless you; I will make your name great, and you will be a blessing. And I will bless those who bless you, and the one who curses you I will curse, and in you all the families of the earth will be blessed.” (Genesis 12:2-3, NIV). Thus, Abraham brought God’s blessing upon the people of Israel and to all other nations who believe in God.

The second instance of a double call in the Old Testament applies to Moses: “God called unto him out of the midst of the bush, and said, Moses, Moses. And he said, Here I am.” (Exodus 3:4). God’s call to Moses came while Moses was at work as a shepherd, tending to the flock belonging to his father-in-law Jethro. Thus, God’s calling doesn’t focus upon the location, but upon our availability to surrender to his will and plan in our life. I can relate to the above situation for my father-in-law who was working as an engineer in the Middle east, decided to resign when God called him to start a ministry, and all these years, have solely depended on God in faith to sustain him and his family. I believe there are millions of examples like this, where people of high education have relinquished their worldly pleasures to do the great commissioning. This call was a commissioning (command) to Moses to go and bring the Israelites out of slavery. God then confirmed the call by emphasizing that He is Jehovah- Lord God Almighty. God answered, “I will be with you, and when you bring the people out of Egypt, you will worship me on this mountain. That will be the proof that I have sent you.” (Exodus 3:12-15).

God then ordained Moses to lead His people out of Egypt. In doing so, he brought the Israelites out of slavery into the land of Canaan, where they could see God’s protection through the pillar of fire and feel God’s comfort through the pillar of cloud. He was thus instrumental in leading the Israelites to God. As disciples of Christ, we have been called for this dual purpose – spread the
light through our professional works, and life as a whole. As engineers, we must adhere to the code of ethics in our profession, and practice what we preach through our actions and words. It may be difficult to share the gospel in a secular industry/academic setting, but our actions will speak a lot about the light that we carry inside. Prayer inside the war-room will allow us to be continually inspired and confirm the calling, allowing the Holy Spirit to convict the heathen and bring them to the marvelous light. Faithfulness at work is an inherent part of who we are as Christians. Moses was faithful in the duty that was given to him, a shepherd - a monotonous job with nothing much to do. From being an Egyptian prince to a shepherd, spending the prime forty years of his life on a lowly job, humbled, he remained faithful and diligent in his work. He considered himself not worthy, being slow of speech, but God used him as a messenger to deliver His message to Pharaoh, and finally free the Israelites from the bondage of Egypt. “By faith Moses, when he had grown up, refused to be known as the son of Pharaoh’s daughter. He chose to be mistreated along with the people of God rather than to enjoy the fleeting pleasures of sin. He regarded disgrace for the sake of Christ as of greater value than the treasures of Egypt, because he was looking ahead to his reward. By faith he left Egypt, not fearing the king’s anger; he persevered because he saw him who is invisible. By faith he kept the Passover and the application of blood, so that the destroyer of the firstborn would not touch the firstborn of Israel.” (Hebrews 11:24-28, NIV).

It doesn’t matter how timid or shy we might be, but God can work through our weaknesses to be his messenger as long as we are faithful in our responsibilities and duties at our workplace. Luke 9:48 (NIV), “For it is the one who is least among you all who is the greatest.”

Moses was hidden by his parents for three months, and when they could not hide him any longer, put him into a chest of bulrushes and released him into the water, carefully watched by his sister Miriam. Little did they know that this event was going to be a big life changer in the life of Moses, who was found by Pharaoh’s daughter and was adopted as her son. This was the beginning of God’s training for Moses to be a leader. “Moses was educated in all the wisdom of the Egyptians and was powerful in speech and action.” (Acts 7:22, NIV). Thus, Moses went through a period of intense training and education in Egypt before he was called to be the leader and was saddled with the responsibility of bringing the Israelites out of the same place where he was trained.

One of the qualities of a leader is to remain humble and also be ready to be subjected to higher authority. Moses was also subject to the authority of Jethro when he tended his flock. He could have claimed the high position of being an Egyptian prince, but as Paul says in Romans 13:1 (NIV), “Let everyone be subject to the governing authorities, for there is no authority except that which God has established. The authorities that exist have been established by God,” Moses continued to do his best at his job and got his first opportunity to see God at the burning bush while he was at work. If Moses was not faithful at his work, he would have missed the call at his appointed place and time. Thus, his commissioning was to be a leader, under whose leadership the Israelites were freed from the bondage of Egypt, thereby fulfilling his double call.

The third example is Samuel, whom Hannah allowed to be under the tutelage of Eli, the priest. This gave him the training for his future calling as the prophet of Israel. Samuel was ministering to the Lord under the authority of Eli, when he heard his name being called. Being unsure as to who called him, he went up to Eli, who realized that it was the Lord calling, and asked him to respond, which he duly obeyed. This displayed his character of obedience that is so required for a
person to work under man and under God. When God called Samuel repeatedly, Samuel replied, “Speak, for your servant is listening.” (1st Samuel 3:10, NIV). God was preparing Samuel for a dual purpose:

1. To be a judge over the people of Israel: 1st Samuel 7:15 (KJV) says that Samuel judged Israel all the days of his life. A judge was often a military champion or a deliverer that was appointed by God to win victories over Israel’s enemies. “Then the Lord raised up judges, who saved them out of the hands of these raiders.” (Judges 2:16, NIV). Some familiar military judges whom God used in olden times included Joshua, Gideon, Deborah and Samson. Samuel was also the last judge of Israel. While God was preparing Samuel for a professional call, he was also mended, molded and fashioned to be a prophet.

2. To be a prophet or God’s voice to prepare the people of Israel for the Davidic kingdom: During the time of Samuel, God rarely spoke, due to the wickedness of the people, and whenever He spoke, it was a word of judgment. “In those days the word of the Lord was rare; there were not many visions.” (1st Samuel 3:1). Hence, as a prophet, Samuel was instrumental in delivering God’s message and bridging the gap between God and his people. It could be that God is trying to emphasize a matter of extreme significance when He calls twice, or perhaps, it could be out of his sheer love. As engineers, we need to understand that our calling is great, and we must be true to that calling.

**Calling of New Testament saints**

Saul was a big religious fanatic, filled with hatred for the Christians, and sought to destroy the church in Damascus, when he had a life changing encounter with Jesus. Jesus met him on the road to Damascus: “Saul, Saul, why persecutest thou me?” (Acts 9:4, KJV). The dramatic calling and conversion experience led Saul to be renamed as Paul and be the greatest apostle in New Testament history. Paul was a highly qualified Jew, who claimed “If someone else thinks they have reasons to put confidence in the flesh, I have more: circumcised on the eighth day, of the people of Israel, of the tribe of Benjamin, a Hebrew of Hebrews; in regard to the law, a Pharisee; as for zeal, persecuting the church; as for righteousness based on the law, faultless” (Philippians 3:4-6, NIV). He knew firmly what he believed, and he stood his ground for it to the point of undergoing suffering and persecution and ultimately sacrificing his life. He was a disciplined logical scholar of the first magnitude, and his belief was unwavering in the gospel he preached so fervently. Even his critics acknowledged his rugged independence (Jackson). And so, as McClintock & Strong suggested, this argument itself constitutes “a demonstration sufficient to prove Christianity to be a divine revelation.” (McClintock, Strong). Peter, the apostle, says in 1st Peter 3:15 – “Always be prepared to give an answer to everyone who asks you to give the reason for the hope that you have. But do this with gentleness and respect.” Being engineers, who are trained to design and build anything based on scientific principles, we must use our logical abilities to defend the gospel in every sphere of life.

Jesus himself, at the time of crucifixion cried out to the Lord saying, “My God, My God why have you forsaken me.” (Matthew 27:46, NIV). When Jesus called out to His father, he was fulfilling his duty both as a man and as a God. Jesus stepped into His role as a man and died for mankind as a willing sacrifice to redeem His people from their sinful nature into His marvelous grace. For the Bible says in 2nd Corinthians 5:21 “He made Him who knew no sin to be sin on
our behalf, so that we might become the righteousness of God in Him.” He was made sin for us so that we could be sinless in His presence. In 1st John 3:5 “You know that He appeared in order to take away the sins; and in Him there is no sin.” On the other hand, He is fulfilling His responsibility as God to His people by interceding and advocating for them, preparing an eternal home, and actively working within us to shape our character to carry out His will.

**Dual call of a Christian Engineer**

Being a Christian and an engineer at the same time is part of the dual call. As Christians, it is our responsibility and our commitment to live all the areas of our lives in a way that honors and pleases God.

There are many reasons why Christian engineers select this life-long career:

1. Christian engineers seek God’s perfect will before choosing this path in their career. One could have taken a different path based on the annual income, the career that our friends took and perhaps due to familial or peer pressure. But, in the end, we decided to take the path of engineering due to the passion, desire and intellectual capacity that our eternal Father bestowed upon us.

2. God is our creator and has designed the universe, the plants, animals and our human body so intricately and exceptionally (“I am fearfully and wonderfully made”- Psalms 139:14) that when we as God’s creations, design and build things on this earth that He gave to us to dwell, we bring glory to God. 1st Corinthians 10:31- “So, whether you eat or drink, or whatever you do, do all for the glory of God.”

3. God has given each one of us talents. More often, we are tempted to showcase these talents as arising from our own abilities, instead of humbling ourselves and proclaiming that these are gifts of God. We are to use our God given talent wisely and faithfully which is not meant to be compared to others, despised or wasted away. There will be a day when we will be judged about how we utilized the talents we were given and held accountable for the wisdom, knowledge and career that He gave us.

4. Engineers are taught to think through problems and create or improve things that impact the public’s health, comfort and safety. However, Christian engineers have the unique capability to use their intellect to enhance the ministry. For example, King Solomon was considered greater in riches and wisdom than all the other kings of the earth (1st Kings 10:23). 1st Kings 3:12,13 (NIV): “Behold, I have done according to thy words: lo, I have given thee a wise and an understanding heart; so that there was none like thee before thee, neither after thee shall any arise like unto thee.” Even though he was the most intelligent king, he used his God-given wisdom and riches in the construction of the temple of God, thereby glorifying God. In a similar way, we as Christian engineers, have the opportunity to utilize our knowledge and wisdom both to advance professionally, and also be a blessing to others.
How are Christian engineers different from secular engineers?

1. The capacity in which God calls each engineer whether in a secular or a Christian work environment is different. No two people may have the same intellectual ability. However, a Christian engineer can take comfort in the fact that God does not call the qualified, He qualifies the called. “But God chose the foolish things of the world to shame the wise; God chose the weak of the world to shame the strong.” (1st Corinthians 1:27). Often Christians have challenges when working among non-Christian colleagues and co-workers. We often wish we didn’t have to face those situations; nevertheless, God has strategically placed us for His divine purpose which the word of God states is a mystery. The Bible talks about His purpose in this: “To them God has chosen to make known among the Gentiles the glorious riches of this mystery, which is Christ in you, the hope of glory.” (Colossians 1:27, NIV).

2. Our ethical and moral values are also different. As Christian engineers, we do have a greater responsibility to pray for our employer, co-workers and people that God has placed in our lives. We are kept as watchmen in our town, city and institution that God may have His way on all areas through us. In Ezekiel 22:30, “I looked for someone among them who would build up the wall and stand before me in the gap on behalf of the land so I would not have to destroy it, but I found no one”. On the other hand, we read in Genesis 39:5 “From the time he put him in charge of his (Potiphar) household and of all that he owned, the Lord blessed the household of the Egyptian because of Joseph.” The blessing of the Lord was on everything Potiphar had, both in the house and in the field. Thus, if we are diligent in both our work life and prayer life, God will surely shew favor and bless the company or institution that we are employed in.

3. The degree and extent of our responsibilities differ as well. Christian engineers are not only accountable to their employers, but also to their Heavenly Father. Hence, we are expected to perform as working for the Lord, a raised bar compared to secular engineers. “Whatever you do, work at it with all your heart, as working for the Lord, not for human masters.” (Colossians 3:23, NIV).

How can a Christian engineer heed this dual call?

a) Mission trips: Several organizations support missions and cross-cultural ministries in developing countries by sending engineers on project trips to design facilities such as wastewater disposal systems, hospitals, and work on hydro-electric projects. An engineer can use his/her engineering skills as "tentmaker." A tentmaker is a bi-vocational missionary whose main purpose is to share the gospel, especially in countries of greatest spiritual need and receives little or no pay for his work. Working in the field of expertise as complex as engineering is, helps to explain concepts more logically, enabling to share our faith and building relationships. On the academic front, nearly every Christian university has some sort of short-term missionary trips allowing the students to use their engineering skills and get them prepared for their future endeavors with respect to their two-fold calling.
b) Glorify God: A Christian engineer’s highest priority and primary motivation must be to glorify God. “A Christian engineer is someone who uses their God given gifts of specialized technical knowledge and practical abilities to transform creation into an image of what the new creation will be like, so that God is glorified, and society is improved.” (Spencer, Clifford). Our objective within the long hours of work we put in must be foremost to develop an intimate relationship with our Savior. “But seek ye first the kingdom of God, and his righteousness; and all these things shall be added unto you.” (Matthew 6:33, KJV). We need to prioritize our relationship with God more than our professional goals. Are we spending more time on our research, professional development than spending time with God, our creator? Is our work leading us away from Christ than leading us more and more closer to our Heavenly Father? As Jesus says, “What good will it be for a man if he gains the whole world, yet forfeits his soul?” (Matthew 16:26).

c) Be an advocate for Christ: Professional organizations such as ABET (Accreditation Board for Engineering and Technology) and IEEE have lately recognized the full worth of subject topics like ethics, sustainable human development and its relationship to technology. According to Spencer, often these terms are poorly defined; hence, many engineers are ill-equipped to address such non-physical concepts. Engineers are practical people, who use scientific and mathematical logic to develop solutions to practical problems. Here is where the Christian engineer has a clear advantage and moral framework by contributing to discussions on these topics (Spencer, Clifford), and fill the vacuum to address the physical and spiritual needs equally. There are plenty of opportunities in academic and industry setting to show the light within us. Precisely, that was one of the main reasons, the authors decide to be a part of Mount Vernon Nazarene University, a Christian liberal arts university in the small city of Mount Vernon, Ohio. The 3-day a week chapel services and the emphasis on studying about God in the classroom was a great attraction for the authors, who believe that this is a divine opportunity to influence the current generation of students. Judges 2:7-8, Judges 2:10 : “The people served the Lord throughout the lifetime of Joshua and of the elders who outlived him and who had seen all the great things the Lord had done for Israel. Joshua son of Nun, the servant of the Lord, died at the age of a hundred and ten… After that whole generation had been gathered to their ancestors, another generation grew up who knew neither the Lord nor what He had done for Israel.” Joshua and his generation saw God’s miracles with their eyes, the wonders humanly impossible, but unfortunately the following generation did not know the Lord. The baton of faith was either dropped or not handed off properly, resulting in a crippling effect on the next generation. There is a reason for us to be where we are, and if we don’t use the opportunities wisely, then perhaps we won’t be able to pass on the skills required for our next generation to win the race that we were born to win, and we will be accountable for their failures. Also, we may, in the line of duty, meet people with very different ideologies, but we must exhibit the courage to speak up for Jesus – lovingly, humbly, and respectfully.
Conclusion

Our two-fold call can not only pertain to the call as an Engineer and as a Christian, but also can imply the call to bring the people to God and God to the people. The way we can bring God to the people is through our great commission, and faith (Matthew 28:16), seeking the lost, plundering hell and populating heaven. The way we can bring people to God is by means of our daily fervent prayers for the lost, and faithfulness. It is a calling that we should be proud of and at the same time, be encouraged to live out the call faithfully and ardently.

References

Guiding Principles for Integrally Christian Engineering Work in Industry

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with David Lammers², Andy Landman³, Jeremy Van Beek⁴, and Jason Wyenberg⁵

Abstract

What is integrally Christian engineering? Or to ask it slightly differently, what does engineering look like if it is faithful and obedient to God’s will as revealed in His Word? I do not think we, as finite and creaturely Christ-followers, can expect to exhaustively determine God’s biblical directive for every facet of engineering and technology on this side eternity. However, if we truly believe that Christ is Lord of all of life and that He calls us to grateful service in everything we do, we need to continue to wrestle with these questions. One framework to help navigate these questions that has been proposed and previously presented consists of five guiding principles for engineering. These principles were developed by focusing on God’s Word as the Christ-narrative, the Creation-Fall-Redemption story, and applying this lens directly to engineering. The guiding principles have been applied in academic settings including both curriculum and scholarship, and in this paper they will be used to analyze and critique service in a few different engineering settings of the work-a-day world. Reflections on these principles from engineers in different industries including manufacturing, power distribution, building systems, and civil infrastructure will be collected and presented to shed light on how it makes a difference in the daily lives of engineers to view their work through a distinctively Christian lens. My prayer is that this work will help us continue to learn how to engineer in a way that gives all glory to God as we live in the already and not yet of Christ’s kingdom.

Introduction

I have been in Christian higher education in engineering for almost 11 years. But 12 or 13 years ago, I never would have envisioned that the world of academia would be God’s plan for me. During that time, I was in the middle of a stint that lasted over 5 years working as a structural engineer in a consulting company that specialized in work related to heavy industry (oil production, steel production, power production, etc.) I could have seen myself continuing in that line of work for 30 or 40 years. One of my main motivations in that work was the recognition that the work we did made a difference for society. My Christian world and life view helped me recognize that love of God and love of neighbor should be the primary motivators for my work, and it gave me joy each day to be able to reflect on these principles and seek to discern how to be faithful in this call. It probably comes as little surprise for me to reveal that my cubicle-dwelling neighbors at work had

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a hard time finding similar joy in their work, even when it was nearly identical to mine, when their main motivator was making money to live for the weekend.

God instilled this passion of how my worldview makes a difference in my daily work primarily during my time as a student in a Christian institution with an engineering program. In a surprising direction-changer for me, God used this passion and motivation to eventually show me that He wanted me to be involved in Christian engineering education as well, to pass along this perspective and to help aspiring Christian engineers to see that their 8-5 journey each day can be as much a part of their faith walk as their time with their families or their time at church on Sunday. In my experience, my worldview definitely affected my posture and perspective on my work. However, one of my lingering questions (and a question that comes regularly from students as well) is how and when a biblically faithful approach makes a difference in specific day-to-day engineering decisions. Six years ago, this question led me and a couple colleagues to develop guiding principles\(^1\) to help think in a more structured way about engineering work from a biblical perspective. In the years since, I’ve tried these principles out with students in class and in some of my own scholarship. However, only recently have I had the opportunity to introduce these principles to practicing engineers and get their take on the usefulness of these principles in the real-world engineering environment. This paper presents the results of that work.

### A Brief Look at the Guiding Principles

The guiding principles mentioned in the introduction were developed in recognition of the metanarrative of Christ that we find in God’s Word. This metanarrative is sometimes summarized as the Creation-Fall-Redemption paradigm, as has been fleshed out by Albert Wolters\(^2\) and many others. By carefully considering the implications that an understanding of Creation-Fall-Redemption have in engineering-related work, five guiding principles have been fleshed out and are briefly stated as:

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’s hands and feet, we are involved in the alleviation of both human and nonhuman suffering.
5. We live in the already and not yet of Christ’s reconciling work.

These principles were fleshed out in a previously-published reference\(^1\); they are explained in detail there. They have not been presented as the only Christian approach to engineering but rather as a helpful framework that can provide guidance in discerning how to engineer in a way that is integrally Christian. Particular work has already been done in using this framework to evaluate our engineering curriculum\(^3\) and its effectiveness\(^4\).

Before I dive into the work at hand, a bit of elaboration on the purpose of the principles may be helpful. These principles were developed after a lot of discussion on how to really think biblically about engineering. The original goal of this work was not to develop principles; it was merely to work toward a more practical understanding of what it means to do engineering biblically. Thinking back, I think the starting point was a recognition of how difficult it is to know God’s
particular will toward specific decisions in the trenches of engineering work every day. For example, as I write this paragraph I am sitting in front of a wall painted a deep red with purplish undertones. Based on my current knowledge, I am quite comfortable that it was an obedient and normative decision to paint that wall as such. (And I do feel strongly that there are biblical norms, such as those fleshed out by Monsma et al.\textsuperscript{5} and applied by Schuurman\textsuperscript{6} that should inform and guide every decision we make.) But there may be something about the decision to paint the wall that particular color that doesn’t follow God’s biblical directive as it should. Perhaps an animal or plant outside the adjacent window is adversely affected in a completely unknown way by the reflection of light off that wall color, or maybe there is something about the paint production process that makes that particular color less stewardly in resource conservation, or possibly this color does something psychologically that puts me in a less loving mood. We may actually learn through research one day that one or more of these is true, but hopefully this as a hypothetical example illustrates the almost-infinite and definitely impossible task it is to have confidence that we know God’s complete will related to every technological decision we make.

I do not believe it is reasonable to expect God to reveal all such directives to us in our lifetime; such an expectation does not seem to fit the salvation narrative of initial justification and continual sanctification that God reveals in His word for the way He works in our lives. But recognizing the overwhelming nature of discerning God’s biblical directive for engineering is not an excuse to quit trying. Hence, we have developed these guiding principles, not to be an exhaustive, prescriptive list of how to engineering Christianly, but to help think through a biblical framework and ask the right questions in seeking to discern God’s will for whatever engineering challenge is at hand. Hopefully these principles provide us a better posture to feel the Spirit’s guidance in making obedient engineering decisions.

**The Approach**

The current effort with the guiding principles is to try them on for size in a real-world engineering environment. The approach that I have used for this work is as follows:

1. I asked practicing engineers in a variety of industries whom I know to be professing Christians if they were willing to critique their engineering work through the lens of a biblical framework.
2. For engineers who agreed to participate, I provided the guiding principles in the form shown in Figure 1. This summary format is one that I have used regularly with engineering students over the past few years.
3. I asked participating engineers to provide written reflections on the guiding principles, based on their professional experiences. The prompt I used for this request was, “Write a paragraph or so on each principle, reflecting on how it applies to your professional work (or if it doesn’t, why not), being specific if possible.”
4. After receiving written reflections from the participating engineers, I convened an in-person meeting to discuss their thoughts on the principles. For the meeting, the prompt questions used were: (a) If you think about your current engineering work, are you able to see ways where the guiding principles might be helpful (either in specific design decisions or approaches, or in posture and vision)? (b) Do you have any critiques (positive or
negative) of the principles? (c) Do you have other thoughts on ways other than the principles to challenge each other to do our work faithfully Christianly?

5. Excerpts of the participating engineers’ written and verbal responses are gathered by principle in “The Results” section below.

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**Biblical Guiding Principles for Engineering**

Often in engineering it is challenging to envision how God’s will revealed in His word plays a direct role in our daily decisions, particularly in the technical decisions that may not feel explicitly “obedient” or “disobedient.” I have found it helpful to reflect on five guiding principles that have been developed from what I believe is a proper understanding of the Creation-Fall-Redemption story of Christ in Scripture. These principles can help to inform why and how we do our engineering work as Christians.

1. **The world (and everything in it) was created for God’s glory.**
   - “For from him and through him and for him are all things” (Rom. 11:36).
   - “God’s goal at every stage of creation and salvation is to magnify his glory” (J. Piper).

2. **God gave us dominion over creation and instructs us to develop and conserve it (at the same time).**
   - We give creation its proper due by treating it with care that brings healing and renewal and enables it to unfold and grow (L. Kalsbeek, Gen. 1:28, 2:15).

3. **We are creatures...always finite, currently sinful.**
   - Humans are the crown of creation; we have a unique role ... but salvation does not come from the work of our hands (Ps. 8:4-6, Eph. 2:8,9).
   - We are not saviors. We are finite, sinful, and corrupted.

4. **Our sin caused creation’s suffering. We have a responsibility to ease suffering by engaging the human and non-human creation.**
   - “For the creation was subjected to frustration, not by its own choice, but by the will of the one who subjected it ... the whole creation has been groaning” (Rom. 8:20-22).

5. **We live in the already and not yet of Christ’s kingdom.**
   - Christ’s kingdom is already here, and one day it will be fully consummated!
   - We work out of gratefulness for Christ’s saving work, and we trust Christ to use our work as he wills to fulfill his perfect plan.
   - We work as a reflection of the Spirit’s sanctifying work in our lives.

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Figure 1: Biblical Guiding Principles for Engineering

**The Contributors**

The four practicing engineers who agreed to collaborate with me on this work provide a relatively diverse subset of engineering industry connections. All four engineers are Christ-followers who are active in their churches and would identify with evangelical Christianity. Andy Landman is a licensed professional engineer with 21 years of experience in electrical engineering, currently a practicing design engineer and partner at a consulting engineering firm that specializes in
commercial building systems. Jeremy Van Beek has 19 years of experience working as a mechanical design engineer in a light manufacturing industry. Jason Wyenberg has 10 years of experience working as a project engineer in a large electrical power distribution design-build company. David Lammers has approximately 8 years of experience as an industrial engineer in manufacturing, the last couple years serving as a materials engineer in a company that specializes in heat treating. Bringing in my own experience of over 5 years as a structural consulting engineer (prior to my now 11 years of service in academia), we have a relatively broad portfolio of engineering experience among the five of us. As presented in the remainder of the paper, we found a few differences that we experience in trying to approach our work Christianly, but it seems we found even more similarities despite the diversity of our experiences.

The Results

*Principle 1: To God’s Glory*

A couple specific points made by the contributors highlighted the usefulness of this principle. Van Beek (mechanical design in manufacturing) states, “As we use the resources around us and the laws of nature to design/implement systems, we do this for the glory of God. We can have an understanding of the orderliness of the creation and that God has created natural laws that we can use.” Along a similar train of thought, Lammers (industrial design and heat treating) makes the following observation: “God is consistent in his upholding of creation; therefore we are able to predict outcomes based on previous results.”

In thinking back to my work in structural engineering, I think this principle affected my posture more than my direct work. It helped to motivate me, to keep my head up, and to keep a smile on my face in the cubicle farm of the consulting engineering world. It made a real difference to know that I was working to give God glory and not to give glory to myself. I believe this mindset made a difference for me every day, particularly with my day-to-day attitude. Recognizing that we are working not for our own selfish motivations but for the greater good and ultimately for God’s glory provides a different outlook on our work. This posture and mindset may not always result in different design decisions, but it certainly produces a different individual attitude and awareness for the engineer.

An important point that comes to light in the previous paragraph is determining what is the “greater good” and recognizing that we are always dealing with a restricted viewing window in truly knowing what is the greater good. The history of engineering and technology is littered with unintended consequences, some which should have probably been fended off at the pass by better engineering and judgment early on, and some which it is hard to envision anyone could have foreseen. Petroski has written much about the inevitable humanness of engineering, which in fact gets fleshed out in the third guiding principle that is considered a bit later in this paper. Hopefully, our awareness of doing things to God’s glory pushes us to think even harder about the broader implications of our work and whether the results of our work truly do give God glory.

The flip side of the mindset in the previous paragraph is that we use the idea of doing things to God’s glory as a cop-out to do whatever we want. A helpful critique in the process of developing this paper helpfully pointed out this very danger, which is real and is worth addressing. While it
may have inferred in past publications related to the principles, I am not sure it has ever been stated that the principles need to all be incorporated as an overarching framework; they cannot be used individually in isolation to somehow “sanctify” a particular decision. A design decision that is justified by saying it gives God glory but yet ravages a particular portion of the creation or oppresses a particular people group or brings suffering in some other way is by no means an obedient decision. Using a principle to carelessly justify a poor or selfish decision has certainly never been our intent in the use of these guiding principles.

*Principle 2: Develop and Keep*

This principle generated a few more thoughts from the contributors. Wyenberg (electrical power distribution) observes how he always wants to further his understanding of what he was doing, and he sees this desire to be directly correlated to God’s call to have dominion over the creation. Many of the thoughts provided by Lammers fall mostly under this principle, related to the balance of “science” and “art” in material development and treatment methods. Van Beek states, regarding this principle, “We want to design systems that efficiently and effectively use the resources available to us, including time.” Landman (commercial building systems) observes, “Each project requires an acknowledgement of our limited resources.” In my experience, the “nuts and bolts” of my engineering work fell almost entirely under this principle. As a structural engineer, most days were spent trying to find the most materially and economically stewardly solutions for whatever design challenge was at hand.

Design engineers, whether in the electrical world or the mechanical world or the structural world, have to engage with this principle whether they recognize it or not. Engineering by definition has been involved with “development,” and Christian engineers are often quick to embrace God’s mandate to us in Genesis 1:28 to “subdue…and have dominion” over the earth. Those involved in industry in the last 150 or so years, and the engineers that have been a part of it, have in many ways made a mess out of this dominion, and we’re only starting to realize the extent of it. In the last 10-15 years, engineering professions are realizing this negligence and working harder to encourage better management of our resources, often under the buzz word “sustainability.” This focus shift seems to have produced some positive results; however, it seems like typical approaches pit engineering development versus the environment. As Christians, we can be difference-makers in industry by recognizing that it is not about the competing interests of nature domination versus nature worship, but that Genesis 2:15 clearly presents us with a single mandate to develop and keep God’s creation. This singular two-fold mandate has been fleshed out previously at this conference and elsewhere.

While there is not room in this paper to revisit in depth the ideas that are wrestled with in the mentioned references, it is worth mentioning that it is not at all the intent of the second principle to justify the ravaging of the nonhuman creation. Genesis 2:15 is a call to us as humans to flourish the creation, which includes both the human and nonhuman creation. Proper implementation of this principle will by all means contemplate how the beauty of the lilies of the field (Matthew 6:28-29) integrates with God’s call to responsibly steward His creation.
Principle 3: Creaturely and Finite

All the collaborators had helpful reflections on this principle. Both Landman and Lammers are quick to observe how the knowledge that all of us are flawed is invaluable for interpersonal relationships. Inevitably, engineers and constructors will have different opinions, and acknowledging that no one is perfect can be very helpful in communicating and navigating these differences. The following excerpt from Landman is well-stated:

“Consulting engineering occupies an area of design that can often stretch engineers in uncomfortable ways. Building design teams come together, each member offering their own area of expertise to the project, whether it is architecture, interior design, or structural/civil/mechanical/electrical engineering. Bringing together our different perspectives on design intent, design constraints, and overall project goals can be arduous, difficult, and a great lesson in grace. Each project requires an acknowledgement of our limited resources, as well as large doses of humility and forbearance with each other as finite creatures. For me personally, being able to see others as fellow image bearers, while acknowledging my own fallen and proud nature, is critical to being able to practice grace-filled engineering. Consulting engineering is not only about applying our technical knowledge of the building systems to the problem at hand, but it also involves taking the time to understand our fellow image bearers – those who will use the building, those constructing the building, and those operating as part of the design team. So I am stretched in every building project, stretched to understand each person involved as God’s image bearers, stretched to find ways to best use and conserve limited resources, and constantly stretched to bring God glory through my daily work.”

Similar to the reflection from Landman, the concept of image bearing related to this principle is brought in by Lammers:

“We are finite sinners who have finite knowledge, but we are created in God’s image. As image bearers of the Ultimate Creator that means using our finite creativity and resources to coax out the desired properties. Craftsmanship lies in how you work within the tolerances. In many cases it is ideal to be directly in the middle of the tolerance, but if you know what is occurring afterword and the parts intended use sometimes it is favorable to shift the goal target slightly within the limit to provide the best possible outcome (i.e. avoid unnecessary stress/distortion or provide optimal part hardness for grinding).”

Van Beek also latches onto this principle:

“This affects how we interact with our co-workers every day, our bosses every day, but also those we come in contact with. We have to be mindful of our own human nature and treat others with the grace that God has shown to us. We have to keep an attitude of humility and patience in our interactions with those around us. At the same time, we need to be ready and prepared to confront/deal with words and actions of others. These may just be words and actions that we disagree with or they
may be words and actions that are destructive/inhibitive to the work and goals we are trying to achieve as a company and as individuals. We also have to recognize that we don’t have all the answers and be open and willing to engage different ways of achieving the goals we have regarding making systems fit the customer’s needs in a responsible way.”

It does not surprise me that the idea of our creatureliness resonates with Christians in engineering industry. Our culture seems to have a “STEM will save the world” mentality, but as Christians our worldview is different. We recognize that Christ is the only Savior of the world, and that as humans we are deeply flawed because of our fall into sin. Keeping an awareness of our creatureliness close at hand as we do our day-to-day engineering work is valuable and necessary.

I greatly appreciate the collaborators bringing in the idea of image bearing. We fleshed this idea out a bit more in our discussion meeting as well. The principle of us being image bearers of God was not captured very well in the original formation of the principles, and upon further reflection I believe this biblical concept is important enough to highlight as a separate guiding principle. This addition to the principles will be discussed a bit more later in this paper.

**Principle 4: Alleviate Suffering**

As I have worked with these guiding principles the past several years, this fourth principle is the one that I’ve most wanted to tweak. The contributions of the collaborators and my subsequent conversations with them have supported this desire. In some ways, it feels like this principle is what engineering is all about. After all, one of most common simplistic definitions of engineering is that it is “problem solving,” which is exactly what this principle gets at. However, perhaps the dilemma is that it is “problem solving,” which is exactly what this principle gets at. However, perhaps the dilemma is that there is a bit too much stuffed into this principle. The statement, “We have a responsibility to ease suffering…” is one that occasionally rubs well-meaning Christians the wrong way. It can feel a little bit like an about-face to say in the previous principle that we are NOT saviors, but then seem to say in this principle that we are responsible to be the saviors. We are of course called by God in His word to “do justice” and “love mercy” (Micah 6:8), to be “salt” and “light” (Matthew 5:13-16), and to care for “orphans and widows in their affliction” (James 1:27). It is not necessary to tie these directives to our responsibility for sin; the principle will likely be more helpful by simply providing the biblical directive to care for each other.

One of the most helpful collaborator reflections on this principle is from Van Beek, who interestingly brings in the idea of image bearing here (noting that Landman and Lammers both introduced image bearing in Principle 3):

> “Regarding easing suffering by engaging the human creation, we have hourly and daily interactions with co-workers, suppliers, customers. Do we show genuine concern and care for each of them as God’s image bearers? What does that look like? Taking direct steps to ease suffering can be hard to quantify, but how we interact with people shows our attitude toward God and them. We can inject the gospel into daily interactions; we can ask about things that are happening in their lives; we can take listen to suggestions willingly; we can challenge and encourage
people to think about the lives they are living and why. We need to pray for wisdom for appropriate responses to all the daily interactions we have.

“We also try to keep in mind how systems will be used and try to design them ergonomically so those using the systems we design can do so more easily and not dislike coming to carry out their work because of a poorly designed system.”

One more observation on this principle: Wyenberg mentions how he appreciates this principle because it helps us be aware of how we might be causing suffering ourselves, and it helps us treat each other more respectfully by having this awareness.

The focus of collaborators on personal interactions and human engagement related to this principle is helpful. The lack of focus on “problem solving” is also helpful, as it indicates that perhaps more things should probably be fleshed out from this principle in order for it to serve as intended.

A further note on this principle is that in our original work\(^1\), we felt it was important to flesh out our call to engage both the human and the non-human creation. The mention of the non-human creation is primarily based on what God teaches us in Romans 8:20-22: “For the creation was subjected to futility, not willingly, but because of him who subjected it…For we know that the whole creation has been groaning together in the pains of childbirth until now.” The collaborators on this project struggled to articulate engagement of the non-human creation in light of this principle. Upon reflection, I think there are a couple reasons for this difficulty:

1. Scripture gives us very little insight as to the specifics of sin’s effect on the natural creation. The Bible provides us precious little information on how the mountains, birds, trees, rivers, etc. existed prior to the Fall. The world that we see around us and all the science we have ever known is based on a world suffering from the effects of the Fall. Consequently, it is difficult and perhaps unhelpful for us to seek to engage the creation with a posture of alleviating the effects of the Fall.

2. The second principle (God’s call to develop and keep His creation) already emphasizes the importance of respecting His creation and using it responsibly. Emphasizing this point a second time, except for doing it this time in light of sin and suffering, seems in practice to add confusion rather than clarity.

Principle 5: Already and Not Yet

Over the years, I have appreciated having this principle serve as a bookend with the first principle. Both have similarities in that their strengths are more related to posture and attitude rather than to specific decisions. Van Beek sums it up nicely:

“Knowing this allows us to live joyful and thankful lives and use the talents and abilities God has given us. When things aren’t going right, we can work toward solutions with the attitude that Christ has won the war, so we don’t need to be discouraged. We can still forge ahead doing our best while also understanding that not everything will go as planned. Not everything will work exactly like it was planned because the kingdom is not fully here yet. But we know that as long as we
are carrying out our tasks for God’s glory in service to His kingdom, what we do is meaningful because God has placed us where we are.”

God accomplishes His purposes, sometimes through us and sometimes in spite of us, but He always accomplishes his purposes. This awareness gives us joy when things go well and peace when things do not.

**Where Do We Go from Here?**

It has been a valuable process to engage these principles with practicing professionals who were willing to “try them on for size” so to speak. The process provided very little pushback on the principles but plenty of ideas for minor adjustments that might be helpful. Based on the interaction described in the preceding sections, here are my proposed summary statements for the modified guiding principles, with additions in italics and deletions struck-through.

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 image bearers.*
4. We are creaturely and finite; we are not saviors.
5. As Christ’s hands and feet, we are *called to engage in meeting needs as part of His reconciling work.* involved in the alleviation of both human and non-human suffering.
6. We live in the already and not yet of Christ’s kingdom. reconciling work.

It may be valuable to dig into this modified framework a bit more in the future, gathering Scriptural references and providing more depth and explanation for each principle. However, as the main objective of the current effort is to focus on the feedback from practicing engineers, I believe that task is better left for future work. Briefly, my thought on adding “image bearing” as Principle 3 is that it fits best with the “Creation” portion of Creation-Fall-Redemption. In the proposed framework, Principles 1, 2, and 3 tend to align most closely with Creation. Principle 4 bridges between Creation and Fall; we were created creaturely and finite even before the Fall, but certainly our sin as a result of the Fall exacerbates our creaturely and finite tendencies. Principles 5 and 6 bridge between Fall and Redemption. In Principle 5, meeting the needs around us inevitably means addressing the effects of sin, and of course Christ’s reconciling work brings us Redemption. In Principle 6, the “already” exists in our current world that still experiences the effects of the Fall, and the “not yet” alludes to the completed Redemption (sometimes referred to as the “Consummation.”) The rewording of Principle 5 (formerly principle 4) helps to resolve a bit of the confusion described earlier in the paper while not explicitly detaching this principle from the needs of either the human or the non-human creation. (An important side note on the rewording: it will still be very important to keep both the human and nonhuman creation aspects of this principle at the forefront when wrestling with it, perhaps as one of the primary subpoints of this principle.) Finally, it seems to fit to bring the phrase of Christ’s reconciling work in with the re-wording of Principle 5 and therefore to adjust the wording of Principle 6 to instead refer to the kingdom to eliminate redundancy.

I believe this framework of guiding principles can continue to be a valuable resource for Christians, both in academia and industry, who want to discern what it means to be a Christ-follower in their
day-to-day engineering work. There is plenty of work that could (and perhaps should) still be done with respect to these principles. Some next steps include:

- Continuing to seek opportunities to engage with brothers and sisters in Christ who work in engineering beyond the walls of academia and are interested in exercising and evaluating these principles in their industry work.
- Comparing the responses of the collaborators in this paper to student responses that I have collected over several years and determining whether similarities or contrasts become evident and whether these observations might provide helpful insight on how to engage the principles within our curriculum.
- Developing a concise display format for the latest modification of the principles, including helpful subpoints, Scriptural references, etc.
- Continuing to wrestle with the implications of the principles and improving them where necessary to provide a manageable biblical framework for evaluation of engineering work.
- Related to the previous subpoint, focusing particularly on the revised Principle 5 and whether it might be better in the end to actually bring the “human and non-human” wording back into the principle itself.

Conclusion

I am thankful that God has provided the opportunity to work with a variety of people who care about pursuing engineering and technology in an integrally Christian way. The development and refinement of the guiding principles presented here has provided a formative journey, and I believe the principles have been helpful in shedding light on what it means to walk faithfully as disciples of Christ in our engineering work. Perhaps just as valuable, or even more so, have been the relationships that have developed and deepened along the way. My prayer is that God will continue to accomplish His purposes through our engineering work.

References


Current Disciplines and Worldviews are Insufficient to Address Sustainability Challenges

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Abstract
Modern society is confronted with grand sustainability challenges that are complex, interconnected, and multifaceted. Christian engineers working on solutions to sustainability problems are trained to address technical tradeoffs. However, neither academic disciplines nor traditional Christian theology provide adequate guidance for sustainability tradeoffs within and among the environmental, social, and economic arenas. A series of questions rooted in sustainability issues are used to demonstrate this gap. Finally, it is argued that a robust theology of corporate sin and redemption is a first step to address the gap between the philosophical and theological frameworks we have and those that are needed to put humanity on a path toward sustainability.

1 Introduction
The circumstances of the world today make concerns about environmental, economic, and social issues significant. The concept of “sustainability” encompasses all three areas with a view toward the future. (See Figure 1.) One definition of sustainability is “Sustainability emerges from choices that, on balance, promote economic vitality, social equity, and a flourishing natural environment both now and for generations to come” (Calvin College Environmental and Energy Stewardship Committee). Several of the National Academy of Engineering’s grand challenges for engineering relate to sustainability, which could be considered a meta grand challenge. Becoming more sustainable requires solving complex, multidisciplinary, and multifaceted problems with both technical and nontechnical aspects. Sustainability challenges occur at both the macro level (where international coordination is needed for effective action) and the micro level (where individual and person-to-person interactions can be beneficial).

Engineers design and operate the machines and systems that (a) enhance the natural environment, (b) generate economic growth by providing employment and economic output, and (c) enhance society by bringing people together through communication technologies. But engineers also design machines and systems that (a) consume non-renewable materials and emit pollution, thereby contributing to environmental degradation, (b) replace human workers, and (c) foster online hate. Which direction a particular machine or system propels society is a function, in part, of both its design and of the macro socio-economic policies that inform the design. Because design is a cen-
tral function of engineering, engineers have an important role to play in determining the sustainability of our future.

But what guides engineers to make design choices that lead to sustainability? And what guides policy-makers to make socio-economic-environmental policy choices from which sustainability can emerge? This paper explores two traditional answers to those questions: the academic disciplines and theology/ethics. But we begin by introducing several questions relevant to sustainability that illustrate the need for guiding principles for design and policy. We conclude with the claim that, as presently constituted, neither the disciplines nor theology/ethics is capable of providing guidance to engineers and policy-makers for developing machines or policies that produce a sustainable society.

2 Sustainability questions

We begin with several motivating example questions. Each question is preceded by a few introductory sentences that set the stage for the sustainability issue. This list of questions is not exhaustive, nor is it meant to cover the entire sustainability triangle of Figure 1. Rather, the questions illustrate the technical and nontechnical, even philosophical, dimensions of sustainability challenges and their complex, multidisciplinary, and multifaceted nature. The questions are organized by their location in Figure 1 and are focused around the social vertex.

2.1 Social

Many sustainability questions exist at the social vertex of the sustainability triangle. We start with a set of questions about population. We postulate that for any given level of technological development, there must exist some upper limit to the human population level that the Earth can support. Calculating this upper limit is a technical problem with a technical answer, even if the
calculation is difficult. But many nontechnical questions flow from the postulate above.

1. What is the ideal total population (which is less than or equal to maximum possible population)?

2. How should we manage for and arrive at this ideal population?

3. Where should people live and what is the ideal geographical distribution of population?

Answers to these questions expose human values, which inform relative preferences for social justice, standards of living, environmental versus economic and social tradeoffs, and the relative importance of the means versus ends.

Questions about population issues at the social vertex do not end with the list above. In fact, if decisions about numbers and locations of people are to be made, rights emerge as a central issue. What “right” do people have to food, water, air, medicine or health care, property, or a “living” wage? Where do these rights come from? What rights does the nonhuman world have, and what is the origin of nonhuman rights? What rights do future generations have, and what is their origin? What tradeoffs exist among these rights? How do/should Christian assessments of tradeoffs change when costs and benefits of decisions about population accrue to different (groups of) people? Should decisions about population depend on whether many benefit at the expense of a few or whether a few benefit at the expense of many? Should decisions depend on whether benefits and costs accrue to different generations? Should decisions depend on the size of the benefit/cost? Does the number of people in the group matter? If so, what is a “large enough” difference to matter?

Additional questions at the social vertex go beyond population to climate change and world energy supply, about which many gloomy predictions have been made. Responses to these gloomy forecasts range from “don’t worry, it will all work out,” to “no it won’t.” To which “prophets” should we give credence? The Old Testament criteria for determining the legitimacy of prophets might provide guidance. But as we learn from the Old Testament Israelites, even when true prophets are discerned, it can be very difficult to follow those prophets’ advice.

Finally, beyond prophets, the opinions of ordinary members of society (not prophets) should also be considered for designs and policies. But among non-prophets, we have topic experts and non-expert “people in the street.” Should the opinion of an expert researcher or technologist count for more than a non-expert “man on the street” on sustainability issues? How about a government leader? Does it matter if the question under consideration is technical or nontechnical?

2.2 Social economics

Sustainability questions exist both at the vertices of Figure 1 (as illustrated by the discussion of the social vertex above) and along its edges. To illustrate, we raise several questions along the edge between economics and social.

The questions emerge from a hypothetical policy proposal to ban all air travel. Air travel is a par-
particularly carbon intensive activity on a per-person, per-mile basis. In 2013, air travel was responsible for about 3% of US greenhouse gas emissions. Therefore, banning air travel could be an important step to making the world a more sustainable place.

Engineers are well equipped to analyze some of the effects of this hypothetical policy. For instance, engineers could estimate additional carbon emissions from increases in use of other forms of transportation (road and rail, for example) resulting from a hypothetical ban on air travel. But there are other effects, too, many of which engineers are not well-placed to evaluate. For example, GDP may decrease, because movement of goods from manufacturers to buyers will become more difficult. There will be reduced air and noise pollution near airports, enhancing the aesthetics of nearby properties and possibly increasing their economic value.

We note that any policy change, such as banning air travel, will have direct dollar-measurable impacts (such as change in GDP), indirect but still dollar-measurable consequences (such as increased property values), and consequences that aren’t measurable in dollars (such as improved aesthetics).

The field of economic cost-benefit analysis attempts to express non-dollar-quantifiable social and environmental effects in dollar terms, thereby providing a consistent numeraire and allowing direct comparisons among social and economic (and environmental) effects. But questions arise here, especially for Christian engineers: how should we evaluate design choices and policy prescriptions whose effects are both dollar-quantifiable and non-dollar-quantifiable?

Furthermore, banning air travel might be considered a “clean” or “ideal” policy option. Other policy options could be classified as pragmatic, such as improving air travel energy efficiency. How should Christians navigate the space between ideal and pragmatic policy proposals when both dollar-quantifiable and non-dollar-quantifiable effects are present?

Finally, some consequences of a ban on air travel could include the destruction of the air travel industry and reductions in ancillary industries (hotel, rental car, etc.). The social effects of job losses would be sizable and would likely prompt implementation of remediation policies. Would we do the same if job losses resulted from technological innovation or market forces? If not, why not?

2.3 Environmental social justice

Moving from the social–economic edge to the environmental–social edge yields several questions related to social and environmental justice.

Both the Old and New Testaments teach that Christians should care for those who are less fortunate (often by working to eliminate poverty). But we are also called to care for the nonhuman creation. So how should Christians balance these two imperatives? And how do we respond to the observation that alleviating poverty increases economic consumption, which has negative environmental consequences?

To make this tradeoff concrete, consider two examples. First, suppose an impoverished farmer
lives on the edge of a rainforest. Is it permissible for the farmer to slash and burn the vegetation to create another subsistence farm? Or put another way, would it be unjust to deny the farmer the opportunity to lift their family out of poverty by reducing the size of the rainforest, thereby reducing the CO$_2$ absorbing capability of the planet? It seems inhumane to reinforce current suffering (the farmer’s poverty) for the sake of an imagined future benefit ( hospitable plant for our grandchildren).

For the second example, we note that some say coal mining is good, because the benefits of employment provided by mining outweighs any (potential) environmental harm caused by burning mined coal. How large does the social benefit need to be relative to the environmental cost for this to be true? And, yet again, how are the non-dollar-quantifiable social and environmental costs and benefits to be weighed?

2.4 Multifaceted

The questions above clearly demonstrate that sustainability questions are multifaceted. And the sustainability triangle of Figure 1 provides a useful means to organize those questions.

The multifaceted aspects of sustainability can be summarized in the following short questions:

- How should the environmental, economic, and social aspects of sustainability be weighted against each other?
- What is the balance between the needs of the present and the needs of the future?

As a society, we have de facto arrived at answers to the summary questions above. However, there is increasing evidence to believe that these de facto answers will not lead to a sustainable future. Given that our de facto answers are unsatisfactory, it may be prudent to re-examine how we have arrived at this place. The values that guide our answers come from somewhere, and it is worthwhile to re-examine those sources.

We suggest that the values that guide the designs and policies that contribute to sustainability (or not) are shaped by both academic disciplines and the combination of theology and ethics. In the two sections that follow, we examine each, starting with academic disciplines.

3 Sustainability and the academic disciplines

As the questions above illustrate, moving toward sustainability is challenging, because environmental, economic, and social challenges are complex, multidisciplinary, and multifaceted, with both technical and nontechnical aspects. One traditional source of knowledge for addressing difficult problems is the academic disciplines, which are both generators of and repositories for accumulated human knowledge about a problem domain. There are academic disciplines at each vertex of the sustainability triangle (Figure 1): Environmental Studies (or Ecology, Biology, etc.) for the Environmental vertex, Economics for the Economic vertex, and Sociology for the Social vertex. But, as shown above, difficult sustainability-related challenges exist across disciplinary boundaries and, by definition, cannot be addressed or solved by a single vertex discipline alone.
In a hopeful interdisciplinary sign, disciplines have emerged along the edges of Figure 1. (See Figure 2.) Environmental Economics was founded in the 1960s, focusing on valuation of ecosystem services and internalization of externalities associated with environmental degradation. In the 1970s, Environmental Sociology emerged along the Environmental–Social edge to study interactions between society and the natural environment. Along the Social–Economic edge, Socioeconomics (also called Social Economics) emerged in the early 1980s to study interactions between societies and their economies. Ecological Economics, founded in the late 1980s, is a reaction to the perceived narrowness of environmental economics, emphasizing that the economy as a subsystem of the environment. Academic journals showcase the work being done along each edge. Examples include the *Journal of Environmental Economics and Management*, *Environmental Sociology*, the *International Journal of Social Economics* and the *Journal of Socio-Economics*, and *Ecological Economics*.

However, our assessment of the vertex and edge disciplines, as presently constituted, is that they are not up to the challenge of answering the hard questions on sustainability, some of which are provided in Section 2.

The edge disciplines often assume that difficult tradeoffs can be avoided (or don’t exist), that is, they assume that sustainability isn’t a zero-sum game. For example, much of the literature on sustainability assumes that it is possible to have both “development,” by which it is meant lifting people out of poverty, and environmental conservation. For example, “Humanity has the ability to make development sustainable ... widespread poverty is no longer inevitable if policies that nurture and favor growth are adopted and implemented” (Ngome).

Sometimes the edge disciplines are right, particularly at the micro level. For example, technical innovation sometimes can both improve living standards and reduce energy consumption (for example, modern automobiles last far longer and use less fuel per kilometer compared to those...
produced in the 1960s). But sometimes, and particularly at the macro level, sustainability really is a zero-sum game, and prosperity and conservation really are at odds. For example, you can’t both use fossil fuels and conserve fossil fuels. Economic activity requires input of resources and produces outputs such as pollution. Fundamentally, economic growth is itself unsustainable; at some level of economic activity, the Earth will not be able to supply the inputs needed and/or absorb the wastes our economies produce. Too often the edge disciplines fail to grapple with these macro realities.

Another common error in the sustainability literature of the edge disciplines is the assumption that it will be possible to move from our current situation to a particular envisioned sustainable future. These studies look forward without serious consideration of whether such a future state is practically, physically, and/or technically achievable. One helpful question to discern fanciful or wishful thinking is “what would have to be true for this to happen?” For example, it is generally understood that a carbon-neutral energy sector is necessary for sustainability. What would have to be true for the world to transition to an energy sector that doesn’t emit greenhouse gases?

- There would have to be massive investments in renewable-energy generation. Replacing all coal-fired power plants in the United States (1.2 trillion kW-hrs/yr) with solar generation would require about 4 million acres of land (about 0.2% of the US land area, or about half the state of Maryland) and an investment of $2 trillion, which is about one tenth of the annual US GDP.

- There would have to be massive energy storage. Eighteen to 40 hours worth of electricity storage would have been needed for a fully renewable grid to get the Midwest and Northeast through the January 27–February 2, 2019 polar vortex (Wood Mackenzie).

- There would have to be massive changes to the electricity distribution grid to allow much greater flexibility in routing power.

- There would be massive disruptions to large sectors of the economy. Oil and gas exploration and extraction would be almost entirely eliminated. Gas stations would be out of business—or maybe changed to charging stations.

Furthermore, these edge disciplines exist, almost by definition, on the fringes of the vertex disciplines: E.g., Ecological Economics is not considered “real” economics by many economists. Even if the edge disciplines had the right answers to sustainability questions, they would not affect the vertex disciplines.

Thus, the academic disciplines, as presently constituted, do not provide answers to important sustainability questions. Their vision is not broad enough to be policy-relevant at the macro scale, they too-rarely grapple with the non-zero sum aspects of sustainability, and they too-often fail to explore the practical, physical, and/or technical constraints on sustainability policies.
4 Sustainability and worldviews

If old and new academic disciplines are not up to the task of providing guidance to engineers and policy-makers on sustainability challenges, perhaps theology and ethics and the worldviews inspired by them will be beneficial. Our starting point for this exploration is the thesis that all things (even the academic disciplines discussed in Section 3) are informed by worldviews. Worldviews, in turn, are both shaped by and contribute to religions, theologies, and ethics. Sustainability challenges, too, exist within, are surrounded by, and are informed by all of the above: worldviews, religions, theologies, and ethics. To illustrate the point, we surround the sustainability triangle and edge disciplines with the milieu of worldviews, religions, theologies, and ethics in Figure 3. In this section, we’ll use the shorthand “worldviews” to mean the milieu as shown in Figure 3. Our focus below is on Christian worldviews associated with the vertices of the sustainability triangle, first discussing “Environmental” and ending with “Economic” and “Social” together.

4.1 Environmental worldviews

The book *Ecologies of Grace* (Jenkins) provides a topology of Christian thought regarding the nonhuman creation and the environmental aspect of sustainability. In it, Willis Jenkins identifies three schools of thought: stewardship, eco-justice, and ecological spirituality, which loosely correspond to Reformed (or evangelical protestant), Roman Catholic, and Eastern Orthodox traditions. To Jenkins’ three, we add a fourth: consumptive economic prosperity and the conservative evangelical tradition. These four schools of thought span a wide range of Christian stances toward the nonhuman creation and consequently outline a range of possibilities for Christian responses to environmental sustainability challenges.
Stewardship  The stewardship school of thought emphasizes that all of human existence is a response to God’s redemptive acts and God’s providence to humans. Knowing God leads to vocational responsibility to care for nonhuman creation, the means by which God provides for humankind (Jenkins 19). Thus, all human work to care for the creation is seen as service to the Creator out of gratitude for redemption (Jenkins 77). Earthkeeping (Wilkenson) provides a cogent summary of the importance of stewardship for Reformed Christians doing creation care.

The idea of stewardship is a reaction against themes of human dominion over the nonhuman creation (often implemented as domination) that emerge from some interpretations of the creation stories in Genesis. Christians in the stewardship tradition are inspired by an interpretation of Gen 1:26–28 in which “the proper exercise of dominion yields shalom: the flourishing of all creation” (Bouma-Prediger). As such, the first order of business for stewardship-minded Christians is to act as shalom-building caretakers of God’s creation.

The stewardship viewpoint acknowledges that tradeoffs are present in every policy and in every decision. So, in an engineering sense, Christian environmental stewardship could be considered an optimization problem in which policies that bring about the most good are to be preferred. Furthermore, designs and policies can be critiqued based on the process by which they emerged. Were all voices heard? Was the assessment of tradeoffs accurate? Who decides what goods matter most is important, and all voices should be heard on each matter. Ignoring or disregarding voices is dangerous, since injustices could result. Humans will be persuaded on the right course of action for sustainability policies by weighing the tradeoffs among environmental, economic, and social factors.

Weakness of the stewardship approach are

- deliberation needs to be exhaustive and can be exhausting,
- imperfect information can lead to disastrous results,
- biblical support for stewarding creation is limited,
- stewardship causes separations between God and the creation and between humans and the nonhuman creation by constructing (a) an absent God and present, stewarding humans and (b) separating humans from the nonhuman creation that they steward, and
- stewardship leads to an instrumental view of the nonhuman creation.

For these and other reasons, some argue that we need to move beyond stewardship for effective Christian environmental thought and action (Warners and Heun).

Eco-justice  The eco-justice school of thought emphasizes that God’s grace reveals the creation’s inherent integrity (Jenkins 19), giving it natural value and inherent moral standing (Joldersma). Thus, Christians must respect creation’s inherent value and respond to its moral standing in all activities. If the nonhuman creation can’t speak for itself, we must speak for it and defend it when necessary.
The *Laudato Si* encyclical (Pope Francis) is a clear enunciation of the eco-justice perspective on environmental sustainability issues. In it, Pope Francis portrays the nonhuman creation as a “sister with whom we share our life and a beautiful mother who opens her arms to embrace us” (Pope Francis 3). However, our sister and mother “cries out to us because of the harm we have inflicted on her by our irresponsible use and abuse of the goods with which God has endowed her” (Pope Francis 3). With this framing, the Holy Father evokes centuries of Catholic social teaching about the need to support the oppressed, the poor, and the vulnerable. Christians in the eco-justice tradition would point to the beatitudes (Lk 6) for reminders of the inherent value of those who are oppressed. The first order of business for eco-justice-minded Christians is to bring justice to the nonhuman creation, to right the wrongs of abuse that humans have heaped upon the nonhuman creation.

The eco-justice point of view weighs the environmental justice of any design or policy against the possible economic injustice of depriving others (especially the poor). Eco-justice adherents would be more likely to approve a design or support a policy if it were accompanied by a robust and reliable way to ensure that one people group or another are not disproportionally affected.

Furthermore, eco-justice is based upon the moral standing of the nonhuman creation, meaning that the nonhuman creation itself must be given a voice. To properly evaluate sustainability tradeoffs, someone must be empowered to speak for the nonhuman creation and give voice to unjust and unfair aspects of policies and decisions that have implications for sustainability and the nonhuman creation. Humans will pursue the right course of action on sustainability issues when someone speaks eloquently and forcefully for the those who can’t speak for themselves, including the nonhuman creation.

A significant weakness of the eco-justice point of view is that, in practical terms, time and attention are limited. “Speaking up” for the nonhuman creation is a tall order for most humans. More than that, we probably can’t do it. Humans don’t have the perspective to speak for nonhumans, and it would be presumptive of us to do so.

**Ecological spiritualities** The ecological spiritualities school of thought highlights the union between all of creation and God. Consequently, and by virtue of both owing their existence to the creator, there is a radical connectedness among all human and nonhuman creatures in the creation (Jenkins 93).

The speech “To Commit a Crime Against the Natural World Is a Sin” (Bartholomew I of Constantinople 133-136) provides an excellent summary of the ecological spiritualities point of view on the nonhuman creation. In it, Bartholomew I of Constantinople states, “at the heart of the relationship between man and environment is the relationship between human beings. As individuals, we live not only in vertical relationships to God and horizontal relationships to one another, but also in a complex web of relationships that extend throughout our lives, our cultures, and the material world.” (Bartholomew I of Constantinople 133–134) Thus, any harm done to the nonhuman creation is a harm done to other human beings, but any good done to the environment is a good done to humans, and praiseworthy. In the ecological spiritualities school of thought, tradeoffs among the environmental, economic, and social realms of sustainability fade into the background.
The first order of business for Christians in the “ecological spiritualities” mindset is asceticism, self-restraint for the good of the nonhuman creation and for others. Asceticism will lead to practices that look much like conservation of the nonhuman creation.

A weakness of the ecological spiritualities school of thought is that by assuming away tradeoffs, it fails to grapple substantively with tradeoffs among the three aspects of sustainability in real-world situations.

**Consumptive economic prosperity**  The consumptive economic prosperity school of thought holds that the nonhuman creation is resilient, robust, and self-correcting. Furthermore, its well-being is assured by God, because part of the “goodness” that God designed into the creation is robustness to human actions; God is always in control. In this school of thought, human well-being is paramount. Thus, humans are to be consumers of the nonhuman creation to provide economic prosperity and lift people out of poverty. Documents from the Cornwall Alliance provide a summary of conservative evangelical thinking on creation care issues (Cornwall Alliance).

People with the consumptive economic prosperity worldview will claim that any environmental degradation caused by humans will be fixable, given sufficient economic resources guided by the free market’s invisible hand and/or that technical innovation, that is, human ingenuity, will provide complete solutions to environmental problems. Thus, reducing economic prosperity will, ultimately, be bad for the environment, because we will have fewer economic and technical resources with which to address environmental damage. The first order of business in the consumptive economic prosperity school of thought is economic growth, which provides resources, technology, and incentives for remediating environmental problems.

Weaknesses of this approach to the nonhuman creation include:

- the assumption that technology will be our savior,
- a reluctance to grapple with human impacts on the nonhuman creation, and
- reduction of the nonhuman creation to economic terms.

4.2 Economic and Social Perspectives

Worldviews on economic and social issues are often grouped together, and we follow that tradition here. An instructive axis on which to consider the economic and social aspects of sustainability is the range between “Individualistic” and “Collectivistic” points of view, as shown in Figure 4. Christians of all stripes (denomination, gender, ethnicity, nationality) hold individualistic or collectivistic points of view, so we do not associate these perspectives with any particular branch of Christianity or group of Christians. (In fact, political persuasion is a more-accurate predictor of location along the individualistic—collectivistic axis than denomination or other factors.) After discussing the range of Christian economic and social perspectives, we illustrate our points by applying the perspectives to the classic “tragedy of the commons” problem.

Biblical teaching in the economic and social realms is often recognized as two sides of the same
coin. For example, Micah 2:1-2 denounces unjust deeds that are economic in nature. Biblical teaching on economics and justice is not a systematic, over-arching theory (macro), but rather focuses on individual interactions (micro). (One partial exception to this pattern is the Old Testament sabbatical/jubilee system of canceling debt and returning property. In modern economic terms, canceling debts and returning property would serve to minimize income inequality and ensure that there was universal access to the means of production. Indeed, much of the Bible’s teaching on money relates to generosity to the poor. Numerous Old and New Testament passages instruct God’s faithful to give generously to the poor, the disadvantaged, and the marginalized, where “giving” is meant to be some combination of money (traditionally called “alms”), material goods (such as food or clothing), and justice or fairness. The purpose of the Bible is to bring us into a saving relationship with God. Macro policy proscriptions for sustainability fall outside of its purview.

Some Christians view wealth itself as a root of evil. This view goes beyond merely the love money being the root of evil (I Tim 6:10). Proponents of the view that money itself is a source of evil would point to Jesus telling the rich young man to sell all his possessions and give to the poor and Jesus’ further comment that it is easier for a camel to go through the eye of a needle than for a rich man to enter the kingdom of God (Mt 19:16-30, Mk 10:17-31, Luke 18:18-30). At the other end of the spectrum of Christian thought, worldly wealth is seen as God’s blessing, even an indication of God’s favor.

In terms of modern economic views, Christians hold a wide range of positions. Some Christian traditions advocate a collectivistic economic arrangement, in imitation of the early church (Acts 2:42-46). Examples range from monastic orders such as might be found in Roman Catholic or Eastern Orthodox traditions to the Hutterite and Bruderhof communities, which come from an Anabaptist tradition. At the other end of the economic spectrum, many Christians advocate for an economic system based on individual ownership and freedom of enterprise. Some key verses that support a more individual view include the comments “Didn’t it belong to you before it was sold?”

<table>
<thead>
<tr>
<th></th>
<th>Individualistic</th>
<th>Collectivistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Table for individualistic and collectivistic views on economic and social issues.
And after it was sold, wasn’t the money at your disposal?” (Acts 5:4) and Paul’s instruction that we should work to eat (2 Thes 3:10) and to share with those in need (Eph 4:28).

Likewise, Christian social perspectives can stress individual freedom or collective behavior. A liberal (individualistic) approach to providing for poor widows would be tied to instruction that widows should be provided for, first of all, from their own families (1 Tim 5:4). The collectivistic approach is represented by the group effort of caring for widows at the beginning of Acts 6.

To illustrate the individualistic and collectivistic approaches to the economic and social aspects of sustainability, we apply those perspectives to a classic sustainability problem, the tragedy of the commons. The term “tragedy of the commons” was popularized by Hardin (Hardin) and provides a shorthand reference to situations where (a) there is equal and open access to a resource or pool of resources and (b) it is in the rational self-interest of every individual to maximize their use of the resource, even if this results in the net effect of destroying the resource itself through over exploitation. This class of problems is recognized as “having no technical solution.” Instead, sustainable solutions emerge from decisions (policies) that address all vertices of the sustainability triangle: environmental, economic, and social.

As originally stated, each herder has incentive to add more animals to his or her flocks grazing on the common land, because the benefits (the extra animals) would accrue solely to the herder but the cost (degradation of the land) would be split among all herders grazing on the land. Moreover, because each herder knows that all other herders face the same incentives, it is rational to predict that the land will be ruined and that each should “get while the getting is good.” The “tragedy” lies in the “remorseless working out of things.”

A collectivistic economic solution to the tragedy of the commons is for all of the animals grazing on the commons to be common property. Every member of the community would receive an equal share of the common herd (for example, cash value of the meat sold at the end of the year). It would thus be in every individual’s self-interest to maximize the total output, not just the output of their own animals. On the other hand, an individualistic economic solution is to charge each herder an increasing amount of rent for each additional animal placed on the common land, which would create a financial incentive for each herdsman to keep only a reasonable number of animals.

An individualistic social solution to the tragedy of the commons would value individual freedom above group results. Moreover, it would be expected that individuals, as rational moral beings, can solve their own problems. The tragedy of the commons would be self-correcting. A collectivistic social solution would involve the entire community establishing regulations regarding how animals total are allowed to graze on the common land.

One way to understand the tragedy of the commons is that herders are guilty of a collective sin: in pursuit of personal wealth maximization, the group of herders, corporately, are guilty of sinning against the nonhuman creation. A presumed good (wealth maximization) on one level (micro) leads to a negative consequence (destruction of grazing land) on another level (macro). Today’s theologies are ill-equipped to address corporate guilt and, thus, existing Christian theologies are unhelpful when addressing sustainability considerations that bridge the micro and macro
levels. Macro level problems for which everyone is responsible (destruction of grazing land, climate change) are nobody’s fault at the micro level.

4.3 The need for and a robust theology of sustainability

In our view, the worldviews associated with the three vertices of the sustainability triangle (as presently realized) are insufficient to support comprehensive solutions to the sustainability grand challenge. All of the environmental worldviews (Section 4.1) are flawed in some way. They are too deliberative, too instrumental toward the nonhuman creation, time-impractical, ignore important tradeoffs, are reluctant to grapple with human impacts on the nonhuman creation, and/or reduce the nonhuman creation to economic terms. The economic and social worldviews (individualistic and collectivistic) are too focused on the micro rather than the macro. All of which points to the need for a robust theology of sustainability, one that (a) is comprehensive, allowing us to address the “all at once” nature of sustainability challenges and (b) strengthens the idea of corporate sin.

5 Conclusions

It is evident that human society in its current state is unsustainable. Further, the future direction also looks to be unsustainable. The reasons for our unsustainable trajectory are multifaceted and complex. However, it is due, at least in part, to the fact that humans are philosophically and theologically poorly equipped to think about sustainability solutions on the scales that the sustainability challenges exist. As presently constituted, academic disciplines are unable to address sustainability concerns. Section 3 suggests that robust, truly transdisciplinary inquiry is needed. Likewise, existing Christian theology is not up to the task of addressing sustainability challenges. There is a need for a robust theology not just of individual guilt and redemption, but also of corporate guilt and redemption. Section 4 suggests that an adjusted theology and ethics is needed, ones that (a) are comprehensive, allowing us to address the “all at once” nature of sustainability challenges and (b) strengthen the idea of corporate sin.

There is certainly much work to be done. The challenges of sustainability involve both technical and nontechnical aspects, but engineers have important roles to play in addressing both.

Works Cited


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CONFLICTS BETWEEN FAITH, TENUOUS ENGINEERING ETHICS, CULTURE AND WORKPLACE NORMS

Yunus D. Salami

ABSTRACT

Engineering practice is regulated in many countries around the world and engineers are held to very high standards. In the United States, engineering students learn some of these guidelines of practice in school and must then improve their knowledge of and adhere to them as practicing engineers. Depending on the project location, local guidelines, and other challenges the project poses, engineers who are adherents of a particular religion can experience multiple conflicts of interest. Faith or a personal belief system may lie in irresolute contrast with questionable cultural beliefs, overtly or covertly corrupt business norms and practices, and ambiguous, arbitrary or seemingly non-existent guidelines of practice.

Even where local ethical codes exist, their foundations and enforcement system may be tenuous, or the local laws may be deliberately bypassed to facilitate graft. Whether they are a fresh graduate with an idealistic notion of their new role in the workplace or an experienced project manager, each Christian engineer must confront these issues and ultimately seek to resolve them with their profession’s tenets and personal faith in order to be effective on the job.

This paper details the experiences of a young Christian and fresh engineering graduate born outside the United States and working in his first roles in civil engineering practice. Qualitative and quantitative information was used to depict the extent to which local guidelines conformed with or deviated from those set by a renowned body like the American Society of Civil Engineers. As an interesting parallel observation, personal accounts and experiences of other engineer co-workers who are adherents of another faith were sought and found to markedly agree in some cases – and disagree in others – with the experience of the Christian engineer. The work experiences were with both local and foreign-owned firms working on similar projects in the same country but there appeared to be similar conflicts between personal faith, ethics, and local business norms experienced while working at each. This suggests some sort of ‘cultural acclimatization’ where expatriate firms with otherwise strict codes of practice back in their home countries become witting or unwitting accomplices in questionable practices overseas.

Some lessons learned here could help prepare (i) Christian engineering firms and engineers for such conflicts of interest in the line of duty (ii) engineering educators at Christian institutions to emphasize integration of faith with not just learning but practice.

Keywords: faith conflict, engineering ethics, overseas projects, culture, faith integration

1 INTRODUCTION AND BACKGROUND

1.1 Engineering Code of Ethics and the Need for Revisions

The American Society of Civil Engineers’ (ASCE) Code of Ethics was first adopted in 1914. Since then, the body has sometimes revised its code of ethics to cater for new issues that engineers encounter in the line of duty (ASCE 1976; Vesilind 2002; “ASCE Code of Ethics” 2018), with its most recent update completed in 2017. For example, prior to its revision in 1997, the code of ethics of the ASCE did not centrally address the engineer’s interaction with his environment. In essence, engineers who were seeking guidance on their professional responsibility discovered that only on issues where their actions posed a risk to other humans was the Code useful (Vesilind and Gunn 2002). This meant that the Code of Ethics did not

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address environmentally harmful actions that were not clearly detrimental to the 'health, safety, or welfare of the public.' Eventually, the ASCE leadership accepted that civil engineers face daily issues related to environmental quality and prompted the Society to review its Code of Ethics to include a statement on 'sustainable development.' (Vesilind and Gunn 2002). This has been very well received because of the relevance of sustainability in contemporary engineering practice.

1.2 Engineering and Unethical Practices

Just like US-based engineers subject to ASCE Codes of Ethics, foreign-based engineers often have to deal with professional practice issues under the auspices of the engineering societies in their home countries. For example, there are other issues that may be considered ambiguous or 'gray areas', like what constitutes proper professional conduct when executing projects in foreign countries with ambiguous local laws. This is because despite the existence of codes of ethics and regulations for engineering practice in many parts of the world, some places have acknowledged the need for - but not followed through with - necessary revisions (Barco 2006; Devine 2004). Sometimes, there is no clear provision for enforcement. This results in a situation where practices like the submission and review of project bids, the grounds for unbiased and objective evaluation, and the final award are rife with corruption and favoritism (Brown and Loosemore 2015; Niazi and Painting 2017; Isaksson and Kotsadam 2018; Sohail and Cavill 2008). Often, while there appears to be an implicit awareness of wrongdoing, the practice is so widespread that it appears to be the way business is done (Werlin 2005; Makgala 2010; Nordin, Takim, and Nawawi 2011; Niazi and Painting 2017).

Vardi et al. (2013) discussed maintaining zero tolerance for bribery, fraud, and corruption. That study created a hypothetical situation in which an American engineering firm encounters political corruption overseas when attempting to acquire a construction contract there. It proceeded to discuss the responsibilities of members of the American Society of Civil Engineers (ASCE) under its code of ethics and the U.S. Foreign Corrupt Practices Act (Vardi et al. 2013). The following crucial question was then posed: “What steps should the engineering firm and its employees take to ensure that they do not fall foul of their legal obligations or of ASCE's Code of Ethics? It answered this with a recommendation based on the following revision to canon 6 of the Code of Ethics: "Engineers shall act in such manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession and shall act with zero tolerance for bribery, fraud, and corruption." Employing the phrase "zero tolerance" firmly suggests that ethical behavior is not just shunning an obvious act of bribery but requires an engineer to be vigilant in recognizing and averting situations in which somebody might seek to derive selfish benefit through an improper payment or a corrupt transaction (Vardi et al. 2013).

1.3 Engineering Practice and Faith

Not many studies have been conducted on how scientists and engineers handle conflicts between faith or religious convictions, corrupt work practices, and established ethical guidelines. This is perhaps because spirituality and engineering education or practice are separately compartmentalized in the lives of individuals except for occasional discussions in ethics classes or service-learning projects (Thompson, Chua, and Joslyn 2014). But openly talking about and living out values of faith as engineers in a predominantly secular world is
still uncomfortable for many Christians. Along this line, Thompson et al. (2014) thoroughly examined the interactions of spirituality with both teaching and research practices in engineering education, evaluated the discomfort of such a dialogue in a secularized technical culture, and explored the tensions of multiple and often conflicting perspectives of faith on each topic. In science and some non-engineering fields, the difficulty of coping with combining one’s faith with one’s professional life at work to manage work conflict has been documented (Valenti 2002).

One interesting but little-studied situation is one in which an engineer finds his personal faith in conflict with tenuous engineering ethics (of both local and foreign firms) while working overseas. Faith conflicts may be in the form of practices listed in Table 1. In essence, the possibility of becoming complicit with, say, bribery and corruption run afoul of both the engineer’s professional and personal convictions. This paper presents a new perspective on this issue by detailing the experience of a new graduate engineer confronted by a similar situation at work and their reflections in hindsight of what similarities these conflicts bear when juxtaposed with ASCE Code of Ethics.

2 METHODOLOGY AND BASIS OF EVALUATION

2.1 Context of Professional Experience at Each Company

The study location and names of the two companies referenced in this paper have been deliberately anonymized due to the sensitive nature of the topic presented and to hopefully prevent reader bias. The two companies will be referred to as Company #1 and Company #2. Company #1 was a local firm completely staffed by local engineers and staff and possessed an orderly hierarchical structure based on experience and level of education. The author worked here as a civil engineer for one and a half years until an opportunity opened up at Company #2. Company #2 was a foreign-owned firm whose personnel consisted of about 90% expatriates who were citizens of the company’s parent country. After leaving Company #1, the author was hired here as a civil engineer for one and a half years working on very similar projects in the same location before leaving to go to graduate school.

2.2 Local Engineering Regulations

Two affiliated regulatory bodies exist for the standardization of engineering in the study location; one for licensing and professional practice issues and the other for guidelines and code enforcement. Although local engineering practice guidelines and codes of ethics in the study location are established by these bodies, they will not be published here for similar reasons to Section 2.1 above which is to maintain anonymity. Instead, the extent to which both these guidelines and observed practices conform with established standards like those of the ASCE will be described.

2.3 Comparison with Code of Ethics and Justification for Comparison

There are eight fundamental canons in the ASCE’s Code of Ethics and under each canon is a set of guidelines to practice. Each company was evaluated to see whether or not its practices are in agreement with these guidelines to practice and how many of these guidelines it conformed with under each canon statement. The Code of Ethics of the ASCE was used as a basis for comparison because of its relative simplicity, ease of comprehension, and the strict
standards to which engineering and engineers under its auspices are held. It was also chosen because of the length of time the code of ethics has been in existence, the extent of scrutiny the codes and the importance attached to adherence to them, and the timely and necessary revisions the code has undergone. This paper does not suggest a moral superiority of the ASCE code. Rather, it is hoped that using established canons like the ASCE’s will make for easier comparison and evaluation of the international professional experiences presented in this paper using a basis familiar to its mainly American audience. The guidelines to practice described under each of the eight main canons were matched with the observed practices at each company and also with the local guidelines (Table 2). As shown in Equation 1 below, the number of guidelines to practice that each company’s practices are in agreement with were multiplied by 100 and divided by the total number of guidelines to practice and a percent agreement was determined.

\[
\text{Percent agreement} = \frac{\text{number of guidelines to practice agreed with under each canon}) \times 100\%}{\text{total number of guidelines to practice in each canon}}
\]

2.4 Evaluation of Christian Faith Conflicts

A basis for evaluation was established by compiling ten practices considered unchristian, with scriptural references for each taken from the Bible (Table 1). Checkmarks were assigned where there were practices at each company that conflicted with tenets of the Christian faith (Table 3).

Table 1: Christian Faith Conflicts and Scriptural References

<table>
<thead>
<tr>
<th>Christian faith conflicts observed</th>
<th>Scriptural references</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Funds misappropriation at the expense of work quality</td>
<td>Luke 14:28; Colossians 3:23-24;</td>
</tr>
<tr>
<td>2 Discrimination based on tribe, age, or religion</td>
<td>Deuteronomy 24:14; 1 John 2:11; Exodus 22:21</td>
</tr>
<tr>
<td>3 Disrespect/disregard for coworkers' faith and religious freedom</td>
<td>Romans 14:1-4; John 13:34-35; Acts 10:28</td>
</tr>
<tr>
<td>4 &quot;Incentivization&quot; (bribery)</td>
<td>Exodus 23:8; Proverbs 15:27; Ecclesiastes 7:7</td>
</tr>
<tr>
<td>5 Intimidation of subordinates; suppression of dissent</td>
<td>Ephesians 6:9; Deuteronomy 24:14</td>
</tr>
<tr>
<td>6 Corruption; falsification of numbers, documents, etc.</td>
<td>Proverbs 11:1; 1 Thessalonians 4:6; Leviticus 6:1-5; Leviticus 19:13</td>
</tr>
<tr>
<td>7 Use of foul-language at work</td>
<td>Ephesians 4:29; Matthew 15:11; Ephesians 5:4</td>
</tr>
<tr>
<td>8 Insubordination; disregard for professional superiors</td>
<td>Titus 3:1-2; Hebrews 13:17</td>
</tr>
<tr>
<td>9 Conspiracy to conceal work incidents of concern</td>
<td>Proverbs 6:16-19; Colossians 3:9-10</td>
</tr>
<tr>
<td>10 Cronyism</td>
<td>1 Timothy 5:21; James 2:1; Job 34:19</td>
</tr>
</tbody>
</table>

2.5 Evaluation of ‘Other Faith’ Conflict

Islam was chosen as the ‘other faith’, being the other predominant religion practised in the area. A Muslim engineer who worked at one of the companies was also asked to retrospectively evaluate his experience based on the same set of practices. The engineer had
worked in a similar role as the author and at a similar level. However, the engineer was
encouraged to complete the assessment completely at their own discretion, based on what
they considered permissible by their faith. The results are presented in Table 4.

3 RESULTS AND DISCUSSION

The results from the evaluation and comparison of each company are presented below.

3.1 Results of Comparison with ASCE Code of Ethics

The results from Table 2 show that for canons #6 and #8, both companies’ employees had
practices that run afoul of these canons. This is the reason for the zero percent obtained. Some
factors responsible for this are the practices of bribery, corruption, and employment
discrimination observed in both companies. Remarkably, this trend is also reflected in the
Christian faith conflicts evaluated (Table 3) and explained in section 3.2 where faith conflict
evaluations flagged items #2 and #4 which are discrimination and bribery respectively. This
demonstrates an interesting match between the findings from the faith conflict evaluation and
from ASCE Code of Ethics comparison. For canon #7, Company #1 and #2 both agree 100%
perhaps because of the emphasis placed on professional development and career
advancement of engineers. For canon #1, while the practices of Company #2 agree 100%, those of Company #1 show .3%. This difference is most likely due to Company #1 engaging
in practices that deviate from guideline (c) which states that “Engineers whose professional
judgment is overruled under circumstances where the safety, health and welfare of the public
are endangered, or the principles of sustainable development ignored, shall inform their
clients or employers of the possible consequences.” (“ASCE Code of Ethics” 2018).
Examples of such practices include deliberately failing to report safety violations. Again, this
was observed in the faith conflict evaluation item #9 which is conspiracy to report work
incidents of concern. One key observation is that the overall qualitative assessment of the
practices of Company #2 was not significantly better than Company #1. In essence, Company
#2 performed no differently than one would expect a local firm to. This perhaps suggests
some a kind of ‘cultural acclimatization’ where expatriate firms with otherwise strict codes
of practice back in their home countries become witting or unwitting accomplices in
questionable practices overseas due to lax laws.
<table>
<thead>
<tr>
<th>Canon #</th>
<th>Fundamental Canons</th>
<th>Guidelines to Practice under the fundamental canons</th>
<th>Guidelines in agreement with, and percent agreement</th>
<th>ASCE’s guidelines similar to local guidelines?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties</td>
<td>6 a, b, c, d, e, and f a, b, d, e, and f</td>
<td>83.3 a, b, c, d, e, and f 100</td>
<td>Yes, explicit</td>
</tr>
<tr>
<td>2</td>
<td>Engineers shall perform services only in areas of their competence.</td>
<td>3 a, b, and c a and c</td>
<td>66.7 a, b, and c 100</td>
<td>Yes, implicit</td>
</tr>
<tr>
<td>3</td>
<td>Engineers shall issue public statements only in an objective and truthful manner.</td>
<td>5 a, b, c, d, and e a, c, d, and e</td>
<td>80 a, c, d, and e 80</td>
<td>Yes, explicit</td>
</tr>
<tr>
<td>4</td>
<td>Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.</td>
<td>7 a, b, c, d, e, f, and g a, b, e, f, and g</td>
<td>71.4 b, e, f, and g 57.1</td>
<td>Yes, explicit</td>
</tr>
<tr>
<td>5</td>
<td>Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.</td>
<td>8 a, b, c, d, e, f, g, and h b, c, e, f, and g</td>
<td>62.5 c, e, f, and g 50</td>
<td>Yes, explicit</td>
</tr>
<tr>
<td>6</td>
<td>Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession and shall act with zero-tolerance for bribery, fraud, and corruption.</td>
<td>6 a, b, c, d, e, and f</td>
<td>0 0</td>
<td>Yes, explicit</td>
</tr>
<tr>
<td>7</td>
<td>Engineers shall continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers under their supervision.</td>
<td>4 a, b, c, and d a, b, c, and d</td>
<td>100 a, b, c, and d 100</td>
<td>Yes, explicit</td>
</tr>
<tr>
<td>8</td>
<td>Engineers shall, in all matters related to their profession, treat all persons fairly and encourage equitable participation without regard to gender or gender identity, race, national origin, ethnicity, religion, age, sexual</td>
<td>3 a, b, and c</td>
<td>0 c 33.3</td>
<td>Yes, implicit</td>
</tr>
</tbody>
</table>
3.2 Results of Evaluation of Christian Faith Conflicts

Workplace practices observed at each company are indicated in Table 3 by checkmarks. These show both frequent or semi-frequent practices exhibited by staff of both companies.

Table 3: Faith Conflicts Observed at Companies

<table>
<thead>
<tr>
<th>Christian faith conflicts observed</th>
<th>Company #1 (local)</th>
<th>Company #2 (foreign)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Funds misappropriation at the expense of work quality</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>2. Discrimination based on tribe, age, or religion</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3. Disrespect/disregard for coworkers’ faith and religious freedom</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>4. 'Incentivization' (bribery)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>5. Intimidation of subordinates; suppression of dissent</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>6. Corruption; falsification of numbers, documents, etc.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>7. Use of foul-language at work</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>8. Insubordination; disregard for professional superiors</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>9. Conspiracy to conceal work incidents of concern</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>10. Cronyism</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Some practices like funds misappropriation at the expense of work quality and conspiracy to conceal work incidents of concern were engaged in more subtly. But others were practised more openly and unabashedly, including cronyism and employment discrimination based on ethnicity, age, and faith. With the latter, the individuals involved comfortably practised what seemed like institutionalized biases and were apparently oblivious that there were potentially unethical concerns. These results markedly agree with those from section 3.1 and Table 2 on all common metrics of evaluation. For example, canon #5 only saw 62.5% and 50% agreements with Company #1 and #2 respectively (Table 2) due to the missing guideline (a) in both companies’ practices. Similarly, the results in Table 3 (items #4 and #6, which are bribery and corruption respectively) appear to compare favourably with this missing guideline. This guideline states that “Engineers shall not give, solicit or receive either directly or indirectly, any political contribution, gratuity, or unlawful consideration in order to secure work, exclusive of securing salaried positions through employment agencies”.

3.3 Results from Evaluation of ‘Other Faith’ Conflict

The results shown in Table 4 below are from a parallel evaluation of Company #1 performed by a colleague who is an adherent of the Muslim faith. These agree with those in section 3.2 based on personal Christian faith convictions, except for workplace practices #3 and #4. The reason given for this difference in workplace practice #3 was that they were not awarded sufficient time off to observe Muslim religious events and holidays despite similar concessions being regular granted to Christian employees. Other reasons included not being
allowed to perform the five daily Muslim prayers during work hours and overhearing uncomplimentary remarks about Islam made by co-workers. They also opined that motivational perks and monies paid to clients for additional projects and to unskilled laborers in construction projects undertaken by the company were “necessary investments” and did not count as bribery. This is despite the fact that payments were often apart from the recipients’ regular wages, were arbitrary in sum and frequency, and set up to indirectly solicit additional favours. It appears that personal perception was responsible for the minor differences observed in results of faith conflicts as opposed to different faith tenets. Except for items #3 and #4, the comparison between Table 3 and Table 4 shows marked agreements.

Table 4: Evaluation of “Other Faith” Conflict

<table>
<thead>
<tr>
<th>Faith conflicts observed</th>
<th>Company #1 (local)</th>
<th>Company #2 (foreign)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Funds misappropriation at the expense of work quality</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>2 Discrimination based on tribe, age, or religion</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>3 Disrespect/disregard for coworkers’ faith and religious freedom</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>4 “Incentivization” (bribery)</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>5 Intimidation of subordinates; suppression of dissent</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>6 Corruption; falsification of numbers, documents, etc.</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>7 Use of foul-language at work</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>8 Insubordination; disregard for professional superiors</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>9 Conspiracy to conceal work incidents of concern</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>10 Cronyism</td>
<td>✓</td>
<td>N/A</td>
</tr>
</tbody>
</table>

4 CONCLUSION AND LIMITATION

This paper examined the experience of a new engineering graduate working in his first roles in civil engineering practice and the conflicts experienced between faith, ethics, and questionable professional practices. Even though the work experiences were with both local and foreign-owned firms working on similar projects in the same country, the results suggest that there were similar conflicts between personal faith, ethics, and business practices experienced while working at each. Some lessons learned here could help prepare (i) Christian engineering firms and engineers for such conflicts of interest in the line of duty (ii) engineering educators at Christian institutions to emphasize integration of faith with not just learning but practice. One limitation of this study includes the use of mainly data from one person’s experience rather than several employees. Another limitation is the use of only two work places although the inherent difficulty in collecting such sensitive data is obvious. Also, without space constraints, a more detailed description of the guidelines to practice under the ASCE’s Code of Ethics would have better served readers less familiar with these guidelines.
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The Challenge of Transhumanism

Derek C. Schuurman

Abstract
Technology like glasses, pacemakers and artificial limbs aim to restore normal human capacities that have been lost or damaged due to disease or accidents. In contrast, transhumanism is a movement that seeks to use technology to enhance humans far beyond the limits of their current physical and intellectual capacities to evolve into something better. The goal is for humanity to take control of its evolutionary destiny and move towards a “posthuman” future. A key element of the transhumanist worldview is morphological freedom, the notion that one has the right to modify oneself according to one’s desires. Some transhumanists even believe we will conquer death by shedding our human bodies and downloading our brains into a computer. These notions of disembodied existence reveal some Gnostic notions embedded in certain transhumanist ideals. We need to be cognizant that some of our current technologies, such as virtual reality and social media, come with liturgies of control that can make us more comfortable with morphological freedom. The longings of transhumanists point, in part, to a recognition of our fallen condition with disease and death, and that things are not the way they are supposed to be. But they look to technology instead of God (or in addition to God) as savior of the human condition. We need to remember how the incarnation reveals the value God places on our physicality and humanity and how Christ, “the Word who became flesh” (1 John 3:2), models what it means to be truly human. Recognizing the importance of valuing bodies and presence should therefore also inform the design and use of our technologies.

Introduction
A 1972 novel titled Cyborg tells the story of an astronaut, Steve Austin, who suffers a catastrophic crash resulting in the loss of several limbs and an eye. The story unfolds as Austin is equipped with mechanical prosthetics called “bionics” which give him strength and capabilities that far surpasses his original body parts. This mixture of man and machine is called a cyborg, hence the title of the novel. The novel was later made into a popular 1970’s television show called the Six Million Dollar Man that aired when I was a young boy. I remember the popular Steve Austin action figure toys that included features like “bionic grip” and a bionic eye that you could peer through from the back of the head. I also recall the theme music and the iconic lines from the opening of the show: “Gentlemen, we can rebuild him. We have the technology. We have the capability to make the world's first bionic man... Better than he was before. Better, stronger, faster.”

The desire to transform humanity to make itself better, stronger, and faster lies at the heart of a philosophical movement called transhumanism. Nick Bostrom, one of the cofounders of the World Transhumanist Association (now named Humanity+), authored an article titled “Transhumanist Values” in which he writes, “Transhumanists view human nature as a work-in-progress, a half-baked beginning that we can learn to remodel in desirable ways. Current humanity need not be the endpoint of evolution. Transhumanists hope that by responsible use of science, technology, and other rational means we shall eventually manage to become posthuman, beings with vastly greater capacities than present human beings have.” The Humanity+ website

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defines transhumanism as “The intellectual and cultural movement that affirms the possibility and desirability of fundamentally improving the human condition through applied reason, especially by developing and making widely available technologies to eliminate aging and to greatly enhance human intellectual, physical, and psychological capacities.” These efforts include “bio-hacks” for anti-aging, enhanced senses, memory augmentation, amplified intelligence, and genetic enhancements.

In our modern era, “the attempt to upgrade humans into gods takes humanism to its logical conclusion.” A fascination with superhuman capabilities is evident in themes explored in superhero fiction literature. Superheroes are characters who somehow have achieved abilities far beyond human limits. Examples include the X-men, Iron Man, Batman, Spiderman, the Hulk, and Captain America. Each of these heroes have backstories that describe how they became technologically or biologically enhanced human beings. Many of these stories are based on archetypes that go back to the mythology of ancient Greece and Rome with characters like Daedalus, Icarus, Prometheus, and Poseidon. Clearly, the attraction of superhuman capabilities is nothing new to the human imagination. In fact, the fascination with transcending human limits goes back the original temptation of “you will be like God” in the Garden of Eden (Gen. 3:4).

**Transhumanism and Morphological Freedom**

One of the key values of transhumanism is the concept of “morphological freedom.” The futurist Anders Sandberg defines morphological freedom as “an extension of one’s right to one’s body, not just self-ownership but also the right to modify oneself according to one’s desires.” The philosopher Jean Bethke Elshtain observes, “Bodies are thought of increasingly as the exclusive property of an individual for one to do with as one sees fit. Bodies are also construed as malleable and ‘constructable.’”

Francis Fukyama identifies a line between “therapy” and “enhancement.” We already use technology in therapeutic ways to restore normal human capabilities. One common example is glasses, which are a technology meant to correct for poor vision. Other examples of technologies used to bring healing and restoration include pacemakers, dentures, artificial limbs, and cochlear implants. We regularly use technology to enhance human capabilities: calculators for speed, telescopes to see further, vehicles to travel faster, and radio to hear over a distance. But all of these technologies are external to ourselves and do not fundamentally change what it means to be human. In contrast, the goal of transhumanists is to direct technology towards enhancing ourselves.

There is a fundamental difference between wearing a jet-pack and modifying one’s DNA to grow wings. Jacob Shatzer writes “These are the changes that advocates of morphological freedom are after. Not the ability to wear glasses or have surgery, but to have a tail if you want to.” Some have argued that the line between therapy and enhancement is not clear and can be difficult to determine in practice. Are “deviations from some presumed norm” a disease that should be treated or part of normal variations? The technology initially developed for healing might later be applied to enhancement. In fact, Yuval Noah Harari suggests that “[h]ealing is the initial justification for every upgrade.”
While developing technology to heal and restore normal human functioning is clearly one way to love our neighbor, enhancement is another matter. Some enhancement technologies, like eugenics, have already been rejected. Other attempts at human enhancement are driven by human hubris, building a modern-day Tower of Babel. But even seemingly benign technologies often come with unintended consequences that can take away from some aspect of our lives. The dystopian novel *Brave New World* depicts a futuristic world in which suffering has been eliminated but at the expense of genuine human flourishing. English professor Christina Bieber Lake writes “Transhumanism is wrong not because it promotes change, but because it promotes a dangerously thin definition of the good life, as if to be healthier, have a longer life, or experience less suffering will necessarily amount to a better life.”¹¹ Christian philosopher Albert Borgmann suggests that the “friction” and burdens we bear are often the place where we encounter the living God.¹² Craig Gay suggests that while we can “strive to improve our circumstances” we must “rule out seeking – impatiently and by means of technology – to redeem ourselves now.”¹³ He cautions that “just as impatience may well have aroused the original sin, so impatience must continue to drive us away from the divine purpose.”¹⁴

**Transhumanism and Gnosticism**

An early church heresy called gnosticism arose from both Greek and pagan influences and viewed matter as evil and the spirit as good. Bodies were seen as a necessary evil until the spirit could eventually be freed. This attitude appears in other early writers like Cicero who describes the body as a prison for an immortal soul which is eventually freed with death. St. Augustine rejects this view in his book, *City of God*, “For anyone who exalts the soul as the Supreme Good, and censures the nature of flesh as something evil, is in fact carnal alike in his cult of the soul and in his revulsion from the flesh, since this attitude is prompted by human folly, not by divine truth.”¹⁵

C.S. Lewis explores this theme of gnosticism in his science fiction novel, *That Hideous Strength*, which centers around a scientific organization which plots to rid the earth of organic life while preserving only the mind. One character, a scientist named Filostrato suggests “In us organic life has produced Mind. It has done its work. After that we want no more of it. We do not want the world any longer furred over with organic life... all sprouting and budding and breeding and decaying. We must get rid of it.” This destruction of organic existence will extend to humanity once minds can be sustained without bodies. Filostrato explains, “[s]lowly we learn how. Learn to make our brains with less and less body: learn to build our bodies directly with chemicals, no longer have to stuff them full of dead brutes and weeds.”¹⁶ The story later reveals a severed head kept artificially breathing in an attempt to keep the mind alive without a body. They are seeking “the man who will not die, the artificial man, free from Nature.”¹⁷ Thomas Howard observes “...the drama of this tale happens to disclose for us the diabolical horrors that stand at the far end of the disjuncture of mind and body – of gnosticism, say. That very old and popular and persistent idea that the division between spirit and flesh is a division between worthy and worthless...”¹⁸ More recently, the science fiction movie *The Matrix* explores gnostic themes with minds trapped unawares in a virtual world while their physical bodies are kept in pods where they are used as an energy source.

Some of the themes Lewis imagined in *That Hideous Strength* are being embraced by futurists yearning for a day when they can discard the limits of their bodies by downloading their brains.
into a computer where they hope to live forever. Author and historian Yuval Noah Harari writes “for modern people death is a technical problem that we can and should solve.” Ray Kurzweil, an inventor, author, engineer, and winner of the 1999 US National Medal of Technology and Innovation, makes the bold prediction that:

Actually there won’t be mortality by the end of the twenty-first century… Not if you take advantage of the twenty-first century’s brain-porting technology. Up till now, our mortality was tied to the longevity of our hardware… As we cross the divide to instantiate ourselves into our computational technology, our identity will be based on our evolving mindfile. We will be software, not hardware.

Kurzweil’s predictions are based on a particular worldview that suggests the material world is all there is. More specifically, it relies on physicalism, the presupposition that “the human mind is fully explainable with reference only to the biological brain and the laws of physics and chemistry.” Kurzweil’s idea of disembodied existence reveals some of the Gnostic notions embedded in certain transhumanist ideals. Once a brain is downloaded into a computer, what is the point of mortal bodies? Ray Kurzweil writes, “[w]e don’t always need real bodies. If we happen to be in a virtual environment, then a virtual body will do just fine.” Kurzweil suggest that even romantic relationships can be disembodied, “virtual reality will be a great place for romance in general. Stroll with your lover along a virtual Champs-Élysées, talk a walk in a virtual Cancún beach… Your whole relationship can be in cyberland.” Kuzweil’s ideas are not just his own, but are being pursued by a wide range of individuals, scientists, and organizations.

The truth is that Scripture indicates that God cares about our human bodies. In particular, the incarnation reveals the value God places on our physicality and humanity. Christ, “the Word who became flesh” (1 John 3:2), models what it means to be truly human. The way we become what we were meant to be is not primarily through technology, but through the sanctifying work of the Holy Spirit, who makes us more like Christ (2 Cor. 3:18). Christ’s incarnation gives us a picture of the perfect image of God (Heb. 1:3). For this reason, we should not be so eager to shed our current humanity. In fact, Jesus did not shed his body after his work on earth was done, but ascended into heaven in human form. Our new bodies will not be realized through technological enhancement but through Christ, “the Word who became flesh” (1 John 3:2). In the words of Christian philosopher Craig Gay, “Christ’s incarnation is an extraordinary endorsement of ordinary embodied being.”

Technology Liturgies
C.S. Lewis’ Screwtape Letters imagines a series of letters between a junior devil, Wormwood, and his Uncle Screwtape. The letters include advice from Screwtape to his nephew about how to tempt a British man referred to as his “patient.” In one letter, Screwtape advises his nephew to keep his patient from “withdrawing his attention from the stream of immediate sense experiences” since this will enable him to attend to “universal issues.” Screwtape continues his advice, “Your business is to fix his attention on the stream. Teach him to call it ‘real life’ and don’t let him ask what he means by ‘real.’” Many of our digital devices do exactly that: they “fix our attention on the stream” and present it as “real life.”
The lure of disembodied experience is no longer found on the fringes, it is becoming more common. The writer Wendell Berry laments that “[o]ur bodies have become marginal… because we have less and less use for them… we use them only as shipping cartons to transport our brains and our few employable muscles back and forth to work.” Some recent statistics seem to support this. Since the introduction of iPhone in 2007, teens are less likely to go out with friends, get their drivers license, and are living a more isolated existence. We need to be cognizant how some of our current technologies, such as virtual reality and social media, encourage us to act and communicate without use of our bodies. Rod Dreher observes “Technology itself is a kind of liturgy that teaches us to frame our experiences in the world in certain ways and that, if we aren’t careful, profoundly distorts our relationship to God, to other people, and to the material world – and even our self-understanding.” The “liturgies” that accompany our technologies nudge us in certain ways and these habits over time shape our lives. Andy Crouch writes that “[t]he makers of technological devices have become absolute masters of the nudge” and we are often unaware of how our technology is nudging us. In fact, certain technologies may make us more comfortable with disembodiment while making morphological freedom more attractive.

To be sure, these nudges are not always negative, technology can help point us in healthy directions as well. Andy Crouch writes “Technology is in its proper place when it starts great conversations. It’s out of its proper place when it prevents us from talking with and listening to one another.” To determine how technology is nudging us, the Christian philosopher Craig Gay suggests asking the following questions: Do our technologies enhance our actual experience of ordinary reality? Do they give us time to take life in to really listen? Do our technologies give us time to think and reflect? Do our technologies enable us to dwell richly in those places where we are most at home? In general, we should cultivate technologies that nudge us toward embodied experiences and practices.

Conclusion
The longings of transhumanists point, in part, to a recognition of our fallen condition, and that things are not the way they are supposed to be with disease, suffering, and death. For this reason, aspects of the transhumanist philosophy can be enticing, also to Christians. The issue with transhumanism is that it looks to technology to fix (or enhance) the human condition instead of to God (or in addition to God).

C.S. Lewis explores the pitfall of combining faith in God with something else in his book, *The Screwtape Letters*. In one letter, Screwtape writes to his nephew, “What we want, if men become Christians at all, is to keep them in the state of mind I call ‘Christianity And’”. You know – Christianity and the Crisis, Christianity and the New Psychology… Christianity and Vegetarianism, Christianity and the Spelling Reform… Substitute for the faith itself some Fashion with a Christian colouring.” To be certain, many of the technologies referenced by transhumanists have normative uses that we should not reject or neglect. The tower of Babel does not negate the legitimacy of building certain large construction projects. Advances in medicine, genetics, and neuroscience can be used to treat diseases. Artificial intelligence can be employed to care for the earth and show love for our neighbors. Robotics can be employed to free humans from tasks that are dull, dangerous, and dirty. The issue arises when people strive for autonomy and look to technologies to be like God. In essence, this is a form of idolatry, “having or inventing something in which to put our trust instead of, or in addition to, the only
true God.” In his book, Playing God, Andy Crouch observes that “Every idol makes two simple and extravagant promises. ‘You shall not surely die.’ ‘You shall be like God.’”

The transhumanist value of morphological freedom is a very different posture than the opening of the Heidelberg Catechism which states “I am not my own, but belong body and soul, in life and in death to my faith savior Jesus Christ.” Rather than seeking autonomy through technology, we need to recognize our creatureliness and dependence on God. In the words of philosopher George Grant:

Most of us have forgotten our true status. We do not have complete control of ourselves, we are not independent of others, at birth and death we are helpless, and never at any time are we autonomous (the maker of our own laws). In much modern theology about death, it seems to have been forgotten that we are creatures, dependent on God’s love, and not simply our own masters.

In the words of Ursula Franklin, we should cultivate “holistic technologies” which allow people to flourish rather than “prescriptive technologies” which require a compliance and conformity. The design and use of holistic technology ought to be informed by the importance of embodied experience. In the words of Craig Gay, “the incarnation seriously puts an entirely new spin on what we ought to use our technologies for.” Rather than striving for the goal depicted in the Six Million Dollar Man to make ourselves stronger and faster, we ought to develop technology that can help make us more human.

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8. For instance, see the discussion in chapter 4 of James C. Peterson, Changing Human Nature: Ecology, Ethics, Genes, and God (Grand Rapids, MI: Eerdmans, 2010).
10. Fukuyama, Our Posthuman Future, 55.
14. Ibid.
17. Ibid. 177.
22. Kurzweil, The Age of Spiritual Machines, 142.
Ibid. 148.


25 This theme was discussed in Derek Schuurman, “Transhumanism and the Incarnation”, *Christian Courier*, December 11, 2016.


32 This theme is explored in the later chapters of Shatzer’s book *Transhumanism and the Image of God*.


37 *Heidelberg Catechism*, Q & A 95.


God's Grace in Weights and Measures

Douglas F. De Boer*

Abstract

The title of this paper was inspired by a phrase from Proverbs 16:11, “. . .all the weights in the bag are of his making.” (NIV) The thesis of this paper is that the Lord has an unusual concern for honest measures and correspondingly has provided a generous benevolence of grace to humanity in the form of providential standards of measurement.

At the 2017 CEC John Tixier presented a paper titled, “Observations on Things Measured in the Bible,” in which he recounted the Lord’s great interest in honest measures and the Bible’s presumption that the reader will understand the standards of measurement being used [1]. In Biblical times the maintenance of standards of measurement was the responsibility of temple priests, particularly to facilitate taxation [2]. As cultures have developed, the role of keeping standards of measurement has become a governmental function, usually via a bureaucracy of scientists who specialize in metrology. During about the last 150 years there has been a clear historical record of basing definitions on observations of nature that give universal results—natural constants as best we can understand them—artifacts of creation. Recently, in November 2018, the General Conference on Weights and Measures (Conférence Général des Poids et Mesures, CGPM) redefined The International System of Units (Le Système International d’Unités, SI) in such a way as to define all units of measurement in the SI on defined (rather than measured) natural constants. Most other systems of units refer themselves to the SI, for one example, U.S. Customary units, so the redefinition of the SI by the CGPM has fundamental importance to almost any measurement one could perform.

The nature of historical debates about measurements and standards of measurement have been remarkably peaceful. No government, no matter how corrupt or unloved, has tolerated vendors who use “differing weights,” one for buying and one for selling [3]. What debate there has been about standards has been mostly confined to making the standards practical, accurate, and repeatable. Standards of measure have been mostly free from fundamentally rebellious types of conflict. This paper, partially inspired by John Tixier’s paper (ibid), explores Biblical perspectives on metrology throughout history with emphasis on more recent developments and up-to-date attention given to the November 2018 meeting of the CGPM.

Keywords

General Conference on Weights and Measures (CGPM), grace, International System of Units (SI), measurements, metrology, providence, standards, U.S. customary units.

Introduction

The Holy Bible includes many expressions of God’s concern for measurements. At the 2017 Christian Engineering Conference John Tixier elaborated in his paper [1] on the ways that God shows interest in numbers and measures and how God, in some situations, expects measurements to be made. Jesus even speaks of faith as something that can be measured. Tixier also describes

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how measurements are used in God’s judgements on humanity. (One illustration: “You have been weighed on the scales and found wanting” [4]) Tixier’s paper demonstrates that God has a strong interest in measurements.

The particular subject of honesty in measurements appears within many books of both the Old and the New Testament. One web site lists about 100 texts that relate to this subject [5]. Proverbs 16:11 is one such text. “Honest scales and balances belong to the Lord; all the weights in the bag are of his making” [6]. Other translations end this verse with, “...of his work.” In the tradition of wisdom literature in which Proverbs stands, especially the phrase, “all the weights in the bag are of his making” or “...of his work” is intriguing and gets one thinking: Are standards of measurement in some sense a product of God’s handiwork? How do standards of measurement depend on God’s creation and our human response to that creation? Are standards of measurement an outflow from God’s grace?

As an introductory teaser, which highlights the central difficulty with keeping standards of measurement, consider the story of the noon-day cannon [7, pp 13-15]. Once upon a time, before the era of radio or the internet, as a convenience to mark lunch-time, a small town set off a cannon each day at noon. One child in the town was interested in how the cannon-master knew when to set off the cannon, so he asked the cannon master. The cannon master showed the youngster a fine pocket watch that he used to demarcate the time for setting off the cannon. The youngster, now generally interested in how people set their clocks, asked the cannon master how he set his watch. The cannon master told the youngster that each Sunday he went to the downtown jewelry store, where there was a large clock mounted on a pedestal by the road in front of the store. Knowing that the jewelry store’s clock was considered very accurate and was used by many people in the town to set their clocks, the cannon master was confident in the accuracy of setting his watch by this clock. The youngster, of course then asked the proprietor of the jewelry store how the big clock on the pedestal was set. You guessed it—the big clock was set according to the cannon shot. The youngster, now knowing how each clock in town got set, was satisfied. Every question had an answer. Yet the youngster felt some unease without being able to pin down the reason for the unease.

For much of history this story describes the situation of many standards of measurement that have been used. The main reason these earlier standards did not seem as ridiculous as the story of the noon-day cannon is that the intervals of checking the standards against (circular) references was long, obscuring the insubstantiality of the standard. There has long been a sense of unease with standards, centered on a desire to find a standard that could serve as an ultimate reference. The story highlights the desire for a standard that transcends humanity.

**Definitions**

Before going further, it will be helpful to digress a bit to define some vocabulary. The definition of a measurement in Tixier’s paper is useful. “To measure something is to determine a certain set of its properties in reference to a standard.” [1, p 140] In the literature there may be some variation in the language used to further elaborate on the definition of a measurement. In the following pages, there are seven distinguishable concepts defined for the purposes of this paper: 1) a measurement of an object, 2) a unit of measure, 3) a common standard of measurement, 4) a prototype standard, 5) an intermediate standard, 6) a natural standard, and 7) a master standard. A penny will be used as a running example to illustrate these seven concepts of measurement.
The word “penny” can refer to a measured object—a coin. As an object it has some primary purpose, in this case the embodiment of monetary value. We can measure the value of a penny: one cent. (Similarly, we can measure the value of a dime: ten cents.) Aside from the penny’s functional value (one cent) we can measure the diameter and mass and other aspects of a particular penny. Maybe one particular penny was run through a souvenir penny-press (Figure 1), making the measurement of it particularly interesting. Or we can measure aspects of objects inserted into a penny-press in payment. This way the penny-press can recognize a penny and reject a slug. A penny is an object that can be measured, in fact numerous aspects of a penny can be measured.

2.) There is a unit associated with a penny, the cent. Sometimes we confound the value with the unit. If one says that a certain candy costs, “two pennies,” then one dime would purchase five pieces of the candy—no pennies involved. It would have been more correct to say that one piece of the candy costs two cents, but people use language in various ways. Sometimes such confusion is normalized. For example, mileage measured in miles, voltage, measured in volts. We need to distinguish the units from the measured quantity when language is used that way.

3.) One could quantify mass in “pennies” as a common standard of measurement. For example, the mass of a package of sugar could be measured by balancing the sugar with the mass of several pennies drawn from the normal circulation of pennies. Then the price of the sugar could be stated in cents per penny! That is, penny-coins (or monetary equivalent) per penny-mass; or one could also use “the penny” as a unit of length (the diameter of a penny); or “the penny” could be a unit of volume; or a penny can be used to measure tire-tread depth (Figure 2.), etc.
4.) A prototype standard penny might be held at the mint to judge the proper manufacturing of pennies. One particular penny could be held in reserve as being exemplary of a properly manufactured penny. This penny would be the standard by which all other pennies are judged. Only one prototype standard object may be designated; otherwise no unique authority is established. If by some accident the prototype standard should be lost or destroyed (war, earthquake, carelessness, vandalism, “moths and rust” [9], etc.) an existing penny could be selected and promoted to the role of prototype. This hints of the noon-day cannon story since the choice of penny to promote can have no fundamental assurance of being the ideal penny upon which to standardize.

Interestingly, an important prototype standard, the international prototype kilogram, has been kept for about 130 years as a prototype standard from 1889 [10] until just a little over a month ago, as of the presentation of this paper [11].

Figure 3, “Le Grand K,” The international prototype kilogram, under three nested bell jars, maintained by the Bureau International des Poids et Mesures, Sèvres, France [10].

5.) A natural standard is a set of instructions. The instructions describe the process for building an intermediate standard (defined below). These instructions must have two properties: The first property is that if the natural standard is followed with state-of-the-art technique, the objects produced will always be comparably identical—as measured to the state-of-the-art. Any one of the resulting built objects will be suitable to serve as an intermediate standard. In the case of a penny, a natural standard might be a written description of dimensions, materials, design for the face and obverse sides, etc. The second defining element of a natural standard is that one must be able to make functionally identical copies of the instructions for making the intermediate standard. Non-substantive variations of the instructions such as fading ink, yellowing paper, shrinkage of paper, coffee stains, minor typographic errors (such as the one you just read) and so forth must have no effect on the ability to carry out the instructions with state-of-the-art precision.

Hints of the noon-day cannon problem may arise when natural standards are devised. How does one specify instructions for making something without reference to the measurement being standardized? However, should a natural standard be achieved, then it of course will demote any prototype that may have been previously recognized. If that does not happen immediately upon creation of a natural standard, it will happen eventually due to the difficulty of maintaining prototypes and the undesirable variations found in common standards.
6.) An intermediate standard is an accurate copy of a prototype or it is an object produced from a natural standard. It is used expressly for the purpose of geographic distribution and practical use of the standard while minimizing the risk of losing or damaging a prototype standard or minimizing the expense and time required to apply a natural standard. An intermediate standard may also be an accurate copy of another intermediate standard, so long as there is a traceable record of comparisons back to a prototype or natural standard.

In the analogy of a penny, if a country has several mints, one mint might be charged with maintaining the prototype standard penny and the others may be equipped with intermediate standard pennies.

7.) The most authoritative standard that exists for a measurement is called the master standard. It may be a common- a prototype- or a natural standard.

**Crease’s Properties of Standards**

Robert Crease defines three “important properties” of a measurement standard. While each important property is important of its own accord, in practice they get traded off against each other simultaneously in the determinacy of the over-all acceptance of the standard. The three important properties Crease defines are: [7, pp 19-20]

1.) **Appropriateness** to the intended task. If one desires to measure the distance between cities, the use of a finger-width would be less appropriate to the task than the use of the length of a person’s stride. Different units and standards for the same physical phenomenon may be used for different tasks. In our present era the relationships between such units as kilometers and miles (or even mils for that matter) are now precisely defined and refer to a single master standard, making the conversion of units a simple mathematical maneuver and the choice of units is fundamentally moot—a mere convenience. That has not always been the case through history. Some units had been optimized for particular purposes in ways making compatibility with other applications impractical, the relationships between the different standards being unknown at the time. At any rate, the standard chosen (not just the units) will have a degree of appropriateness to the task.

2.) **Accessibility.** Some natural standards such as “fist-full” or “pinch” are highly accessible since practically every person embodies the standard and can easily follow the instructions. If the standards are rare in occurrence or more difficult to maintain or produce, accessibility declines. The use of the standard and measurements derived therefrom should be able to be widely repeated without undue labor or cost.

3.) **Assurance** of a satisfactory result. A measurement needs to reliably deliver the accuracy needed for the intended tasks and the tools involved need to be sturdy enough to maintain their accuracy and usefulness for some practical duration.

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† Crease presents them in the order of Accessibility, Appropriateness, Assurance. They are re-ordered here to align them with the norms for technology mentioned in Monsma et al’s book, *Responsible Technology*[12]
Multi-Aspectual Normativity Theory

In Monsma et al’s book, *Responsible Technology: A Christian Perspective* (RT) [12] a Biblically responsible holistic approach to technology is described. Chapter 5 of RT develops the case that the simultaneous consideration of six *aspects* of technological design offers a holistic perspective. Christians can anchor their evaluation of these aspects with respect to *norms* derived from one’s understanding of the Bible. Norms are essentially rubrics by which one may qualitatively measure the aspects. In Chapter 7 the authors of RT propose norms for each of the six aspects they have proposed. In other words, in RT the Bible is treated as a natural standard by which technology can be qualitatively measured, using norms as tools. This theory of aspects and norms has been used in other engineering contexts, for one example, in the evaluation of complexity theory [13]. Even standards of measurement can be measured by this theory as measurable objects. The Bible is much more than this of course! But RT holds that this is an appropriate use of the Bible. The multi-aspectual normativity theory of RT will be used here to evaluate standards of measurement in various eras of history. To begin this process, Crease’s concept of “properties of standards” will be related to the theory, as set forth in RT.

Crease’s Properties of Standards Related to Multi-Aspectual Normativity Theory

In Chapter 5, RT puts forth the case for six aspects of technology needing consideration: Cultural appropriateness, stewardship, delightful harmony, justice, caring, and trust. The outcomes of a technology should be considered in terms of each of these aspects. The norms (rubrics) chosen to evaluate these aspects reflect a person’s religious convictions. In Chapter 7 the authors of RT develop norms based on Biblical principles for each of these aspects, one norm per aspect except two norms for the cultural aspect. Those are the norms of “cultural appropriateness” and “openness and communication.” For practical purposes, RT presents seven norms, displayed in Figure 4.

- Trust
- Caring
- Justice
- Delightful Harmony
- Stewardship
- Cultural Appropriateness
- Openness and Communication

*Figure 4, Seven norms described in Responsible Technology [12].*

RT advocates that all seven norms need to be considered simultaneously because technology exists holistically. In addition to this RT advocates that the norms have an order of dependence in that each norm shown in Figure 4 depends to a degree on the norms below it. For one simple example of these dependencies, if justice is not achieved, caring and trust must be compromised, whereas if caring and trust are not achieved, justice is not necessarily compromised, though they may be compromised for other reasons. This suggests an order of development for a technology in which the earlier norms (lower ones in Figure 4) receive an initial priority of consideration in the development of a technology, followed later by giving increasing priority to the consideration of the later norms (higher ones in Figure 4) as time passes and technology is developed.
Now, compare Crease’s important properties of measurement standards with the norms for technology mentioned in RT, working from the bottom of Figure 4 upward.

Crease’s important property of appropriateness corresponds well with RT’s norm of cultural appropriateness. Especially with regard to the technology associated with maintaining a standard of measurement, in RT the need for a “balance of scale” is specifically mentioned as one of five characteristics of cultural appropriateness.

Crease’s important property of accessibility corresponds with the norm of stewardship, found in RT, particularly regarding the, “amount of energy and materials to be deployed in the fabrication and use of technological objects” (e.g. a measurement standard) discussed in RT.

The important property of assurance corresponds with RT’s norm of justice. The norm of justice is defined in RT as assuring that each person gets their due. As far as standards of measurement go, that is the essential point of the standard. Steve Vanderleest has written considerably more on this norm. In the context of technology, he calls it the norm of technological justice. He explains that technological justice is more than the absence of injustice. Justice needs to be intentional because humans are fallen creatures, “naturally inclined to choose evil. Only by the grace of God can we counter this inclination.” Standards-of-measurement need to achieve a “fair and equitable treatment of others.” [14]

What of the other norms for technology presented in RT? Although Crease does not mention them, the application of these norms to standards-of-measure seems relevant. They are:

**Openness and Communication:** RT describes this as having no secrets about the value judgements being expressed, the knowledge being used, or the side effects that are known about a technology. The point of a measurement standard is especially to enable proper expression of value judgments. The Bible’s imperative of not secretly keeping differing weights [15] is describing exactly this type of openness, in addition to matters of justice.

**Delightful harmony** has three factors to assess that relate to aesthetics. Is there a sense of joy achieved in the operation or application of the technology? Is there a melding of function and beauty? Does the technology enhance shalom? By “shalom” the authors of RT are referring to a webbing together of God, people, and all of creation in right relationships. Later in this paper, as we consider various prototype and natural standards, we will see that this norm is motivational for moving away from prototype standards and toward natural standards. There is something intrinsically appealing and delightful about natural standards. Crease writes much about this in a general way, without formally recognizing it as an identifiable “important property” or “norm” of a standard.

**Caring.** Technology should promote interactions among people that promote care and love for one another. Technology should not place needless barriers between people or promote manipulation of people. While this design norm has, for example, obvious relevance to technology (e.g. social media) it is perhaps not such an “important property” of a standard of measure beyond the simple observation that measurements are helpful in many acts of caring. For example, medical prescriptions involve measurement. Care for the sick is enhanced by
having agreed-upon measurement standards. Stating a drug-dose in SI units while providing a measurement tool calibrated in U.S. customary units would be a careless act.

Trust. With appropriate reliability, a technology should do what it is supposed to do, and not do what it is not supposed to do. The distinctive issue here is the fullness of the consideration of what should not be done by the technology. This question needs to be answered with depth that goes beyond the obvious purpose(s) of the design. As an example, it is not good enough that the brakes on my car work reliably. (If I merely get what I paid for, that’s justice.) It is also necessary that the brakes on my car can be serviced efficiently and without exposing the service technician to a dangerous material such as asbestos. The general trust shown for a technological design should ideally be an outcome of design work faithfully done in response to God’s Cultural Mandate [16]. There needs to be a recognition of the finite human ability to fully model and understand a situation and a respect for our duty to our Creator that is reflected in corresponding real-world testing and refinement of the design and experience with the design. Crease’s important property of assurance would satisfy this norm to the extent that the standard delivered on these broader matters of what the standard should not do.

One more: Humility. Steve VanderLeest has proposed one more norm for technology, that of humility. “Engineers should design technology with a certain modesty, knowing that (as created beings) we are finite, and thus cannot predict all the ways our technology might be used or abused.”[17] The choice of a new standard for measurement is usually fraught with very intentional humility in the sense of understanding with as much foresight as possible, the limits of uncertainty that the standard will entail.

Standards of Measurement Through the Ages

How do standards of measurement depend on God’s creation and human response to that creation? We can find answers by considering who sets standards and how people have judged standards. We can also consider who challenges standard-makers and why. We can compare measurement-standards-making to the process of making other standards, such as railway track standards for an example. This will be discussed in three broad eras: 1.) ancient through modern, 2.) the advent of the SI system, and 3.) the recent meeting of the CGPM in November 2018.

Standards from Ancient Through Modern Times

At the most ancient times of standard-setting activities, things we take for granted now were not available. Arabic numerals as symbols, and the concept of symbol-place-significance related to a consistent base (e.g. decimal), and the numerical concept of zero, were not yet developed. Counting objects was the foundation of measurement. Fundamentally, the ability to count remains the primary enabler of measurement-standards. These days counting may be performed with the assistance of electronic tools that can count billions of items or events per second.

The oldest surviving accounts of measurements and standards of measurement begin in the era of the Mesopotamian and especially the Babylonian era. Standards of measurement then were typically natural standards that were thought to be repeatable and stable. For example, certain plant seeds have an astonishing uniformity of weight and invite one to use them as a common standard. The jeweler’s unit of the carat, for example, owes its origins to the carob seed, once
used as a common standard [18]. Units of length were often standardized by comparison to human bodies such as a finger, forearm, stride, or foot [19].

Crease points out that there is “nothing unscientific” per-se about the great amounts of local variability and regional incoherence of ancient standards of measurement, often common standards, “as long as they are accessible, appropriate, and assured.” [7, p21] Specifically, they supported observation and reasoning, commerce, taxation, and religious practice. In a somewhat post-modern sense, one could say that a useful standard is merely one that gains popularity and has not been refuted. Standards are not a problem per se unless they are unpopular!

In these ancient standards a combination of cultural appropriateness and stewardship seems to have had priority. Those who set the standards were usually government officials, soldiers, or priests. The differences between government, military, and religious leadership were not well-defined or differentiated, complicating the achievement of the later norms of trust, caring and justice. The purposes of the standards were both practically and religiously oriented.

Contrary to some stories of the amazing accuracy of ancient astrological observations, there was little or no conception of a science of metrology in Babylonian times. In fact, in some ancient religions there was a deification of certain aspects of the natural creation [20]. Speculatively, this combination of primitive representation of numbers, little mathematics beyond arithmetic, and the deification of the sun, moon, stars, etc. may have motivated the choice of natural standards. Ancient calendars with their various counts of days for measuring the seasons to support agricultural activities and to establish times for religious rituals exemplify this era of natural standards based on counting seeds, days, new moons, and similar common objects or natural events.

In Biblical times there is evidence that the temple priests maintained the standards of measurement. There is also evidence that common standards and natural standards were being supplanted by prototype standards, probably to provide more accuracy, which would enhance development of later norms such as justice, or as Crease puts it, the important property of assurance. The shekel, a unit of weight and simultaneously a coin is frequently mentioned in the Pentateuch. The sanctuary shekel, in the sense of a prototype standard, is specifically mentioned several times [21]. It has been observed that the association of the prototype shekel with the temple and the temple priests is an appeal to the fixed standards of God in contrast with the fickleness of humanity [22]. Associating the prototype shekel with the temple enhanced its delightful harmony in the sense of establishing right relationships. This was a development of a later norm than simply cultural appropriateness. The presumed repeatably of the results gained by standardizing on the prototype shekel of the sanctuary is also an appeal to further development of the norm of justice.

By the late 1700s and the time of the French Revolution most natural standards had been replaced by myriads of prototype standards. Unfortunately, like the story of the noon-day cannon, these standards were all self-referential or otherwise arbitrary, coming and going in influence along with the rise and fall of the tribes, feudal lords, and nations. Crease recounts this quite colorfully including stories of the tediousness of conducting a transaction when the buyer and seller bring their own intermediate standards to the venue of the deal, possibly with all intermediates secretly corrupted to each’s advantage [7, Ch. 3].
The Advent of the SI System

In the 1700s the world was in the early ascent of the Industrial Revolution, which was especially focused in Great Britain, but also beginning in France and elsewhere in Europe. Simultaneously there was political upheaval as the last vestiges of feudalism were in their final death-throes and nation-states emerged with central governance having broad geographic reach. Scientific thought had also changed. The prior Aristotelian theories of different regions (earth, air, sky) having different properties and requiring different theories had been abandoned. Nature was coming to be understood by making theories with respect to “observation,” implying the primacy of measurement.

This nexus of industrial development, political upheaval, and scientific emphasis on observation was notably present in France during the time leading to the era of Napoleon. Crease maintains that this nexus created the conditions for a dramatic longing for a renewal of natural standards from which to derive intermediate standards. It was proposed that a meridian of the earth could serve as a natural standard for length. Once length was defined, a specified volume of water could serve as a natural standard for mass. A pendulum of a defined length could serve as natural standard for time differential. This was the initial conception of what became the meter-kilogram-second system (mks) and eventually morphed into the SI system. These proposed natural standards quickly gained appeal.

Earlier in this paper the norm of delightful harmony was mentioned. In the context of new perspectives on observationally-based science and political turmoil, the promise of standards that transcend the past are grippingly appealing. The appeal of natural standards is their ability to promote “right relationships,” which is a concept at the heart of the norm of delightful harmony. The French Revolution was not uniformly a good thing of course. In addition to providing fertile ground for new laws and standards such as the mks system, the French Revolution also popularized the guillotine. After some brief nascent developments in new measurement standards that pointed to the future mks system in the 1780’s, the concept languished in the 1790’s because of the chaos of the French Revolution. Then in the early 1800s development gradually resumed [7, Ch. 4].

On May 1, 1851, the British Empire sponsored The Great Exposition of 1851. This was an international event showcasing the world-wide influence of the British Empire. By this time France, the United States, and England had all been doing work along the lines of the earlier proposed mks system based on natural standards, but none of these efforts had flourished amid the competition of entrenched local systems. The Great Exposition solidified an international recognition that the situation needed to change. In 1853 the first International Statistical Congress was convened. In 1863 the National Academy of Sciences brought the cause to the United States Congress and petitioned to adopt the “metric system.” In 1866 the U.S. Congress did enact the metric system into law as a system suitable to serve in any court of law throughout the country. Initially this hardly changed any practice since it did not forbid any prior practice. But for the first time the mks system had gained legal recognition by a nation. This produced a flurry of advocacy for the system in other countries. Long story short—on May 20, 1875 a treaty creating an International Metric Commission was signed by seventeen countries, including the United States. France not only signed the treaty, they gave the newly established commission
land on the outskirts of Paris. The land contained some buildings affording the commission a place to do its work [7, Ch. 6].

The events of 1875 established a remarkable convergence of talent into the hands of only a few metrologists, now holding international authority with legal standing. The legacy of the treaty of 1875 continues to this day. The norm of trust, the latest norm in RT’s list, had a reached a new level of achievement—or at least so it seemed. The initial enthusiasm for natural standards resulted in the manufacture of some objects based on the natural standards and intended for use as intermediate standards. However, it was found that the natural standards could not be employed with adequate accuracy to repeatedly manufacture usefully precise additional prototypes for use as intermediate standards. Crease recounts one event in which an accidental fire destroyed an intermediate standard. Having been derived from a natural standard, work immediately started to replace the intermediate standard. But it could not be remanufactured satisfactorily [7, p130]. This event could be related to a loss of humility within the community of metrologists. They placed unfounded confidence in their new natural standards prior to adequate real-world experience with them.

Out of practical necessity, the work of the International Metric Commission changed to the preservation of the initially manufactured objects, originally derived as intermediate standards from natural standards, but now being used as de-facto prototype and master standards. The SI system became, for all practical purposes, just another set of prototype standards. The formerly attempted natural standards (meridian, volume-of-water, pendulum,) were now mere window dressing as far as their true functionality was concerned, yet their continued presentation as the conceptual basis for the mks system surely added a measure of delightful harmony to the mks concept. Prototype standards (actual objects) such as the prototype meter stick, prototype kilogram, and a prototype set of clocks, adjusted on occasion—leap-years, seconds, etc.—via astrological observations, maintained by the British Royal Observatory became the master standards of the SI system [11][23][24].

The first unit of measure in the SI system to get a functional natural standard of sufficient accuracy to propel science forward was the meter. Near the dawn of the twentieth century, Charles Sanders Peirce, at various times a professor at Harvard and Johns Hopkins Universities, a founder of the philosophical school of pragmatism, and a metrologist, proposed that the natural standard for the meter be tied to the wavelength of a particular color of light from a noble gas. Initially his ideas were overlooked, possibly due to his unpleasant personality. However, his proposal marks the start of the SI’s transition to natural standards that actually work [7, Ch 9]. One-by-one, the base units of the SI system were converted from prototype standards that were originally inspired by a goal of natural standards to truly functional natural standards. The official change from a prototype meter bar to the standard based on the wavelength of a particular type of light was made in 1960. In 1983, the natural standard used to define the length of a meter was changed again, this time to depend on the speed of light in a vacuum [24][25].

Consider that the first SI natural standard of practical usefulness was a standard based on light—then the wavelength of light, now the speed of light. Jesus said, “I am the light of the world. Whoever follows me will never walk in darkness, but will have the light of life” [26]. From the context in John’s Gospel it is clear that Jesus was proclaiming his authority to lead us to eternal life. Could Jesus also have known that measurements would someday be standardized by the
wavelength of light? If Jesus is the light of the world, could the SI standard of the meter ultimately be referencing Jesus? Consider that a rhetorical teaser, not necessarily deserving an answer... yet!

The November 2018 Meeting of the CGPM

The last SI prototype standard to be deposed by a natural standard was the international prototype kilogram. (Figure 3 on a previous page.) After years of discussion, and as an outcome of the November 18, 2018 meeting of the CGPM, the international prototype kilogram was deposed, effective on May 20, 2019, by a natural standard based on a definition of Plank’s constant and the technological tool called a watt balance (also known as a Kibble balance) [27].

Now all seven of the SI base units have natural definitions. The seven natural definitions use seven constants of the universe as their foundation. (See Figure 5.)

The seven SI base units defined from these standards are the meter, kilogram, second, ampere, kelvin, mole and candela. All the other SI units that have been defined are derivatives of these seven. For example, the unit of force, the newton, is a kilogram-meter per second squared. A coulomb is an ampere-second, and so forth. The historic units of most nations, for example the U.S. Customary units, are now standardized by reference to SI units by law. For example, a U.S. inch is defined as 25.4 mm exactly.

The unperturbed ground state hyperfine transition frequency of the caesium 133 atom
\[ \Delta V_{\text{Cs}} \triangleq 9 192 631 770 \text{ Hz} \]

The speed of light in vacuum
\[ c \triangleq 299 792 458 \text{ m/s} \]

The Planck constant
\[ h \triangleq 6.626 070 15 \times 10^{-34} \text{ J} \cdot \text{s} \]

the elementary charge
\[ e \triangleq 1.602 176 634 \times 10^{-19} \text{ C} \]

The Boltzmann constant
\[ k \triangleq 1.380 649 \times 10^{-23} \text{ J} / \text{K} \]

The Avogadro constant
\[ N_A \triangleq 6.022 140 76 \times 10^{23} \text{ mol}^{-1} \]

The luminous efficacy of monochromatic radiation
of frequency $540 \times 10^{12} \text{ Hz},$
\[ K_{cd} \triangleq 683 \text{ lm/W}, \]

Notice that the symbol “\( \triangleq \)” means “is defined to be equal to.” [28]

More Aspects—But No Associated Norms

The Dutch philosopher Herman Dooyeweerd provides a description of fifteen modal aspects of reality. The six aspects of technological design elaborated in RT are derived from the last (top) eight of Dooyeweerd’s fifteen aspects of reality. RT amalgamates Dooyeweerd’s Social,
Lingual and Historical aspects into one aspect, in this paper named “Cultural.” RT then proposes two norms for the cultural aspect, “openness and communication” and “cultural appropriateness.” That leaves seven of Dooyeweerd’s aspects that have not yet been considered in this paper. Listing them from the later (upper) to the earlier (lower), these seven of Dooyeweerd’s aspects of reality are: analytic, sensitive, biotic physical, kinematic, spatial, and arithmetic [29]. Dooyeweerd posits that norms arise only for the later (top) eight aspects of reality. It is in these aspects that humans have been given choice and creativity in responding to God’s call to obedience. In the earlier (bottom) aspects, our lives are governed by the inescapable laws of the creation rather than by humanly devised norms. As some examples, we encounter no choice beyond matters of efficiency and technique in making rules for counting of several objects. The count is self-evidently correct or not correct. A count of objects just, “is what it is.” As another example, we do not debate the validity of arithmetic. We write “$1 + 1 = 2$” and there is no question about it. We cannot defy gravity (physical aspect) either. We are subject to the creation in all of Dooyeweerd’s early (lower) seven aspects of reality, whereas we have freedom bounded by responsibility to be Biblically obedient to God’s intent for the creation in the later (upper) eight aspects of reality. See Figure 6 for a tabular summary of this paragraph.

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<tr>
<th>Dooyeweerd’s 15 aspects of reality</th>
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*Figure 6. Dooyeweerd’s aspects of reality, RT’s aspects of reality, and RT’s norms for engineering related to each other. [12][29]*

The seven natural constants that now define the SI system have their principle functions in the lower aspects, especially the physical, kinematic, spatial, and arithmetic aspects. These are aspects that are not normed by humanity. We are simply subject to these aspects of reality, and thus subject to the constants of the universe, and ultimately subject to our Creator-Redeemer—Jesus Christ.
God’s Common Grace in Standards-of-Measurement

The Oxford English Dictionary provides many phrases to describe the meaning of grace. In this paper the phrase God’s grace is intended to represent, “something received from God by the individual: benevolent divine influence acting upon humanity to impart spiritual enrichment or purity, to inspire virtue, or to give strength to endure trial and resist temptation.” [30] This common grace is what is meant by the phrase God’s grace in this paper. (In contrast to a saving grace.)

David Chi has discussed the relationship between common grace and engineering in a paper from 2013. He shows how Christians participate in the activities of engineering with a different quality of insight and discernment than others. He also points out that sin is a common reality for all. He distinguishes some different classifications of sins such as sins of individuals and sins of institutions. As an example of the need for God’s grace in technological matters he mentions the possibility of clothing brands intentionally being labeled with smaller size-numbers than are conventional—“vanity sizing”—as an example of institutionalized sin. He concludes that, “The only solution to this problem is the redemptive work of Jesus Christ.” [31]

The seven natural constants upon which the SI now rests are something received from God by His creative and sustaining acts. Their existence and significance to humanity is something beyond the control of humanity. Even people who do not have a Christian faith, generally have faith in these constants. And what else can it be but faith that tells us these are truly constant constants? Any attempt to measure these constants using the present SI system of standards is just as ridiculous as the noon-day canon story. And what better set of standards of measurement could be proposed?

The natural standards that have been defined in the SI system positively serve humanly devised norms for the higher aspects of reality. The SI system and the work of the CGPM have served to inspire virtues such as honesty, justice, and trust. It is in this sense that God, through Christ, has extended a generous measure of grace to humanity through the provision of the creation with natural constants.

The Bible states that, “For in him all things were created: things in heaven and on earth, visible and invisible, whether thrones or powers or rulers or authorities; all things have been created through him and for him. He is before all things, and in him all things hold together.” [32] Jesus Christ conducts himself with self-conscious authority consistent with this perspective. As an example, consider Jesus’ statement that, “In your own Law it is written that the testimony of two witnesses is true. I am one who testifies for myself; my other witness is the Father, who sent me.” [26] Also in his conversations with Pilate before his crucifixion, Jesus displays remarkable self-awareness of his authority and the purposes of his authority.

“You are a king, then!” said Pilate.

Jesus answered, “You say that I am a king. In fact, the reason I was born and came into the world is to testify to the truth. Everyone on the side of truth listens to me.”

“What is truth?” retorted Pilate. [33]
In this ironic scene Pilate does not understand that he is looking into the face of Truth personified but reading between the lines we can see that Jesus perceived himself as the creator and sustainer of truth. These examples are fully consistent with a Jesus who created light in such a way that it could serve as a natural standard for measuring length. The Bible presents Jesus to us as the Creator-Sustainer-Redeemer of all things, including all “authorities,” which seems now to very logically include the seven constants of the universe upon which the SI depends.

Here is an answer to the rhetorical question asked earlier, “could the SI standard of the meter ultimately be referencing Jesus?” Obviously, there is no direct reference to Jesus in the SI standard. But the Bible does make it clear that the SI standard, like all of creation, finds its ultimate foundation in the Creator-Sustainer-Redeemer, Jesus Christ. This is not to claim that the SI—a human invention—has reached the ultimate sine-qua-non. Further progress will likely be made in refining the SI. But Christians can see that the foundations of such standards of measurement, including earlier standards such as the shekel of the temple and the international prototype kilogram, are gifts to us from the Creator.

Max Deffenbaugh points out that, “…there is little difference between how Christians and those of other faiths or no faith do engineering.” He points out that considering engineering as a “common grace activity” offers a reason for the similarity and simultaneously points out a difference between engineers of Christian faith and other engineers. Both groups receive the same gift of an orderly creation, a sense of right and wrong, and even the ability to read the Bible. On this common ground, both groups, given they agree to the same assigned task, generally will produce similar results by similar methods. However, Christians have a sense of vocation in relationship to what Deffenbaugh terms, “common grace ministries.” Through our work, be it technological work, engineering work, or other work, we seek to minister to those around us. Deffenbaugh argues that Christians should be especially sensitive to directing their engineering work toward common grace ministries. He ends his paper with a quote from the hymn Come Thou Fount of Every Blessing, “O to grace, how great a debtor daily I’m constrained to be.” [34][35] Our understanding that measurement standards rest on the bedrock of Jesus Christ is just one facet of how common grace does constrain us and tells of the debt we owe for this benefit. As will be described later in this paper, the “constraint” (or the “fetter”) that the hymn-writer mentions should be given a positive connotation of guidance toward a fulfilling life in a superior relationship to the negative connotation of a list of “thou shalt nots,” though it is, of course, both at the same time.

The Depth of God’s Grace in Standards of Measurement

Imagine the confusion that might result if there was a competing measurement-standard-making authority working to supplant the SI system. Recall the old VHS vs. Beta video-tape marketing wars. There are real issues of path dependence and lock-in which one can manipulate to various advantages [36]. In fact, when making standards there usually seems to be a very serious competition between several competing standards. Railway track gauge is an example of competing standards. In spite of the advantage a uniform track-gauge would offer for convenient international travel and shipping, to this day a plethora of incompatible track-gauge standards limit train travel [37]. The story is similar in many other technological standards such as
building codes, electrical powerline standards, telecommunication standards. Everywhere one looks there are regional variations which have complicated stories.

Sometimes the competition in standard-setting proceeds even to the point of nullification of any value an accepted standard could have brought. Even beyond that, standards-wars can lead to the complete disadvantaging of an entire technology.

The standards competition over AM stereo broadcasting comes to mind as an exemplary disaster in standards-making. About a half-dozen incompatible standards for AM-stereo broadcasting were permitted by the FCC simultaneously. In television broadcasting when UHF channels were added, and again when digital TV was standardized, the FCC created a transition period during which receivers could be optionally equipped to receive the new standards, followed by a date when all new receivers sold had to be capable of the new standards. In contrast, when AM-stereo was introduced, it was explicitly stated that there would be no date by which receivers had to be capable of the new standard. The resulting lack of buy-in from broadcasters (no date to target and plan for) and the extra costs for receivers (for the standard-detection and demodulators capable of handling at least several of the variety of standards instead of just one) hobbled the introduction of AM stereo broadcasting and eventually brought the entire technology of AM broadcasting to the point of world-wide marketplace failure. This happened only on account of competition in standards-setting that was left unchecked [38][39]. Technically, any of the half-dozen or so standards would give superior service compared to the present situation. Instead, each entity involved being fearful of disadvantage and too weak to gain a majority of support, each entity augured for the status quo. Unlike FM broadcasting which has enjoyed a number of upgrades to its standards over the years, (stereo, subcarrier authorized ancillary services, radio-data services, etc.) AM broadcasting has become moribund in standards that are substantially unchanged since the 1930s, save for some transmitting power reductions and other minor tweaks to enable additional channel allocations. In recent years, “FM fill-in translation” and “AM-HD” modulation (also known as “In-Band On-Channel Digital” or just “IBOC”) has been permitted by the FCC in the hope of returning vitality to the AM band, but it may be too late considering the present poor opinion the public has regarding AM and the apparently glitchy performance of the AM-HD modulation [40][41][42]. The FCC certainly did not act deliberately to throttle the life out of AM broadcasting, but by the time the disaster was realized, irreparable harm was done. The point of this paragraph: Standards-making entails the risk of disaster of a scope beyond initial credibility.

In contrast, what competitions there have been in the making of standards-of-measurement have quite progressively and consistently enhanced, rather than nullified or even attenuated, the benefits derived from the standards. Louis Berkhof notes that, “[Common grace] curbs the destructive power of sin, maintains in a measure the moral order of the universe, thus making an orderly life possible, distributes in varying degrees gifts and talents among men, promotes the development of science and art, and showers untold blessings upon the children of men.” [43, as quoted in 31] In contrast to some other standards-making activities, standards-of-measurement seem to have enjoyed a very generous record of common grace throughout history.

Dooyeweerd points out that it is by means of “Law” that the creation exists. It is the Law that establishes the boundary between the Divine and the creation. Dooyeweerd described “Law” not as a mere code of restraints but rather as that activity of God by which meaningful things are
enabled to happen [44]. The seven universal constants and the peacefulness of standards-making activities through history are tangible evidences of Dooyeweerd’s positive conceptualization of Law as the boundary between the Divine and the creation, through which meaningful things are enabled to happen.

Ethan Brue has suggested that, “The nature of engineering (and STEM) education is uniquely resistant to grace.” [STEM: Science, Technology, Engineering, and Mathematics] He argues that grace is not something that can be taught, but is best explained by telling stories [45]. There is a story behind every measurement. Every measurement rests in Christ’s faithful upholding of the creation. The history of the creation of various standards, and especially standards-of-measurement, and how these standards rest in Christ’s faithfulness to us, ought to accompany the related instruction on instrumentation and measurement techniques, uncertainties, sensitivities, and traceable calibrations. The activities of the recent CGPM are part of that story of God’s common grace to all of humanity.

Conclusion: God Gracefully Provides Standards-of-Measurement

Earlier in this paper it was stated that a standard of measurement is itself a measurable object. A list of six aspects of reality and another list of seven norms, plus one more, by which to assess the aspects was described. A further set of seven lower aspects of reality set forth by Dooyeweerd was described with their relationship to standards-of-measurement. For these aspects we have no choice but to follow. By considering measurement standards against these aspects and their norms (if applicable) a standard of measurement can itself be compared (measured) against themes of the Holy Bible, at least in qualitative rather than quantitative terms.

Ancient standards were frequently natural standards satisfying norms of cultural appropriateness, openness and communication to a much greater degree than the later norms such as justice, delightful harmony, and trust. Humanity has progressed from there. Refinement of measurement standards can be related to the achievement of the higher norms for technology.

The advent of the SI was centrally a call back to natural standards. This call was an attempt to enhance the norm of delightful harmony, especially in respect to establishing “right relationships.”

The November 2018 meeting of the CGPM was a long-anticipated milestone in the SI system in which the final plans were laid for the retirement of the last prototype standard. All the master standards of the SI system are now natural standards.

It is challenging to educate students in STEM disciplines regarding God’s grace. The best way to do it is by telling stories. There is a story behind every measurement. These stories should be told in the curriculum when measurement techniques are discussed.

Consider what the CGPM has accomplished in relation to what God has accomplished. Max Plank commented that via natural standards we can achieve units of measure that, “necessarily retain their significance for all cultures, even unearthly and non-human ones.” [46] But the point of this paper is that by the grace of God, constants of the universe imply much more than that. It is not so much that the SI system is of significance even to “non-humans.” It is more like the other way around! God’s unchanging nature and perfect faithfulness bring us to the point of...
recognizing seven universal constants. From this we realize that even the humanly-devised SI system is an outcome of God’s common grace and we recognize the significance and generosity of it to all of humanity. The seven natural constants of the universe are part of a boundary line between the Divine Creator and the creation. They tell of our subject-to-God nature and simultaneously enable the flourishing of culture. They tell of God’s grace to us.

Lord, you have been our dwelling place throughout all generations.

Before the mountains were born or you brought forth the whole world from everlasting to everlasting you are God.

…

May your deeds be shown to your servants, your splendor to their children.

May the favor of the Lord our God rest on us; establish the work of our hands for us—yes, establish the work of our hands [47].

…

Honest scales and balances belong to the LORD; all the weights in the bag are of his making [6].
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http://docs.google.com/viewer?a=v&pid=sites&srcid=Y2hyaXN0aWFuZW5naW5lZXJpmbcub3JnIGNhlc3xneDo0MjBlMjY5MDY5YW5MGQy


[16] Holy Bible, Genesis 1:28


[26] Holy Bible, John 8:12-18


The Design, Build, and Impact of a Basic Utility Vehicle in Uganda

Douglas E. Smith*

Abstract

The Baylor University Basic Utility Vehicle (BUV) student group is organized around the fundamental premise that ‘simple vehicles change lives’. BUVs are low cost, rugged, reliable vehicles able to carry upwards of 1 ton of cargo with a 11hp engine with a focus on helping disadvantaged people in developing countries. In May 2019, Baylor BUV students traveled to northern Uganda to build a BUV with vocational school students at the Village of Hope (VOH) Uganda. VOH provides housing, food, training, and spiritual support for over 350 orphaned children, refugees of the recent Ugandan civil war. Our VOH BUV project engaged the engineering and design expertise of Baylor engineering students and the fabrication talents and local logistical support of the VOH students and staff. Major vehicle components including the engine, transmission, and rear axle, in addition to all steel and wood were sourced locally in Uganda; while detailed drive train components were sourced or fabricated at Baylor and transported to the VOH vehicle build site. Nine Baylor engineering students worked closely with 17 VOH vocational school students to build a running BUV in just 9 days. This paper presents the Baylor BUV design, details of the VOH build experience, key interactions between Baylor BUV and VOH, challenges of doing engineering projects abroad, and trip highlights. As a result of this project, VOH now has a BUV to assist in their agricultural and day-to-day support activities, and both Baylor engineers and VOH vocational students have an experience that will shape their future.

Motivation

As Christians, we are drawn to help others. Reaching out to those in need or who, by life’s circumstance, is less fortunate is central to Christ’s teachings. One needs to look no further than the parable of the sheep and goats to find inspiration for going out of your way to lend a helping hand. In the words of Christ Jesus:

\[
\text{The King will reply, ‘Truly I tell you, whatever you did for one of the least of these brothers and sisters of mine, you did for me. Matthew 25:40 NIV.}
\]

The message is clear, and the objective of our helping hand is broad. This one who is ‘one of the least of these’ could be next door, or across town. They could be in a distant land, or in a country far away. Our world is full of opportunities for us to take part in acts of helping and kindness, taking us closer to Him.

As engineers, we are gifted beyond our imagination with a unique insight into God’s creation, understand how things work, and how to pull together various elements of His masterpiece into useful goods, equipment, processes, and more. Peter instructs us to take our gifts and use them for the good of others:

\[
\text{Each of you should use whatever gift you have received to serve others, as faithful stewards of God’s grace in its various forms. 1 Peter 4:10 NIV.}
\]

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This paper describes the actions of a small group of Baylor University engineering students who traveled to Uganda in May of 2018 to invest in lives of orphaned refugee children (cf. YouTube video (*Baylor BUV in Uganda 2018*)). These children are most likely among those Jesus commands us to help with the gifts he has entrusted in each of us. Our journey included a two week mission trip to the Village of Hope (VOH) Uganda (“Village of Hope Uganda”) where we worked with 17 vocational school children to build a Basic Utility Vehicle (BUV), starting with a pile of steel and some automotive-related machinery and ending with a running BUV and a sense of hope for the future.

**Background**

In the book ‘When Helping Hurts’, Corbett and Fikkert (Corbett and Finkkert) begin with Christ’s purpose exposed through Luke 9:2 with a directive to the disciples to ‘preach the kingdom of God, and to heal the sick’. While Missions are often associated with spreading the Gospel, our focus here is more on the latter, the action of helping the disadvantaged.

Baylor University in Waco, Texas sends out upwards of 700 students a year on ‘discipline specific’ mission trips from various departments across campus. The stated purpose of Baylor Missions (“Baylor Missions”) is to “shape Baylor’s faithful engagement with Waco and the world by creating intentional opportunities to integrate faith, learning, and service within a broad Christian worldview”. Mission opportunities at Baylor include trips like “Hunger in America”, “Kenya Education and Leadership”, “Dominican Republic First in Line”, “Haiti Engineering”, among others. Recently, interest among engineering faculty and students has grown with trips to Haiti to build solar power systems for an orphanage and medical clinic, to Mexico to construct eco-friendly housing, and to Uganda to build a Basic Utility Vehicle (BUV). These trips provide opportunity and experiences to learn from culture, allowing students and faculty to connect to what God is doing in and around the world.

A Basic Utility Vehicle (BUV) is a simple, durable, light-weight, easily maintained, and low cost vehicle designed for rugged landscapes and heavy payloads facilitating communal transportation, economic growth, and hope for the future.

Baylor BUV (“Baylorbuv”) started with a group of Mechanical Engineering students in the Fall of 2014 having the goal of building a BUV that can meet the transportation needs for those in rural developing countries around the world. Our BUV is designed to carry three 55 gallon drums of water using only a 11HP engine. Since that time, we have designed and built vehicles for this purpose and participated each year in the Institute for Affordable Transportation (*Drivebuv.Org*) sponsored BUV competition in Batavia, Ohio. The goal of our students has always been to build a vehicle that can help others. This became a reality...
in 2018 when we built our first BUV in Uganda, Africa as shown in Figure 1. Given that the Uganda BUV was built side-by-side with VOH students, we not only realized our goal of providing basic transportation, but we also touched the lives of many at VOH through the build process itself.

The Village of Hope Uganda celebrated its 10 year anniversary in 2018. VOH was founded by Cindy Cunningham after visiting internally displaced persons camps of northern Uganda during the recent civil war in that country. VOH serves the children of Uganda with the motto “Through the love and hope given by God’s grace, Village of Hope focuses on bringing healing to the hundreds of orphans affected by the brutal attacks of Joseph Kony and his army”. Village of Hope rescues the lives of former child soldiers, sex slaves and their younger siblings orphaned by war with nearly 350 children at two residential villages: one for younger elementary school-aged children at their Bobi village just outside of Gulu, and another for secondary school-aged children and young adults about 2 hours south of Gulu near Bweyale. Both villages provide loving homes, physical and spiritual support, medical services, onsite schools/vocational training and solutions to systemic poverty and hopelessness among Uganda’s most vulnerable children. Our BUV build project was conducted at the Bweyale village vocational school having highly trained instructors in metal fabrication, automotive mechanics, welding, and wood working.

Baylor University periodically sends out flyers to alumni letting them know about campus activities and outreach. In the summer of 2017, a one-page flyer was distributed highlighting the Baylor BUV program and showing Baylor BUV student driving the BUV as shown in Figure 2. The first BUV built at Baylor had been upgraded, and had just returned home from taking 3rd place in the April IAT competition. Fortunately, the flyer landed across the desk of Baylor alum and businessman Bill Baker in Dallas, Texas. Bill is a long-time supporter of Village of Hope Uganda, and saw a unique opportunity for VOH and Baylor in that flyer. He contacted the Baylor School of Engineering and Computer Science seeking to get a BUV for VOH. His request, however, wasn’t that he would ask us to build a BUV and ship it to Uganda. He instead proposed that he would sponsor a trip for Baylor BUV students to travel to Uganda and show VOH vocational students how to build a BUV. Plans began immediately, and by the grace of God, the Uganda BUV in Figure 1 was constructed at the VOH vocational school by 17 VOH Ugandan vocational students and 9 Baylor University engineering students in 9 days.

**Project Description**

Mobility is a basic need, especially where resources and roads are scarce. In places like the African bush, quality of life depends on transportation. In places like rural Uganda, there are
people who’s daily life would benefit greatly from having basic affordable transportation. The BUV provides much needed transportation, and this combined with our collaborating with VOH to build a BUV in Uganda, offered hope to students at VOH.

Our project started by VOH staff obtaining materials for the BUV locally in Uganda prior to our arrival. In projects like this, having a partner in-country who knows the local markets and the logistics of obtaining and moving materials is critical. Staff at VOH headed by their on-site missionary Mike Doud were given a list of required materials and purchased steel tubing, various wood sections, a rear axle from a Toyota Hilux, a front wheel drive transaxle from a Toyota Corolla, a ChangFa 20HP single cylinder diesel engine, tires, wheels, and various engine mounts and brake hardware. It is interesting to note that obtaining many of these items in Uganda is much different than buying them here in the US. The purchase of the main automotive drive train components required that 4 men take a 3 day trip to the capital city of Kampala (with a 6 hour drive each way), and search among salvage yards for just the right parts. Some of the BUV parts we needed were purchased here in the US and transported via checked luggage to Uganda. This included brake cylinders, bearings, pulleys, and a few specific machined components that were needed to complete the drive train.

Baylor and VOH students worked together daily as the vehicle took shape. We found the VOH students and staff to be hard working and exhibited a great attention to detail. They worked tirelessly on cutting and fabrication tasks and were eager to learn and get involved with any part of the project. Once a job was effectively communicated, they worked hard to get the part just right. They were quite experienced at getting things done under non-optimal conditions. Our students learned a great deal working with the VOH students. We learned how to get things done well with minimal tools, and how to make good welds and clean up the welds for them to look quite professional. We could see how grateful the VOH students were to be a part of this project.

In just 4 days, we had a rolling chassis. It took 2 more days to build a powertrain subframe that held the engine and transmission, and get it mounted in the chassis. One day was spent tearing down the manual transmission to weld-up the differential so it would better serve our purpose. It took additional time finishing the chassis, making a seat, adding brake and clutch pedals, and connecting the drive train. It was exciting to see the engine start up for the first time, and the BUV first run. All of the VOH students climbed on as they took off for a ride around the Bewyale village site. Figure 3 shows VOH students gathered around the ChangFa diesel just after they placed it on the power train subframe for the first time. As seen in the figure, the engine mounts in front and above the Toyota Corolla transaxle which is driven by twin v-belts. The transaxle is turned 90 degrees from its typical

Figure 3. VOH students with the ChangFa diesel placement on the power train subframe.
orientation so that the rearward facing output CV shaft forms part of the drive shaft connecting to the rear axle. Figure 4 shows VOH students gathering around the work bench as the transaxle was disassembled in order to access the differential gears. Since torque is only applied to one of the output CV shafts in our application, the gearing in the differential must be welded to lock it so that it would not simply spin freely under load. All of the VOH students took part in the transaxle disassembly-reassembly process. They were all eager to take part in this exercise and see how gearing works inside a transmission.

It was important that the BUV project was built with locally sourced components that would be familiar to those who would use and maintain the vehicle. To this end, a single cylinder Chinese made ChangFa diesel was chosen as the power plant for the BUV. The ChangFa diesel is rated at 20HP at 2200RPM making 47.7ft-lbs of torque. The engine measured approximately 890mm wide x 425mm long x 675mm high, and weight around 160kg. Twin C-belts having a drive pulley at 7inch diameter and a driven pulley at 5 inch diameter connected the engine to the transmission. A custom shaft was fabricated at Baylor to support the original Corolla flywheel so that the car’s automotive clutch could be used. The clutch served as input to the manual 5 speed transaxle in the usual manner which was connected to the Hilux rear axle with a custom drive shaft. The transmission was placed under the bed of the BUV to make room for the engine, which took up most of the room under the seat. The Corolla transmission gear ratios along with the calculated maximum speed of the vehicle appear in Table 1. The vehicle speed computation includes a final drive reduction in the Corolla transaxle of 3.722:1, a rear axle differential gear ratio of 4:1, and a tire rolling radius of 12inch. The maximum expected speed of the vehicle is 17.7MPH.

<table>
<thead>
<tr>
<th>Gear Number</th>
<th>Gear Ratio</th>
<th>Overall Speed Reduction</th>
<th>Computed Vehicle Speed (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.545</td>
<td>38.64</td>
<td>4.1</td>
</tr>
<tr>
<td>2</td>
<td>1.904</td>
<td>20.75</td>
<td>7.6</td>
</tr>
<tr>
<td>3</td>
<td>1.31</td>
<td>14.28</td>
<td>11.0</td>
</tr>
<tr>
<td>4</td>
<td>0.969</td>
<td>10.56</td>
<td>14.9</td>
</tr>
<tr>
<td>5</td>
<td>0.815</td>
<td>8.884</td>
<td>17.7</td>
</tr>
<tr>
<td>Reverse</td>
<td>-3.25</td>
<td>-35.43</td>
<td>-4.4</td>
</tr>
</tbody>
</table>

Table 1. BUV gear ratios and computed maximum speed
A short vehicle completion ceremony was held once the BUV was running on the last day. Our donor Bill Baker, all of the VOH students and staff, and the Baylor students were recognized. VOH students and staff were each given Baylor BUV T-shirts. Figure 5 shows a hand-written list of each VOH student that was recognized for their contribution to the project. Figure 6 shows the entire group positioned on and around the BUV. This project was made possible by God’s grace with all involved working together, each bringing their strengths to the project, and working tirelessly through to its completion. The VOH students named the BUV “Bay-ma-tay” which means “Fantastic” in their native Acholi dialect.

![Figure 5. List of VOH vocational school student who built the BUV](image1)

![Figure 6. VOH and Baylor students and staff positioned on and around the BUV](image2)

**Impact of Missions Driven Learning**

Discipline specific mission trips such as our Uganda BUV project provide unique learning opportunities for our students as well for the VOH vocational students. These short term, mission trips also open the door to unique service-oriented activities not found in other settings.

Missions Driven Learning through projects such as our Uganda BUV build offer engineering students something bigger. Engaging in activities having a bigger purpose is a huge motivation for many students. From the beginning of our Baylor BUV organization, students would often ask: What organization will ultimately get our BUV? To which country will it go? While our students enjoy the engineering design and fabrication challenges, most got involved to make a difference.

Students want to be a part of something bigger. The 2017 Deloitte Millennial survey found that two-thirds of those questioned preferred working for a business driven by distinct purpose (*Gx-Deloitte-Millennial-Survey-2017-Executive-Summary.Pdf*). Millennials believe that businesses should be focused more on impact and less on profit. In fact, over half of young people in North America view ‘sense of purpose’ being more important than salary. They feel a relatively high sense of accountability when it comes to ‘big issues’. Irrespective of faith walk, Millennials rank inequality #3 and poverty #4 among the top 10 concerning issues in the world today.
In addition, Missions Driven Learning through experiences like our BUV build offers engineering programs something richer. Many engineering programs embrace the service learning model where examples include: Humanitarian Engineering, Engineering Programs in Community Service, and others. All of these enjoy high levels of student engagement. Research at The Ohio State University showed that half of the students on their recent Honduras service learning trips were female (Bixler et al.). This compares to only 19% female in that university’s engineering student population. We see similar numbers on Baylor engineering mission trips as well. Studies at UC San Diego also found that service learning has a positive effect on recruitment and retention of engineering students, particularly women and underrepresented minorities (Bratton). Furthermore, research at Gannon University showed that service learning initiatives connect specifically to 7 out of the 11 ABET accreditation outcomes (Vernaza et al.). A quick search finds journal papers and NSF grants related to service learning. Missions Driven Learning projects find application in all of these.

More specific to our Uganda BUV trip, the impact of the experience is best reflected through the words of our students. Our Uganda BUV trip will be a part of the lives of our Baylor students and the students at VOH for years to come. As Baylor BUV student Patrick Jaekle noted “Being able to travel all of the way across the world to build a vehicle is an amazing experience. It teaches you both the culture and it teaches you the struggles they face in their daily lives”. Seth Emig, Baylor student and Baylor BUV president stated “We are helping people who deserve help. They have been through so much, and if we can help them and empower them to do more with what they have, that’s incredible, and I really want to be part of that”. Ocheng Charles, a VOH vocational school student stated “I’d like to say that this program is very good. It will help us and give us knowledge to help those people in this society”. Similarly, VOH student Omony Denis summarized his experience as “I am so grateful for Baylor University for their support during this program. May God bless you so much for what you are doing because actually you are investing new knowledge in us so after we are going to use it for our future”.

Ogwang Charles, the Director of the VOH Vocational School, stopped me one day during our project and thanked me for bringing the BUV project to VOH and for spending time with the students there and teaching them the technology of the BUV. He went on to say that he had never seen the vocational students at the Village of Hope this excited about a project ever. Upon my return I became the Facebook friend of Innocent Onek who was one of the vocational students on the project. Soon after, Innocent sent me the message appearing in Figure 6, a testament to the impact our project had on him.

**Conclusion**

Our role as engineering educators puts us in the position to train young adults a set of skills that provides them unique insight into understanding of how elements of God’s creation are made and how they work together. As Christian engineering educators, we have the amazing
opportunity to help draw these students into activities of service where they are blessed by using their God given gifts to impact the lives of others in a positive way. This could be their neighbor next door, or a new friend half a world away. The Baylor BUV Uganda mission trip provided all involved to be a part of something bigger than themselves while serving those less fortunate as Jesus would have us to do.

References


Engineers as LEDs

Jose Oommen Kochalumoottil* and Pheba George*

Abstract

Light plays a significant role in our everyday life and is crucial to our existence on this planet Earth. The applications of light have revolutionized society, and the effect is far reaching. As Christians, we are the light, bearing the light inside that must be reflected as a part of our great calling to place the lamp atop the mountain so that the lost can be drawn by our light to our Savior. This paper focuses on the spiritualistic comparison between the artificial illuminating agents, primarily LEDs (Light Emitting Diodes) and God’s wonderful creation – that’s us. The paper furthermore explores and categorizes the paradigm of light and darkness, which according to the authors, has a profound spiritual implication on our purpose and obligations, capable of informing and illuminating engineering practice.

A major goal of this study is to exhort the engineers that while they are involved in designing and building the best technologies to serve the human family, the works of light must be demonstrated through their work and their lives. The authors believe that the understanding of the nature and properties of light expressed through a Biblical worldview can provide a significant stimulus to develop an understanding of God’s plan for us as engineers.

Light and its forms

Light (visible) is a form of electromagnetic radiation, that has a wavelength between 400-700 nm in the electromagnetic spectrum. Light can be classified into physical forms of natural and artificial light, as well as can be considered in the spiritual realm.

Natural light: The main source of light on Earth is the Sun. Sunlight provides the energy used by green plants to create sugars mostly in the form of starch, which is utilized by living organisms to obtain energy (Wikipedia). This process of photosynthesis provides virtually all the energy used by living beings. Thus, natural light created by God for us is very crucial to supporting the existence of life on this earth.

Artificial light: In addition to the natural sunlight, artificial light is considered to be one of the important, if not the most important commodity that humans require and use in their daily life. It is often said that the degree of civilization is dictated by the extent of the usage of artificial lighting. Around the world, 1.3 billion people do not have access to electricity. About 600 million people are in sub-Saharan Africa, and more than 300 million are in India alone, with the majority of those – approximately 80% living in rural areas where there is no grid-electricity (Lindeman). Thus God, the creator, gave his creation (human beings) the wisdom to create artificial light. Without the presence of artificial light, existence of human beings on this planet would not be as comfortable as it is now.

Spiritual light: Compare this to the spiritual world, and one would find people living in perpetual spiritual darkness unable to conform their ways to the will of God, as per John 3:19 (NIV): “This is the verdict: Light has come into the world, but men loved darkness instead of light because their deeds were evil.” Thus, spiritual light is the candle that God has lit in us.

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Without the spiritual light, man would continue to live in sin, and be further away from the divine purpose of their existence.

Education as light

Education is the activity that imparts knowledge or skill and is often compared to an enlightening experience - like a light bulb, whereby once lit, one can view the world in a different way. Isn’t it true that much of the world was under the dark ages until the light of education shone through? Nelson Mandela, the former president of South Africa, who was a well-known anti-apartheid activist once remarked that “Education is the most powerful weapon which you can use to change the world” (Strauss). Frederick Douglass, who was a great American social reformer and orator stated that “Education means emancipation. It means light and liberty. It means the uplifting of the soul of man into the glorious light of truth, the light by which men can only be made free.” (Thomas). There is even a well-known quote in the literary world that says “Education is not the filling of a pail, but the lighting of a fire.” Thus, education is considered so important that today there is some form of compulsory education in most countries. While illiteracy is considered a form of ignorance, and hence conforming to darkness, education according to Alan Bloom, is the movement from darkness to light (50 Inspirational Light quotes on becoming awakened). Being educated as engineers, we are in the light. However, there is still ignorance in us because we are separated from the life of God. “They are darkened in their understanding and separated from the life of God because of the ignorance that is in them due to the hardening of their hearts” (Ephesians 4:18, NIV).

It is only when an engineer enlightened by education receives Christ that he truly becomes the light of the world. “You are the light of the world” (Matthew 5:14-16, NIV). There are several problems in this world that can be solved through technological innovations. A Christian engineer must not only use his education (light) but spiritual light to bring glory to God through his works and defense of the gospel. Furthermore, as educators, it should be our passion to equip engineering students with the necessary technical knowledge so that they are proficient in their field of study along with shepherding and guiding them as light emitting engineering disciples of Christ. This advocates the need for us to have a look at a couple of the artificial lighting mechanisms/devices and do a comparative study that will enable us to become better light emitting engineering disciples.

Light emitting diodes (LEDs)

Light emitting diodes are tiny light bulbs that are found in all kinds of devices used in an ever-growing list of technologies. The first visible spectrum LED was invented by Nick Holonyak, Jr., while working for GE in 1962. Between 2011 and 2012, global sales of LED replacement bulbs increased by 22 percent while the cost of a 60W equivalent fell by nearly 40 percent. By 2030, it is estimated that LEDs will account for 75 percent of all lighting sales and over the next two decades could save the US $250 billion in energy cost, reduce electricity consumption for lighting by nearly 50% and avoid 1800 million metric tons of carbon emissions (Matulka). Light emitting diodes (LED) are different from ordinary p-n junction diodes in the sense that they emit light when forward biased. Ordinary p-n junction diodes are either made from Group-XIV elements like silicon or germanium, and emit heat when a hole recombines with an electron. On
the other hand, LEDs are constructed from compounds like Gallium Arsenide or Gallium Phosphide and recombination of an electron with a hole results in emission of light. In the absence of voltage, majority and minority carriers diffuse across the pn-junction and as a result of movement of opposite charge carriers across the depletion region, the current is zero, and hence no light is produced. Upon application of a forward voltage sufficient enough to overcome the barrier potential, the majority carriers on either side of the junction force themselves past the space charge region of fixed ions. Thus, a forward voltage is necessary for carriers to cross, which is analogous to the power of God. 2nd Corinthians 4:7 (NIV) says, “But we have this treasure in jars of clay to show that this all-surpassing power is from God and not from us.” We, who have been born again through faith in Christ, still live in the frail, vulnerable earthen vessels, fashioned from dust – “And the Lord God formed man of the dust of the ground” (Genesis 2:7, NIV). Job 10:9 states that “You made me like clay”. Thus, we are all like clay pots fearfully and wonderfully made (Psalms 139:14) intended to hold a heavenly treasure – God, who by his dwelling, will transform our feeble, perishing bodies. The ordinary earthen vessels have no extra-ordinary thing to boast about, except to draw attention to the contents and not to the container. The Holy Spirit who by His power caused the world to become into being (Genesis 1:1–2; Job 26:13) is the treasure that transcends and overshadows the earthen vessel and manifests itself from within the vessel, causing the world to see the light of the world (Jesus) within us and through us.

A light emitting diode uses a semiconductor to convert electricity into light. On the other hand, a light emitting disciple is empowered by the Holy Spirit to manifest the light within us. A good quality LED bulb can last more than 25 times longer than a traditional light bulb. Similarly, an enlightened disciple can be of great use to the world because God is able to do infinitely more than all that we ask or imagine, according to His power that is at work within us.

LEDs use energy far more efficiently with little wasted heat compared to incandescent bulbs that releases 90 percent of the energy as heat. A light's efficiency is essentially the amount of light produced (measured in units called lumens) by a specific amount of electric power (measured in watts). For comparison, a traditional incandescent light bulb can produce about 16 lumens per watt (Matulka). Fluorescent lights are a bit more efficient, producing 70 lumens per watt. LEDs, at their peak, have produced up to 300 lumens per watt. Early lasers could produce peak powers of some 10,000 watts. Modern lasers can produce pulses that are billions of times more powerful. This prompts us to question how efficient we have been as Christian engineers. Efficiency is defined as being well-organized, competent and resourceful. With the light inside us, we must examine the amount of light that we have been able to reflect and refract or is it that we are hiding the light under the bushel, instead of displaying the glowing light atop the hill. Has there been a shortage of oil in our lamps causing dimness with time, or have we been constantly renewing ourselves through reading and meditating upon the word of God (light), causing us to shine brightly for God? We need to understand that it is the truth about God's love that is capable of overcoming any darkness. Being an efficient Christian means doing our best to serve God and others by making our lives well organized. As Christian engineers, we know that God will hold us accountable for what is presented to us as well as for all what we do with it. Hence, we should be better managers of our time and become great stewards in our calling and mission.
LEDs are used in a wide variety of applications because of its compact size, robustness, and its ability to focus light in a single direction instead of it being scattered everywhere. Accordingly, as Christian engineers, we are not limited by our circumstances or surroundings for we are more than conquerors (Romans 8:37, NIV). Since the word of the Lord is a light unto our path, He directs our steps even amid darkness and challenges to channel the light in a focused manner. An LED is very small in size, yet it produces bright light. The number of engineers who are professed born again Christians may be few, but that shouldn’t prevent us from shining light in great measure.

**LASER:** Laser is an acronym for Light Amplification by Stimulated Emission of Radiation (How Lasers work). When an atom is excited, the valence electrons move to a higher energy level. Upon returning to the lower energy level, the electrons give off energy in the form of light. Laser light is directional (coherent beam), and only has one wavelength, hence one color. A Christian engineer, likewise, must be laser focused on his secular and spiritual goals, and should strive to juggle both goals by depending upon the grace of God.

**Reflection and Refraction:** Light rays change direction when they reflect off a surface (Reflection), or when they travel from one transparent medium into another (Refraction). According to Edith Wharton, "There are two ways of spreading light: to be the candle or the mirror that reflects it" (Meloni). We, who know the light, must reflect and refract the light within us. The moon does not have light on its own and still reflects the light it receives from the sun. It’s interesting to note that moon becomes a light in the darkness at night. Similarly, we, engineers, can be a source of light to the world.

In the following sections, we will look into what makes an engineer a light emitting disciple and use the properties of light to define the virtues of a light emitting engineering disciple.

**LEDs (Light emitting Engineering Disciple of Christ)**

An engineer is a person who designs, builds, or maintains engines, machines or structures (Oxford). We are disciples who are engineers. We are trained and skilled to design. How can we become the engineers that God asked us to be? Matthew 5:16 (NIV) says that “In the same way, let your light shine before others, that they may see your good deeds and glorify your Father in heaven.” In being the light that God wants us to be, others are able to see the good deeds that brings glory to God.

Being a disciple of Jesus Christ, our paths, plans, and purpose are intertwined with the wine of Jesus Christ. Therefore, if we want to know our purpose in life, we need to find the purpose our leader came to fulfill under whom we are disciples. The Lord made it very clear of His purpose on earth. We read in John 8:12-14 (NIV), “When Jesus spoke again to the people, he said, “I am the light of the world. Whoever follows me will never walk in darkness, but will have the light of life.”

There are two ways in which Jesus bore witness:
1. God proclaimed of His son “You are my beloved son in whom I am well-pleased (bearing witness to God) (Mark 1:11, NIV).
2. God also proclaimed of His son to the people “He is my beloved son in whom I am well-pleased (bearing witness to the people around Him) (Matthew 3:17, NIV).

Similarly, our works are being tested in front of the students that we teach, and our coworkers and in front of God who has ordained us in His time and purpose to do the will of the Father.

**Light and its properties**

How does one become light, impart light and walk in the light when God has planted us as an Engineer in his plantation? There are many properties that light brings into the picture.

a. Light provides heat

   Not only does light defeat darkness, but it also reaches into the darkest places to bring warmth and shows the truth and the way. The message of light can be delivered to any audience but if it lacks compassion (warmth) and tenderness, then it loses its purpose. There is a popular proverb: “People do not care how much you know, until they know how much you care”. Even before Jesus did most of His miracles, the Bible teaches us that He moved with compassion (Matthew 9:36). It is one of the greatest and yet gentle weapon that prepares the heart of any individual to receive any instruction, teaching or correction.

b. Light provides light or brightness

   It provides visual distinction between objects, colors, textures and transparency. Darkness can be defined as the absence of light. The darkness in a person is just the absence of the light of God, which can be filled by viewing and receiving His word through the Bible and through the study of the world He created. The more we learn about the world, the more we see God’s work within it. Surely, as Christian engineers, we appreciate that the creative art of the Master in decorating this earth and the work of His hands is beyond any human comprehension and is our inspiration for our ingenuity and creativity.

   Being the light of the world means that one is also a leader and a revealer. As the light of God shines upon us and as we carry the light of God in us, we become leaders and mentors to the people around us. Light also reveals the path that God wants us to take. “Trust in the Lord with all your heart and lean not on your own understanding; in all your ways acknowledge Him, and He will make your paths straight.” (Proverbs 3:5-6).

c. Darkness cannot coexist with light.

   Light has the most impact in places of darkness. Light can drive out the darkness, but darkness cannot drive out the light. Therefore, the Bible exhorts us, “But if we walk in the light, as He is in the light, we have fellowship with one another, and the blood of Jesus, His Son, purifies us from all sin (1st John 1:7, NIV). When the time had fully come for God’s creation and before creating anything, the first thing that was essential for any creation to take place was the presence of light. God said, “Let there be light” and lo and behold, there was light! God created the light with a single sentence from His mouth. Creating the light means creating the very nature of it, it's speed, it's power, the substance through which it can pass, the energy that it carries, its behavior, etc. The Bible says that darkness was upon the face of the earth and the very moment light was declared, darkness
ceased to exist. Hence, whenever or wherever light is introduced, darkness must depart or leave. By the same token, darkness cannot coexist with the light. The one thing to understand from the story of creation is that light can be created while darkness cannot be created. However, darkness invades the same territory in the absence of light without anyone’s permission or invitation. Therefore, one must always be vigilant in keeping the light of God. We must be watchful that pursuits for professional glory in our field should not be a detrimental factor in losing the glorious light. Psalms 18:28 (NIV) “You, Lord, keep my lamp burning; my God turns my darkness into light.” God has bestowed on all of us this candle as mentioned in Proverbs 20:27 (NIV) - “The spirit of man is the candle of the Lord, searching all the inward parts of the belly.” This conscience must be daily examined to see if we are always living in the light. David says in Psalms 139:23-24 (NIV) - “Search me, O God, and know my heart: try me, and know my thoughts: and see if there be any wicked way in me and lead me in the way everlasting.” The psalmist understands if there is any wickedness in him, then the light will depart from him, leading to spiritual darkness. Thus, it is imperative that just like David, we continue to keep our candle burning.

Darkness is often compared to evil and evil hates the light. John writes, “But whoever hates another believer is in the darkness, walks in the darkness and doesn’t know the way to go, because the darkness has brought on blindness.” (1st John 2:11, NIV). An individual who is exposed to light but does not walk in the abundance of light is in dim light. Those who hate, steal, or abuse others do so because they do not see. Darkness obscures reality even in the light. The apostle John writes “Whoever says, “I am in the light, while hating a brother or sister is still in the darkness.” (1st John 2:9, NIV). Even for individuals who are bathed in the light, desires of the flesh can slide us away from the light. Hence, the objective must be to desire God’s will than desire worldly pleasures. “And the world and its desire are passing away, but those who do the will of God live forever” (1st John 2:17, NIV).

Light-emitting educators

The critical question here is how educators can shine light and utilize the properties of light to mold the students to be efficient light emitting engineering disciples. In order for us to be role models, we must dig deeper into the spiritual significance of light. Light, as we discussed before provides life and improves life, but moreover, represents wisdom and hope.

a. Light is a symbol of life – We read in Genesis that God created the plants, the animals and human beings, but before they were all created, He created light. God knew that light was needed for the survival of all creatures, and the life of his creation depended on the light. Hence, as Christian engineering educators, we must focus on the light (word of God) and encourage the students with a Biblical thought first thing in our classes before moving onto the subject material.

b. Light represents wisdom - Light is knowledge and knowledge is acquired by education. Knowledge is the know-how but wisdom is the wise way of using knowledge. The word enlighten means to impart knowledge or understanding to someone. When people get new creative ideas, they speak about a light bulb turning on for them. If they have
attained a better perspective on a scenario, they say that they can look at it in a new light. Proverbs 20:27 (NIV) - “The spirit of man is the candle of the Lord, searching all the inward parts of the belly.” Hence, those who are spiritually enlightened have the wisdom to choose truth over falsehood in their everyday lives. As engineering educators, we must

➢ Create a positive environment for the student: We read in Proverbs 18:21 that the tongue has a power of life and death, hence our words that we speak should not be used to crush the human spirit, but to encourage the students in our classroom.

➢ Empower the students to use their ability: Many a time we have seen that students expect overnight results without burning midnight oil. We must therefore encourage them to be in the growing mindset than a fixed mindset, wherein we must emphasize that regular practice makes progress, progress makes improvements and improvements makes perfection.

➢ Engage students inside classroom: An engineering educator must be creative with presentation materials and projects in order to create and maintain interest of the students in the particular course.

c. Light provides heat (warmth, hope): Isn’t it a fact that people often light candle when praying, thus hoping to create a change in circumstances that seem hopeless. Even on Christmas, we decorate with electric lights to symbolize Jesus Christ as the light of the world who brings hope to millions. A small amount of light is still visible in utter darkness, and therefore, the light of hope is always stronger than the darkness of discouragement and despair.

**Engineering educators as molders of LEDs**

The English bible translator J. B Phillips used the cookie-cutter idea in his paraphrase of Romans 12:2: “Don’t let the world around you squeeze you into its own mold, but let God re-mold your minds from within, so that you may prove and practice that the plan of God for you is good, meets all His demand and moves towards the goal of true maturity (Baker). As Christian educators, it is our utmost responsibility that we set an example before our students, and prepare them to be committed, passionate disciples of Christ. This whole idea of connection between engineering and Christianity and furthermore, being a light emitting engineering disciple was discussed in class as a part of a one-credit hour course on Engineering ethics. Students were also introduced to couple of examples of Christians who made a difference in the engineering profession, notably Gary Starkweather and Michael Faraday.

Gary Starkweather, an outstanding engineer and a well-known inventor, known for his invention of the Laser printer, and who has worked for great companies like Xerox, Apple, and Microsoft, credits his inventions as inspiration from God. He has said that he believes, “God made the world discoverable, hence, His power and majesty knowable. Otherwise, we might just as well be like most animals that are unaware of what makes things tick. Thus, I asked Him to show me a little bit of how the Universe works and what might be done with what He has made. Thus, the discoverability of our world and the fact that he is Creator and has made us in His image gave me reason to believe that when we build things and create things from our ideas this could be a
way of worshipping as well. As Eric Liddel, the great athlete said, “God made me fast, and when I run, I feel His pleasure.” I felt the same way in my field of endeavor.” (Bingham)

Michael Faraday, notable for the discovery of benzene, and formulation of laws of electrolysis, and electromagnetic induction, also worked as ‘Elder’ of the London congregation of which he was a member. During that time, he undertook the spiritual oversight and pastoral care of the people in the congregation. There is ample evidence that Faraday’s faith had a strong influence on his own practice of science, which was manifested in the way he approached the study of nature, and also in the underlying social and ethical principles that is involved with the pursuit of scientific goals. (Hutchinson)

At the end of the class, students were asked how they could demonstrate light or the properties of light, as a student and as an engineer upon graduation. Some of the sample responses were:

1. As a student, this means that I should recognize the point of homework and projects is not solely about getting a good grade, but instead it helps prepare me to become a person capable of bringing light to the darkness. After graduation, this would be using what I have learned in class to best meet the needs of those around me.

2. As a student, we have to carry ourselves to a high standard. Everything that we do should be Christ-like and God honoring. This means that we cannot give into the temptations and trends of college life and we have to work hard towards our goals. In a professional field, we are constantly meeting new people and if we are a light then we can make a difference.

3. The biggest way that students can demonstrate light or the properties of light is to live with and display integrity. This seems to be the biggest problem facing the church today, where we say we are Christians, but we do not put it into practice or live it out except on Sundays. If you can live with integrity, then your light will shine brightly.

Another possible way to demonstrate light is to be unwavering in our beliefs. Just as light travels only in one direction, so our actions should be congruous with how we are called to live as Christians.

If we are able to do these two things then the sphere of influence and the power of God that we draw upon will allow us to increase our intensity and instead of being just a beam of light in the dark, we will grow to be a cone of light emanating from the true light.

Conclusion

The psalmist in Psalms 119:130 says “The unfolding of our words gives light: it gives understanding to the simple.” Our words should be words of light and that in return would enlighten those we come in contact with. As LEDs, we should not talk the talk if we can’t walk the walk. For Paul says in Ephesians 5:8 “For you were once full of darkness, but now you are light in the Lord. Walk as children of light.” Isn’t it true that technological innovations have often led to an explosion in evangelism? Improvement in road transportation led the first
disciples to advance the gospel through the Roman Empire. The invention of the printing press by Johanes Gutenberg allowed the Bible to be printed in various languages in mass volumes. The invention of radio, and television has been harnessed by Christian evangelists to bring the gospel into the living rooms of billions of people. With one swipe, we can watch and listen to podcasts on our cellphones, thanks to the internet. Thus, technological innovations, courtesy the works of the engineers before us, has helped spearhead this massive movement to fulfill the calling to propagate the good news of our Lord and Savior Jesus Christ. We, as Christian engineers must therefore, work together in unity, resolving all differences in a spirit of brotherhood and friendship, and be the light that people can look up to, whether it be in the classroom, community or workplace setting.

References

6. Meloni, Margaret. “Are you the candle or the mirror?” www.margaretmeloni.com/blog/are-you-the-candle-or-the-mirror/
There has been much speculation about how God destroyed Sodom and Gomorrah in Gen. 19:24-25 where God rained fire and brimstone on the cities. A variety of theories have been offered such as a volcano, an earthquake, an airburst produced by a comet, petroleum products under the cities ignited by lightning and explosions, and even a flood. While there are some elements of each of these natural explanations that are plausible, they do not harmonize with the biblical text, they violate the laws of combustion physics, or there is insufficient supporting evidence. The best explanation of this catastrophe is that God supernaturally rained fire and brimstone on these exceedingly sinful cities which are used throughout the Bible as symbols of God’s wrath. Given the complete destruction of Sodom and Gomorrah, the heavenly fire was likely extraordinarily hot which could not have been produced by the technologies available at the time of the event. This paper comprehensively reviews the many theories that have been offered for the destruction of Sodom and Gomorrah from a combustion engineer’s perspective.

INTRODUCTION

The destruction of Sodom and Gomorrah is one of the more spectacular miracles in the Old Testament. Richards wrote, “What marked the destruction of Sodom as extraordinary was its occurrence as a judgment on sin (Gen. 18:20), its pre-announcement by God (Gen. 18:21-23), and its timing — immediately after Lot had safely left the city (Gen. 19:23-24).”2 Leupold called this “one of the most terrifying events of all history.”3 Thomas called Gen. 19 “one of the most terrible chapters in the Bible.”4

Although there is relatively little description of exactly what happened, this has not stopped scholars from speculating about how the cities were destroyed. Harris wrote, “Though there is consensus of the actual existence of Sodom and Gomorrah in the vicinity of the Dead Sea, there is little consensus among Biblical scholars regarding how or when the cities met their

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1 Oral Roberts University, (Tulsa, Oklahoma).


4 W. H. Griffith Thomas, Genesis: A Devotional Commentary (Grand Rapids, MI: Eerdmans, 1946), 173.
Bentor noted, “The central problem in the whole story is obviously the way the two cities were destroyed.”

God destroyed these two cities because of their exceeding sinfulness. The destruction of Sodom and Gomorrah was predicted, extraordinary, and complete. Throughout the rest of the Bible, these cities are associated with both sin and God’s wrath. According to Howard, “The destruction of Sodom and other cities (Gen. 19:24-28) was so spectacular and complete that it was frequently mentioned as a sign of God’s wrath and judgment, and God often threatened Israel and other nations with similar destruction.” Maher wrote, “Two short verses (24-25) describe the disaster that spelled the end of Sodom and Gomorrah, a disaster that was to become the paradigm of the judgment of Yahweh.”

There are several ways the story of the destruction of Sodom and Gomorrah may be viewed: it took place as written, it is a mythical legend, or it has elements of truth from a past catastrophic event. Brueggemann offered another view that the description of this event was imagery in an attempt to describe God’s judgment and should not be taken literally. The position taken here is the event took place as written.

Assuming the destruction of Sodom and Gomorrah actually occurred, there are three general positions taken to explain this event: miraculous where the general laws of science have been suspended, miraculous where the general laws of science have not been suspended, and non-miraculous where a naturally-occurring event coincidentally occurred at just the right time. It is the thesis of this paper that there are significant problems with positions two and three and that the best explanation is the general laws of science were suspended for this miraculous event.

**SOME COMBUSTION BASICS**

An understanding of combustion science is important in analyzing some of the theories that have been offered to explain this event. According to the fire triangle, three things are needed for a fire: fuel, oxygen, and an ignition source. Combustion is a chemical reaction between a fuel and an oxidant which is usually air. Most common fuels contain carbon and/or

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hydrogen and come in solid, liquid, or gaseous forms. Regardless of the form, once the fuel is combusted the products are typically gases including carbon dioxide, water, nitrogen, usually some oxygen, and trace species such as carbon monoxide and nitrogen oxides which are pollutants. The hot gaseous products of combustion are very buoyant and naturally rise because they are much lighter than air due to their elevated temperature.

The purpose of controlled combustion is normally to generate useful thermal energy, while uncontrolled combustion can be very destructive. Fire is an enigma: “As a process, fire can take many forms, all of which involve chemical reactions between combustible species and oxygen from the air. Properly harnessed, it provides great benefit as a source of power and heat to meet our industrial and domestic needs, but, unchecked, it can cause untold material damage and human suffering.” Fire was used destructively in Gen. 19.

Different fuels have different characteristics. Gaseous fuels are generally the easiest to burn because they readily blend with air to form a combustible mixture that easily reacts. Natural gas is a common gaseous fuel which consists primarily of methane and is in abundant quantities inside the earth. It is lighter than air and naturally rises. There are some gaseous fuels such as propane which occur naturally, although in much smaller quantities than natural gas, that are heavier than air and naturally fall due to gravity.

Solid fuels are much heavier than air, fall naturally due to gravity depending on the solid, and are typically the most difficult to burn. They need to be heated to cause the volatiles to come out as gases, which is called devolatilization, so they can burn. Once a solid fuel fire has been started, the heat generated is normally sufficient to sustain the devolatilization process to keep the flame going. Solid fuels generally need to be in very small sizes so the volatiles can come out of the solid more easily and so air can reach all of the fuel. For example, in coal-fired power plants the coal must be finely ground so it will burn properly in the boilers. This also applies to burning large logs of wood where kindling is needed because the logs do not burn very well if at all by themselves. Some portion of the solid does not burn in most solid fuels. A familiar example is the pile of ashes left over after a campfire has gone out.

Liquid fuels generally fall in-between gaseous and solid fuels as they are easier to burn than solids, but not as easily as gases. Liquid fuels must be finely atomized so oxygen can get to the vaporized fuel for the combustion reactions to occur. There is a phenomenon referred to as flaming rain, where larger droplets of liquid fuel do not burn properly in the primary combustion zone but rather are ejected out of that zone and burn gradually as the droplets fall to the ground. This is a potential mechanism for the destruction of Sodom and Gomorrah.

For the destruction of two cities, a massive amount of fuel would have been required because of the considerable amount of non-combustible materials in the cities such as stone and

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brick. While some parts of homes would have had some combustible materials, such as the roofs, this would likely have been a relatively small amount.

The natural tendency for fire is to go upward due to buoyancy, not downward as described in Gen. 19:24 which says the fire rained down from above. This tendency for hot combustion products from fires to rise causes, for example, these gases to naturally rise in the chimney of a fireplace.

For a fire to go downward, it must overcome gravity which leads to three options that do not violate natural laws. The first is that for a downward firing gaseous fuel like natural gas, the downward fuel gas velocity must be sufficient to overcome the upward buoyancy force, at least for some distance. There is no known natural cause for a high velocity jet of lighter-than-air gaseous fuel coming from the sky. The second option is the fuel is heavier than air and would naturally fall down, at least until it burns and produces hot gases that want to rise. Liquid, solid, and heavier-than-air gaseous fuels all meet that criteria. Typical solid fuels like wood and bitumen, liquid fuels like petroleum oils and olive oil, or heavier-than-air gaseous fuels like propane and butane would naturally descend. The third option is another force pulling the fire down such as that produced by a large fan. There are some industrial furnaces, such as steam-methane reformers, where the burners are typically fired downward for process reasons. Those furnaces have an induced draft fan that pulls the combustion products downward, through a heat exchanger, and finally upward through an exhaust stack.

There are significant problems with options one and three. Presumably these divine flames started at a significant elevation and reached the ground to destroy the cities. Therefore, any natural explanation would likely preclude the option of a high velocity gaseous fuel flame reaching all the way to the ground which rules out the first option. The fire that rained down on Sodom and Gomorrah was an open flame (i.e., it was not contained in a furnace) and no powerful fans were available to pull the combustion products down which rules out the third option. Then, from a fuel perspective, the only viable option for any natural explanation is the fuel would have to have been heavier than air, which doesn’t narrow the choices down very much as only lighter-than-air gaseous fuels are excluded.

A second factor related to the fuel is the cities themselves were destroyed which means the fire reached the ground. The text describes the fire as raining from heaven which infers it was fire both in the air and on the ground when it hit the cities. This would then exclude any type of gaseous fuel, even those heavier than air, because once those fuels burn their buoyant gaseous combustion products would rise before they hit the ground. It is not likely the heat alone from such a gaseous fire would have been enough to completely destroy the cities without the flames ever reaching the ground. Therefore, the most likely fuel would have been a liquid and/or a solid because their weight would make them more likely the fire would have reached the ground.

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Fuel Source

In order for a natural explanation to be viable, there must have been a large source of available fuel. Wood believed some type of burning petroleum product fell on Sodom.\(^\text{15}\) The Dead Sea Basin contains gaseous, liquid, and solid hydrocarbons, the latter two of which contain very high sulfur contents.\(^\text{16}\) Bitumen, petroleum and probably natural gas are known to have existed in the generally-accepted region of the two cities, where a significant quantity of natural gas could have been released during an earthquake or subterranean pressure impulse.\(^\text{17}\) Acquistapace argued the fire and brimstone came from below the cities, which he believed were built on petroleum deposits.\(^\text{18}\) It has even been argued the fire falling from the sky was not the primary fuel source which was instead the energy in the soil under the cities.\(^\text{19}\)

One theory is the petroleum products under the cities were thrown into the air by either a volcano or an earthquake and had the appearance of raining down from the sky. Merrill wrote, “The destruction (of Sodom and Gomorrah) evidently was the result of some kind of volcanic eruption or petroleum explosion which threw into the heavens vast quantities of magmatic materials which then rained down upon the earth.”\(^\text{20}\) Beitzel wrote, “the exact nature of the destruction rained upon the two cities has been variously interpreted either as a volcanic eruption or a spontaneous explosion of subsurface pockets of bituminous soil.”\(^\text{21}\) Shelly believed a volcanic eruption caused the spontaneous combustion of flammable gases.\(^\text{22}\) Maher thought it could have been an earthquake that released natural gases that were subsequently ignited.\(^\text{23}\) Kyle argued against a volcanic eruption but for some type of flammable gas explosion.\(^\text{24}\) Angel also

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\(^\text{18}\) Fred Acquistapace, *Miracles That Never Were* (Santa Rosa, CA: Eye-Opener, 1991), 34. It is interesting that Acquistapace wrote of Sodom and Gomorrah that “we don’t know exactly where they were” but somehow he knows what they were built on. No evidence or references are given to support his theory.


\(^\text{23}\) Maher, *Genesis*, 120.

argued against a volcano for the same reason, but believed it was an earthquake. The volcano, earthquake, and combusted petroleum products theories are discussed in more detail later.

In addition to an earthquake and a volcano, other mechanisms have been suggested for how the flammable materials reached the surface. Neev and Emery speculated that hydrocarbons underground could have been thermally cracked and released with the assistance of geothermal heating that would have made them flow much more easily to the surface. Lockyer wrote, “If, as some writers suggest, the fire destroying Sodom and Gomorrah burst forth from a subterranean source, it was yet directed by the Lord.” Maclaren suggested the possibility of underground flammable gases escaping through fissures in the ground and being ignited.

The Hebrew word גְָּפְרִית in Gen. 19:24 is used a total of seven times in the Old Testament and is translated as *brimstone* which is another name for sulfur, which occurs naturally in regions of volcanic activity such as the valley of the Dead Sea. Although sulfur is not normally used as a fuel, it does release heat when burned. It is a yellow, non-metallic element that is soft, melts at 235°F (113°C), and burns with a blue flame when it combines with oxygen and forms sulfur dioxide which is colorless and has a noxious odor. It is likely people in the Near East during the time of this event were familiar with the terrors of burning sulfur. Clarke believed brimstone was used metaphorically to symbolize the utmost punishment. Walton wrote, “The scene is one of divine retribution, and the use of brimstone appears here and
elsewhere as an agent of purification and divine wrath on the wicked (Ps. 11:6; Ezek. 38:22).”

Poole suggested the brimstone could have been used either to carry the fire down since fire naturally wants to rise or to add additional fuel to the fire.

Ignition

A flammable mixture is typically ignited either by contacting hot materials above the autoignition temperature of the mixture or by some type of electrical discharge. In the former case for this narrative, that could have been an existing fire such as from an oil lamp or a fire used for heating or cooking. In the latter case, it could have been from lightning or a static electric discharge.

As an example of the fire starting by contact with hot materials, Acquistapace suggested gaseous fuels under the cities could have been ignited by an overturned oil lamp during an earthquake. As an example of the latter ignition method, some believe the fire was started by lightning. Willis suggested lightning ignited a large field of petroleum, bitumen, and flammable gases seeping out of the ground. Leupold suggested both lightning and sulfur could have rained down. Gill disagreed, “this was not a common storm of thunder and lightning with which often there is a smell of sulphur or brimstone.” Stigers argued it was not lightning that ignited the bitumen, but the brimstone which acted like tinder.

The Hebrew word for fire used in Gen. 19:24 is which can be translated as conflagration or supernatural fire. Hebrew words for lightning or lightning flashes include . None of those words were used in Gen. 19. The author should have used one of

37 Acquistapace, *Miracles That Never Were*, 34.
38 Whitelaw, “Genesis,” 256.
40 Leupold, *Genesis*, 568.
44 Ibid., 21, 140, 304.
45 was used in Ex. 19:16, was used in Job 28:26, and was used in Job 37:3 (Ibid, 140, 304, and 21, respectively).
the words for lightning if God actually sent lightning. It would have been no less a miracle if it was lightning so there is no obvious reason for the author to use fire if it really was lightning.

Smoke

There are multiple potential sources for the smoke Abraham saw rising from the cities during their destruction described in Gen. 19:28. There are several general categories for smoke sources: combustion-generated, debris from the destruction, and ash from a volcanic eruption. Not all methods would be applicable for all of the destruction theories that have been proposed.

There are multiple possible sources of combustion-generated smoke: oxygen-deficient combustion, combustion of sulfur, unburned solids from the raining fire, and unburned solids from flammable materials in the cities. When a carbon-containing fuel is burned with an insufficient amount of oxygen or is poorly mixed with oxygen, some of the carbon may produce soot and generate smoke. The fuel could be a solid, liquid, or gas. Burning sulfur produces a blue flame which could have the appearance of smoke. When burning liquid or solid fuels, there are often some elements such as inorganics that do not burn that can produce ash that could have the appearance of smoke. This method relates to both the fire raining on the cities if it contained inorganics as well as the materials that were incinerated in the cities.

The second general category for producing smoke could have been from the debris produced during the destruction of the cities. Smaller and lighter unburned materials could easily be carried upward by the updraft of hot and buoyant gases produced during combustion. If there was a sufficient quantity of these unburned materials, the plume would have had the appearance of smoke. Kyle suggested the smoke was caused by boiling asphalt that was thrown up in the air by the explosion.46

The third general category for generating smoke is ash from a volcanic eruption. For example, the plume from the eruption of Mount St. Helens in 1980 reached as high as 14 miles (23 km).47 The theory that a volcano was the cause of the destruction of Sodom and Gomorrah is considered in more detail later. Smoke generated from the ash produced during a volcanic eruption would have been easily seen from long distances away from the cities.

Enhanced Combustion

Extremely high temperatures would have been required based on the melted ceramics found at Tall el-Hammam which is the believed by some to be the site of Sodom.48 These temperatures are unlikely to have been produced by the normal burning of fuels such as bitumen or natural gas. Conventional combustion of hydrocarbon fuels with air cannot produce high enough temperatures to melt ceramics given the available technology at the time of the event. There are plenty of technologies today for enhancing the combustion process to produce

46 Kyle, *Explorations at Sodom*, 120.


temperatures high enough to melt ceramics. Some examples include oxygen-enhanced combustion, plasmas, and preheating the combustion air. The only options at the time of the event would have been lightning, a comet, or a supernaturally hot divine flame.

CITIES DESTROYED BY FIRE

There have been some devastating fires throughout history that have destroyed cities. The fire in Rome in 64 AD is one of the more terrible conflagrations in history, although there is some dispute as to how it was started. In the U.S., some famous large and devastating fires were in Chicago in 1871 and in San Francisco in 1906 which was caused by a large earthquake. Considerable advancements have been made in fire science to dramatically reduce the risk associated with such unintentional fires.

The burning of cities by the victorious side in battle was common practice in the Bible. During the conquest of the Promised Land, many of the conquered cities or camps were burned. The cities of Midian (Num. 31:10), Jericho (Josh. 6:24), Ai (Josh. 8:19), Hazor (Josh. 11:11), Jerusalem (Jud. 1:8), Gibeah (Jud. 20:38-40), Ziklag (1 Sam. 30:1), Gezer (1 Ki. 9:16), and the tower at Shechem (Jud. 9:49) were burned with fire. Archaeological excavations have confirmed many of these accounts. The fires used to destroy these cities were all manmade. Amos prophesied the destruction of Gaza (1:7), Tyre (1:10), Rabbah (1:14), and Jerusalem (2:5) by fire.

Scripture says that fire and brimstone rained down on the cities of Sodom and Gomorrah. Fields wrote, “No city is judged and destroyed by God in a more memorable way than Sodom when fire comes down on it like burning rain, leaving no survivors.” Then in the Bible, not only were fires set by conquering nations to destroy enemy cities, but also heavenly fires were sent by God to destroy cities as well.

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55 Fields, Sodom and Gomorrah, 137.
SODOM AND GOMORRAH

Sodom and Gomorrah are mentioned 47 and 23 times, respectively in the Bible. Their destruction is the most frequently mentioned event in the Old Testament. An ancient document called the Eblaite Geographical Atlas lists many places, one of which is believed to be Sodom which is currently the only ancient document outside of the Bible to mention that city. The general locations of Sodom and Gomorrah are known, but the specific locations are not currently known for certain. Briscoe wrote the destruction of those cities “was so complete that even to this day there is no certain knowledge as to their whereabouts, although there is no doubt about their general location.” The location of the cities impacts how God destroyed them according to some of the theories that have been posited.

The general location of Sodom and Gomorrah is believed to be part of a mountain range made up largely of crystalline salt that may today be under water. Some believe these cities were near the southern or southeastern end of the Dead Sea which was called “Lake Asphaltites” in ancient times. Harlan believed Sodom and Gomorrah were located in what is now part of the Dead Sea but was once not covered by water. Gen. 14:10 refers to the kings of Sodom and Gomorrah falling into tar pits in the valley of Siddim, so it is often assumed their cities were not far from there. Lot and his family traveled toward Zoar at the command of the angels to get away from the impending destruction (Gen. 19:22-23). Since they were traveling on foot, Zoar could not have been very far from Sodom.

63 David M. Howard, Jr. (“Sodom and Gomorrah Revisited,” Journal of the Evangelical Theological Society 27, no. 4 [1984]: 385-400) makes a strong case for a southeastern location using Biblical and later tradition literary evidence along with archaeological and related evidence.
The specific location of Sodom and Gomorrah likely ranges between regions north and south of the Dead Sea. Collins suggested a well-watered plain north of the Dead Sea (Gen. 13:10) at Tall el-Hammam. Others suggest the cities were in the southern part of the Dead Sea which is now submerged as the water level is about 30 – 40 m higher than during the time of the destruction of those cities. Several streams feed fresh water from Transjordanian canyons southeast of the Dead Sea. Such a location is consistent with Lot’s selection of the well-watered land when given the choice by Abraham (Gen. 13:10-12). In the ancient world, cities were commonly located near readily available sources of water because of the difficulty of transporting large quantities of water over long distances. Levine noted “Sodom was explicitly depicted as being irrigated “as the Garden of God.” Then, the destruction of Sodom and Gomorrah by fire was even more spectacular because much more energy would have been needed to destroy a well-watered area.

Gen. 14:10 mentions tar pits in the Valley of Siddim which the kings of Sodom and Gomorrah fell into during a battle. That region has a considerable amount of asphalt (tar) and other combustible materials, and is known for earthquakes and volcanic eruptions, so that is a possible location for the cities. Sodom and Gomorrah are believed to have been located near a fault which is part of the Great Rift Valley system. However, that location does not contain large quantities of sulfur.

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65 Collins, Where is Sodom?, 38. Much of the water in antiquity flowed to the surface from underground springs in this region.

66 Harris and Beadon, “Destruction of Sodom and Gomorrah,” 353.


69 James G. Murphy, A Commentary on the Book of Genesis (Barnes’ Notes; Grand Rapids, MI: Baker, 2005; reprinted from 1847 edition), 323. Note that J. Penrose Harland (“Sodom and Gomorrah: The Destruction of the Cities of the Plain,” The Biblical Archaeologist 6, no. 3 [1943]: 43) noted the region is known for earthquakes, but ruled out any possibility of volcanic activity for Sodom and Gomorrah.

70 Harris and Beadon, “Destruction of Sodom and Gomorrah,” 350.

DESTRUCTION THEORIES

God rained fire and brimstone from heaven on Sodom and Gomorrah. Gunkel called this a “heavenly storm.” Fire and brimstone are also paired in Psalm 11:6 and Ezek. 38:22 as “agents of divine retribution.” Keil wrote,

The rain of fire and brimstone was not a mere storm with lightning, which set on fire the soil already overcharged with naphtha and sulphur. The two passages, Ps. 11:6 and Ezek. 38:22, cannot be adduced as proofs that lightning is ever called fire and brimstone in the Scriptures, for in both passages there is an allusion to the event recorded here. The words are to be understood quite literally, as meaning that brimstone and fire, i.e., burning brimstone, fell from the sky. Letellier concurred, “It is not rain, hail or lightning that is dispatched, but gopriṭ waʾēš ‘brimstone and fire.’” Butler provided a unique description of this event, “Sodom was put in a Divine incinerator. Liquid fire drenched wicked Sodom which quickly made Sodom a raging inferno.”

A variety of theories have been offered to explain the destruction of Sodom and Gomorrah. A volcano and an earthquake are two of the more popular theories. A variety of others are also briefly considered next.

Volcano

Many scholars theorize Sodom and Gomorrah were destroyed by a volcanic eruption. Ephros described the fire and brimstone coming from heaven as a simulation for a volcanic

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77 John G. Butler, Genesis to Exodus (Analytical Bible Expositor; Clinton, IO: LBC, 2008), 179.

78 There is no biblical Hebrew word for volcano. Some verses such as Deut. 4:11 are argued by some to refer to a volcano: “and the mountain burned with fire.” This does not necessarily mean it was not a volcano just because there was no word for it at that time.
eruption and contamination of the atmosphere by volcanic ash.\textsuperscript{79} Volcanic rock exists in the vicinity of the Dead Sea where the cities of Sodom and Gomorrah are believed to have existed.\textsuperscript{80}

Volcanoes are unpredictable and often treated as sacred and symbolic of a powerful deity.\textsuperscript{81} The combination of sulfur, fire, and smoke in the description of this event are consistent with the eruption of a volcano.\textsuperscript{82} Thomas believed the two cities were “engulfed by lava.”\textsuperscript{83} Baly argued the only reasonable explanation for fire and brimstone raining down on Sodom and Gomorrah was volcanic activity.\textsuperscript{84} He wrote, “it does seem clear that there is a memory of volcanic activity of some kind.”\textsuperscript{85} He noted the history of volcanic activity in the region.

The word used in this passage for smoke is the thick smoke from a sacrifice.\textsuperscript{86} Although such smoke could be produced by any fire without sufficient oxygen or mixing, smoke is commonly associated with volcanic eruptions which spew out all types of materials, both flammable and non-flammable, into the air which generates a lot of smoke.

An important issue related to volcanic activity in the Dead Sea region is whether the period of activity overlapped the destruction of Sodom and Gomorrah. While Clapp found volcanic rock in the vicinity of where the two cities are believed to have been located, he did not believe they were produced within the past 4,000 years.\textsuperscript{87} Loader suggests the event actually occurred much earlier than the time of Abraham where there is evidence of a volcanic eruption in the area which he argues the author of Genesis is recounting for theological purposes.\textsuperscript{88} Trifonov also believed it was a volcano but that it was not likely in the vicinity of the Dead Sea, but rather


\textsuperscript{80} Clapp, “Site of Sodom and Gomorrah,” 339.


\textsuperscript{83} Thomas, \textit{Genesis}, 173.


\textsuperscript{85} Ibid., 23.


\textsuperscript{87} Clapp, “Site of Sodom and Gomorrah,” 339.

by a volcano in the southern Syria vicinity. Block believed pyroclastics (rocks consisting primarily or solely of volcanic materials) rained down on the two cities from a volcanic eruption in the vicinity of Zarqa Ma’in which is a wadi off the Jordan River between the Dead Sea and the Sea of Galilee.

Earthquake

An earthquake has also been suggested as the cause of fire and brimstone raining on Sodom and Gomorrah. Harris and Beardow argued an earthquake was definitely possible in this region given its geological history. A review of seismic activity along with historical, archaeological and geological data for the Dead Sea Rift over the past 4,000 years demonstrates seismic activity in the Dead Sea region. Historical accounts and measurements show the area has had some destructive earthquakes, the majority of which have occurred in the lake. A maximum magnitude earthquake is possible in the Dead Sea area given the plate tectonic structure in the vicinity, has been shown to occur in archaeological excavations, and is likely to have occurred at about the time of the destruction of Sodom based on the typical periodicity of past earthquakes in the region.

The earthquake theory might be suggested by the verb hāpāḵ “overthrow” or “to turn upside down” and the noun ḥēḵâ “upheaval.” These words seem to fit better with an earthquake than a volcano. Fritsch postulated, “The fissures in the earth destroyed the cities and released sulphurous gases (brimstone) and seepages of asphalt (bitumen) which became ignited and caused a great holocaust (Gen. 19:28).” Walton wrote, One can only speculate about the actual manner of this destruction, but perhaps the combustion of natural tars and sulfur deposits and the release of noxious gases during an earthquake are a part of the story (Deut. 29:23). The mineral salts of the region include sodium, potash, magnesium, calcium chlorides, and bromide. An earthquake in the area

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96 Charles T. Fritsch, Genesis (The Layman’s Bible Commentary; Atlanta: John Knox, 1959), 2:69.
may have easily ignited these chemicals, causing them to rain down on the victims of the
destruction.97

One potential mechanism for causing soil to be thrown into the air by an earthquake is
called soil liquefaction.98 The type of soil, alluvial and floodplain sediments, likely to have
existed at the time of the Gen. 19 event, would probably have been relatively easily liquefied in
the event of an earthquake.99 An earthquake can cause the pressure to rapidly increase in the
surrounding soil which can lead to the soil being thrown vertically upward.

Aalders suggested an earthquake opened up fissures in the soil which released high
pressure flammable gases such as natural gas and caused sulfur to be thrown in to the air.100 The
uncompacted soil in the vicinity of the Dead Sea made it even more susceptible to eruption.101
Hamilton wrote, “This disaster has often been explained as an earthquake, a phenomenon to
which the Jordan Valley with its series of rift valleys would be particularly prone. Lightning
would ignite the compressed gases and the petroleum/asphalt that escaped through the fissures in
the ground.”102 Harris believes a high magnitude (minimum of 6-7 on the Richter scale) seismic
event associated with the Eastern Border Fault caused soil liquefaction producing a tsunami in
the Dead Sea and the total destruction of Sodom and Gomorrah by a combination of earthquake,
fire, and flooding.103

One of the potential problems with the earthquake theory is that if the cause of the
catastrophe was merely an earthquake, the people in the region would have rebuilt the cities
which were in a prime location.104 Since the cities were utterly destroyed, it would seem more
than an earthquake would have been needed for that. For example, the city of San Francisco was
rebuilt after the devastating earthquake in 1906. If it is argued a massive earthquake completely
destroyed Sodom and Gomorrah, archaeological evidence would be expected to be found and the

97 Walton, Genesis, 480.

98 Committee on State of the Art and Practice in Earthquake-Induced Soil Liquefaction Assessment, State
of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences

99 Harris and Beardow, “Destruction of Sodom and Gomorrah,” 357.

100 G. Ch. Aalders, Genesis, Volume 1, translated by William Heynen (Grand Rapids, MI: Zondervan,

101 Neev and Emery, Destruction of Sodom, Gomorrah, and Jericho, 140.

102 Hamilton, Book of Genesis, 47. Others agree with this theory (Robert Davidson, Genesis 12-50

103 Harris, Destruction of Sodom, 151-2.

104 Joseph M. Holden and Norman Geisler, The Popular Handbook of Archaeology and the Bible:
Discoveries that Confirm the Reliability of Scripture (Eugene, OR: Harvest House, 2013), 218.
extent of damage would have been expected to reach farther than those cities including where both Abraham and Lot were at the time.

Another problem with the earthquake theory is there is a Hebrew word for earthquake (חדש) which is used seven times in the Old Testament.\textsuperscript{105} However that word is not used in Gen. 19:24-25. If the author intended to describe an earthquake, he should have used this word assuming it existed at the time of the writing or at least described the ground as shaking.

### Comet

A comet has been suggested as the cause of the destruction of Sodom and Gomorrah.\textsuperscript{106} The word comet comes from the Greek word kometes which means “long-haired star.” Collins and Scott suggested a particular type of comet strike which produces a massive air blast called an airburst where the comet essentially explodes above the ground just prior to impact.\textsuperscript{107} The airburst can cause devastating damage, including leveling standing objects near the strike, while leaving relatively little comet debris. Temperatures high enough to melt sand and ceramics can be generated. The airburst also creates an upward flow of air after impact that usually contains smoke and debris that could have the appearance of smoke. This type of event could have been seen and heard from a long distance away from the strike.

It is believed a comet or asteroid exploded in the atmosphere above the Tunguska River in Central Siberia in 1908 which devastated over 2,000 km\(^2\) of land area and flattened over eighty million trees. No macroscopic fragments of the cosmic body and no crater were found after numerous searches over the past century in the only known airburst in recorded history.\textsuperscript{108}

The challenge with this theory is the lack of evidence to prove or disprove it. The incident at Tunguska was fully documented including numerous eyewitness accounts although no evidence of the comet was found. This compares to the destruction of Sodom and Gomorrah where their exact locations are not even known with certainty let alone having adequate documentation to determine the precise cause of the catastrophe.

### Other

A variety of other theories have been offered for the destruction of Sodom and Gomorrah. Jonathan Edwards believed it was continual flashes of lightning\textsuperscript{109} which would have generated very high temperatures. Clarke suggested the possibility that nitrous particles

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\textsuperscript{105} 1 Kings 19:11-12; Is. 29:6; Ez. 38:19; Amos 1:1; Zech. 14:5.

\textsuperscript{106} Alexander, Myths, Symbols and Legends, 136.

\textsuperscript{107} Collins and Scott, Discovering Sodom, 224-5.


precipitated from the atmosphere and were ignited by lightning or “electric fluid.” Bentor suggested a flood destroyed the cities after the 1st century A.D. historian Strabo but this fails to match key details of the biblical account. A variation of the volcano theory is the sulfur in the ground under and around the cities erupted. A prolonged climatic transformation from a fertile and agriculturally productive region to a barren wasteland which could have been triggered by an event such as an earthquake has been suggested. While that scenario may fit historically with what happened in the region, it fails to adequately explain the biblical text which clearly describes an event that happened on a single day and does not include fire and brimstone raining on the cities.

**Supernatural**

While many natural explanations have been offered, this does not preclude natural phenomenon being supernaturally directed and initiated. Maclaren wrote, “we have to recognize a supernatural element in the starting of the train of natural causes, as well as in the timing of the catastrophe.” Exell wrote, “we have to recognize a supernatural element in the starting of the train of natural causes as well as the timing of the catastrophe.” For example, if the raining fire and brimstone was caused by an earthquake or volcano, the timing would still have been supernatural as the event happened at the time specified by Abraham’s visitors (Gen. 19:15).

This catastrophe was clearly not an accident or a coincident. Hamilton wrote, “the disaster that struck Sodom and its environs was not a freak of nature. Rather, it was sent deliberately by Yahweh himself.” He argued the phrase “from Yahweh in heaven/the heavens” implies Yahweh “hurled blocks of burning sulfur on the cities.” Lyons agreed with this analysis and argued that attempts to explain this event by natural phenomenon are misguided. Matthews wrote, “This heaven’s rain cannot be explained solely as a natural phenomenon, such

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110 Clarke, *Genesis – Exodus*, 214. It is unclear what nitrous particles or electric fluid are.


113 Ari Nissenbaum, “Sodom, Gomorrah and the Other Lost Cities of the Plain – A Climatic Perspective,” *Climatic Change* 26 (1994): 435-446. Nissenbaum considers this biblical miracle to be a myth and a compilation of multiple happenings over several centuries where the main point is the transformation of a fertile area to a wasteland.

114 Maclaren, *Genesis*, 149.


117 Ibid., 47.

as earthquake; it was exceptional, never again repeated.”

Murphy described this event as “A tremendous storm, accompanied with flashes of lightning, and torrents of rain, impregnated with sulphur, descended upon the doomed cities.”

In both Gen. 19:24 and Luke 17:29, the fire is described as raining down on Sodom and Gomorrah. Matthews called it a “deluge of fire.” This is an interesting choice of words as rain is normally associated with water, which is used to put out fires so fire raining down is an oxymoron in that sense. Cohen believed rain from above turned into fire and brimstone before it hit Sodom and Gomorrah. Either of these would be supernatural events.

**DISCUSSION**

In analyzing this narrative, the first consideration from a combustion perspective is the most likely type of fuel used to burn the cities. If a liquid fuel was used and was not well atomized in the air as it was raining down and much of it would still have been unburned before hitting the ground and if the liquid was above its autoignition temperature it could have hit the ground, broken up into smaller droplets and subsequently burned on the ground when it mixed with air. This would have been an effective means to destroy the cities as a hot liquid fuel hitting the ground could have flowed into cracks and crevices and then burned. Nothing would have been safe because it could have run inside buildings. This would be less likely for solid or gaseous fuels.

According to the biblical account, the fire came from above, not from below. Exell argued against either an earthquake or volcano which do not appear to fit the text. The fire was specifically directed at those two cities and did not, for example, fall on Lot and his family. If the fire and sulfur somehow came from below the ground in that area, it is possible an explosion or eruption near the cities could have thrown the flammable elements into the air which the wind could have directed onto the cities. However, this seems to be a less likely scenario given the need for distributed ignition sources in and around the two cities. Therefore, the theory suggesting Sodom and Gomorrah were destroyed primarily by flammables under the city without an earthquake or volcanic eruption is not likely. This does not preclude however flammables under the cities from contributing to the destruction.

Many have suggested a volcano caused the destruction of Sodom and Gomorrah. This seems to be the most likely natural explanation. Volcanic eruptions are known to throw flammable materials for long distances through the air. These eruptions could easily include sulfur since that is often a major component of the materials inside a volcano. The molten solid

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120 Murphy, *Genesis*, 323.


materials (lava) would have the characteristics of liquids while they were hot and could have run inside the cities destroying nearly everything in their paths similar to what happened at Pompeii. The main problem with this theory is proving there was an active volcano in the vicinity. Bentor makes the interesting observation that it seems unlikely Lot would have climbed a mountain to escape the destruction of Sodom and Gomorrah if there was an erupting volcano as he would have been more exposed to the fallout.124

There are significant problems with the earthquake theory. While this seems like a plausible argument, the word for earthquake was not used in Gen. 19:24 as it was in Amos.125 More importantly, while earthquakes cause the ground to shake, they do not generally cause the ground to be continuously thrown high up into the air which would have been required to give the appearance of fire coming from the sky. Those arguing for this theory believe the earthquake caused flammable materials under the cities to be brought to the surface and ignited. Again, because of the difficulties in both igniting flammable soils and getting them thrown into the air, this theory is an unlikely natural explanation. Therefore, this does not appear to be a plausible theory as the primary cause of the fire that came down to destroy the two cities. In a variation of this theory, Gunkel contends the source was a volcano caused by an earthquake.126

Lightning has been given as a possible ignition source for the start of the destruction. Lightning is common in Palestine127 so that by itself is not an unreasonable supposition. However, there are two potential problems with this theory. Lightning normally strikes objects that protrude above others, such as tall buildings and trees. Most scholars believe Sodom and Gomorrah were located in the vicinity of the Dead Sea which in general is at a relatively low elevation so they would not been particularly conducive to attracting lightning strikes. More importantly, the word for lightning was not used in the narrative.128

Bitumen and flammable petroleum gases have been suggested as possible fuels for this event due to the nature of the soils in the region. It would not likely have been bitumen by itself because of the difficulty in burning it in its native state in larger aggregated clumps. The addition of flammable gases would have made burning bitumen more likely to provide the energy necessary to burn larger pieces of solid fuel. Therefore, the natural explanation of flammable materials under the cities as the primary source of the fire and brimstone is not very likely

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126 Gunkel, Genesis, 211.


128 For example, lightning is used elsewhere in the Pentateuch (Ex. 19:16; 20:18) as well as many other places in the Old Testament such as 2 Sam. 22:15; Job 28:26, 37:3, 38:25, 35; Ps. 18:14, 77:18, 135:7, 144:6; Jer. 10:13; 51:16, Ez. 1:13, 14; Dan. 10:6; Nah. 2:4; Zech. 9:14.
although they could have supplemented the primary source. If the solid fuel was molten, such as from a volcanic eruption, then it could have flowed through the cities causing great destruction.

CONCLUSIONS

The catastrophe described in Gen. 19:24-25 is unique in history. While many cities have been destroyed by fire, none have been by fire raining on them. Howard wrote, “The destruction of Sodom and other cities (Gen. 19:24-28) was so spectacular and complete that it was frequently mentioned as a sign of God’s wrath and judgment, and God often threatened Israel and other nations with similar destruction (Dt. 29:23 [MT 22]; Isa. 1:9 [quoted in Rom. 9:29]; 13:19; Jer. 49:18; 50:40; Lam. 4:6; Am. 4:11; Zeph. 2:9; 2 Pet. 2:6).”

Very little explanation is given about exactly how this event occurred. Apparently, that was not the concern of the author. Sarna wrote of the event, “Here, and in all subsequent references to Sodom and Gomorrah, the biblical narrative focuses upon the moral significance of the events. For this reason, the description of the catastrophe is terse to the point of obscurity. This brevity, and the absence of external sources from the biblical period, renders any reliable reconstruction of the details all but impossible.”

It is impossible to say with any certainty exactly how Sodom and Gomorrah were destroyed based on what is given in Scripture. The text merely says God rained fire and brimstone on the cities. The author’s intent was not to satisfy our curiosity, but rather to show God’s wrath against an extremely sinful people. That has not stopped many from suggesting theories about how these two wicked cities were demolished. Assuming the event actually occurred, there are three broad types of explanations: miraculous and natural laws were suspended, miraculous and natural laws were not suspended, and non-miraculous with a coincidental natural event. The third type of explanation is not plausible because the event was specifically prophesied and occurred as described. The second category of explanations was shown here to be highly unlikely. The more popular theories of a volcano or an earthquake have significant problems. There is not enough evidence to support some of the other theories such as a comet or flood.

The best explanation for this event is the catastrophe was supernatural. This is consistent with other fires God sent from the heavens that have no obvious natural explanation. One of the most spectacular was the fire God sent to incinerate Elijah’s offering on Mount Carmel. It is likely the fire rained down on Sodom and Gomorrah was extraordinary because of the complete destruction of the cities. As an example, oxygen-enhanced combustion is a modern-day technology that has been used to clean up soil that has been contaminated by hydrocarbon


wastes.\textsuperscript{132} The contaminated soil is fed through an incinerator which not only destroys the contaminants, but also any other organics in the soil. If those natural organics are not added back to the soil, then nothing will grow in the soil. It is this type of total destruction that may have taken place at Sodom and Gomorrah.

The specific method God used to destroy these cities has been the subject of great speculation. Wenham mused, “The Dead Sea area still reeks of sulphurous fumes, and asphalt deposits are found, but what combination of natural or supernatural agents destroyed the towns remains speculative.”\textsuperscript{133} Ross wrote, “The expositor will probably consider some of the suggestions that have been offered for the conflagration of fire and brimstone. The text, however, simply emphasizes that, whatever means were used, it was the Lord who rained this judgment on them.”\textsuperscript{134} The destruction of Sodom and Gomorrah is one of many fire miracles in the Old Testament that demonstrate God’s sovereignty.


\textsuperscript{133} Wenham, \textit{Genesis 16 – 50}, 59.

Abstract

As increasing numbers of engineers and biologists team-up to reverse engineer living systems, they not only discover more and more about how these amazing systems work, but they also uncover nested affordance structures that speak of the mastery of a cosmic engineer. These structures are reminiscent of those found in artificial systems, except that the natural systems are more elegant, complex, and efficient. By virtue of the organism/environment interface, living systems enjoy a myriad of affordances (capabilities arising from this interface) that only exist because of numerous sequences of intricate dependencies in both space and time. As these systems have evolved, the extent and complexity of these nested affordances has increased to the point where human beings now possess both terrific and terrifying powers for both good and evil.

Drawing on the expertise of those who practice affordance-based reverse engineering of artificial systems, this approach is applied to biological systems in an effort to address questions of meaning and purpose. What was in the mind of the original engineer? And why have living systems evolved to such a perilous predicament? Concepts and techniques from the field of engineering are combined with ideas from biology and environmental psychology, such as epigenetics (how behavior affects gene expression) and niche construction to understand the intergenerational significance of these remarkable affordance structures. Conscious agents make decisions that create or destroy affordances that their offspring will either enjoy or grieve over. This modified set of affordances is then passed on to descendants. What does it all mean? Is there an overarching purpose?

This is where the field of engineering can be of assistance. Engineers create complex devices and environments to accomplish a purpose, and reverse engineers are adept at dissecting such devices in an effort to discern the underlying purpose. It has been suggested that such naturally occurring affordances constitute a compelling candidate for “first philosophy” and offer an objective window into the mind of the Maker. It is believed that this new aspect of natural theology will contribute to a deeper knowledge of God, and assist in the healing of the science and faith schism.

Introduction to Affordance-based Reverse Engineering of Natural Systems

An in-depth study of affordance-based reverse engineering techniques is being conducted in an effort to apply this method to various aspects of the cosmos. This paper represents a brief introduction to this study. It is believed that this approach will lead to a deeper understanding and recognition of God's purposes in the universe. Affordances, as first introduced in ecological psychology, are simply relationships between agents and environments that allow for potential actions to be taken. Engineering researchers have extended this idea to also include relationships between parts of complex systems that ultimately lead to such end-user affordances.

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These researchers have suggested that a focus on part-to-part and end-user affordances greatly assists in reverse engineering studies of both artificial and natural systems.\textsuperscript{2} Reverse engineering refers to the dissection, inspection and analysis of systems in an effort to understand how they work, and why they were engineered to have their particular characteristics. In other words, what was in the mind of the original engineer? This was Albert Einstein's great desire; to know what God was thinking when he made the universe the way he did.\textsuperscript{3} Examples from physics, cosmology, biology, and environmental science are being explored using this methodology. Structures of interdependent, nested (proceeding through space) and sequential (proceeding through time) affordances are being detailed and analyzed to further understanding of how they enable, and even invite certain behaviors in animals and humans.

Affordance structure matrices and other graphical forms of illustration are being developed to depict the organization, flow and implications of these systems. It has also been argued that affordances offer an objective and superior approach to first philosophy. This is because they merely indicate how an object in nature CAN be used, without assuming any a priori teleological stance (involving purpose). Even so, engineers know from reverse engineering studies of artificial systems that individual objective affordances may align in significant sets and structures that ultimately point to purpose or purposes of, not only the object of study, but also the original engineer or engineers. Measures of efficiency used in engineering are being applied to natural systems in an effort to assess the evidence.\textsuperscript{4} 

As expected, the most interesting of these examples culminates in the study of the human race, and the paramount questions of purpose that arise amidst the evidence for biological evolution. In light of redemptive environments and relationships, affordance structures should provide additional insight into potential purposes for evil, pain and suffering in the world. Among other findings, it is believed that new insights will be gained into how the affordance structures of living systems provide indications of a directed evolutionary process that ultimately serves as an invitation to pursue profound and vital knowledge of the original cosmic engineer.

In Jeffrey P. Schloss’s 2018 ASA plenary presentation titled “The Question of Purpose in the Living World\textsuperscript{5},” he suggests that biological evolution doesn’t undermine the existence of God. He points out that something can exhibit design without purpose and that something with purpose may not reveal design. He’s observed that evolutionary transitions lead to the intensification of biotic capacities. Autonomy is actually relinquished at lower levels and enhanced on higher levels. Over time, this trend results in greater diversity and the ability of an organism to maintain homeostasis or equilibrium in their environment. Schloss also adds that as autonomy increased, more cognitive resources, life qualities such as empathy and play, and interactions with the living environment increased. Schloss’s talk demonstrates that purpose in the living world came through evolutionary progression, which indicates elements of God’s design in the natural world.

In Denis Alexander’s book \textit{Is There Purpose in Biology: The Cost of Existence and the God of Love}, he challenges viewpoints that discount the universe as having no purpose or design.\textsuperscript{6} Alexander discusses everything from historical biological events to current scientific research. He uses various examples from evolutionary biology, genetics, chemistry, statistical analysis, and the laws of nature to support this concept. He points out that genomic systems
helped facilitate evolution, which in turn, converted randomness to purpose. Even the very atoms and molecules that comprise matter point to a high degree of organization. The operations so elegantly and intricately performed in the natural world are further proof that systems are not purposeless. Throughout the book, Alexander doesn’t put pressure on the reader to adopt a certain viewpoint. Instead, he examines how purpose and design are exhibited and concludes from his observations that although the cost of life is high, God’s love and purpose for creation is still made evident.

There is still much opportunity for reconciliation of science and faith, especially in places such as the Bible Belt of the USA. This project has promising potential to assist in this reconciliation because it explores how the structures of an evolving creation still provide indicators of ingenuity and purpose. The applicability of engineering principles in this manner has largely remained ignored and underdeveloped. This is unfortunate since a significant percentage of the world’s population work in engineering or technology-related fields.

Affordance-based reverse engineering efforts attempt to understand the current state of ingenious complex natural systems by elucidating the key relationships that are built into the cosmos. As such, they are relatively independent of the details of exactly how and exactly when these systems came about. These are interesting details, to be sure, but they have had a tendency to unnecessarily divide religious believers. A reverse engineering methodology largely transcends these issues. As such, this work has the great potential to bring much-needed unity on these issues. Not that everyone will agree on the details, but that a deeper understanding of the organizational structure of the universe will demonstrate harmony of science and faith.

Affordances Are Readily Interpreted

In regard to affordance-based reverse engineering, let’s consider what may or may not be communicated with affordances. When analyzing a complex device, engineers look for relationships between the various pieces that result in some new capability or potential action (affordance). When designing such a device, engineers use their knowledge, creativity and resourcefulness to exploit relationships in nature, thereby producing valuable affordances for their customers. This is why engineering students benefit by taking several science courses in college (physics, chemistry, material science, etc.). They need to know how nature works if they are to put nature to work for themselves and the rest of the human race.

Engineers do exactly this by producing a variety of products that generally make life better for people. If these products are well-engineered, they readily communicate their usefulness and desirability to the potential customer by clearly presenting the potential positive affordance or affordances to be enjoyed. In addition, consumers are able to assess the quality of these affordances by observing the craftsmanship, materials, and “attention to detail” present in the engineered product. Often, an off-brand or “knock-off” imitation will not measure up to the original product because it was not engineered to the same high-quality standards. This can easily result in lower-quality affordances. I’ve enjoyed building Lego kits with our children for years, but one Christmas I decided to save some money and try another brand of connecting building blocks. I regretted my decision because it quickly became evident that the plastic was of a lower quality, and the interference (press) fit was not as precisely engineered. As a result, the
blocks did not go together as well, or stay together as well as the original Legos. The off-brand blocks still afforded building, but the affordance was of a lesser quality.

Affordances can also be positive or negative. Smart phones provide an incredible number of positive affordances, but they can also lead to some negative situations. They have a way of capturing and holding our attention, even when our attention may be desperately needed elsewhere, as when operating heavy machinery such as an automobile. In addition, since it is more difficult to communicate emotions while texting, missed connotations and misunderstandings can more easily occur than in verbal dialogue. Hence, smart phones provide such positive affordances as communication, access to information, and photography, but also contribute to negative affordances such as distractibility and miscommunication.

There is no question that the natural world presents us with a long list of affordances that make it possible for us to enjoy life on this planet. This can be interpreted in a variety of ways. Some suggest that our life-sustaining universe is just a brute fact, about which we should not bother to be curious. Others suggest that humans are just the lucky recipients of these vital and vibrant conditions, supposing that there are many more universes (the multiverse idea) besides our own. This makes it more likely that there would be at least one universe (our own) with the right natural laws and conditions for life. Now there’s nothing inherently atheistic about the multiverse theory, but there’s something glaringly absent from both of these interpretations. And it is the recognition that in general, affordances are intentionally provided; especially when they show up in large quantities and in nested configurations. As such, an appropriate human response should be one of gratitude, appreciation, and thankful recognition to the provider, or at the very least, curiosity and exploration as to the origin of all these interconnected strings of affordances. See Figure 1 for a simple example from the field of biology.

**Sub-atomic Particles**

- Atoms
- Molecules
- Biomolecules
- Amino Acids
- Proteins, DNA, etc
- Organelles, structures, etc
- Cells
- Tissues
- Organs
- Human body
In his paper, “Affordances are Signs,” philosopher John Pickering recognizes a “primordial intentionality” behind the complex configurations of matter and energy in the universe. And this recognition arises out of an appreciation for the affordances that exist in nature. He writes, “Organism and [environment] are integrated by the exchange of meaning. Affordances are behavioral meanings; they are signs to an organism that actions are possible.” He proposes that the application of semiotics (the study of signs and symbols as elements of communicative behavior) to natural systems provides “a means for unifying science,” especially with regards to questions of origins.

In concluding his paper, Pickering quotes Jesper Hoffmeyer, who writes, “The world is full of subjects and something must have created them. But latent within that ‘something’ there must, inevitably, be ‘someone’. Subjectivity has its roots in the cosmos and, at the end of the day, the repression of this aspect of our world is not a viable proposition.” Pickering returns to his original question, “How can feeling and thought exist if there is only matter in motion?” and answers, “by recognizing that feeling and thought are primordially present in matter.” Since humans “make the effort to find meaning in their surrounding and their experience,” they tune in to the idea that affordances point beyond the methodologically restricted realm of science to the existence of a Maker.

Early in the twentieth century, broadly-thinking scientists like Lawrence Henderson were beginning to recognize the amazing interdependency of various features of the universe for life. In his 1913 book, *The Fitness of the Environment*, he concludes, “The properties of matter and the course of cosmic evolution are now seen to be intimately related to the structure of the living being and to its activities; they become, therefore, far more important in biology than has been previously suspected. For the whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the universe in its very essence as biocentric.” Henderson’s work was an early version of what has now become known as the fine-tuning problem: How is it that the universe appears to be specifically engineered to facilitate the emergence of life?

*The Fitness of the Environment* has become a classic, and was celebrated recently by the publication of a follow-on work by several famous scientists. *The Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning* looks at the delicate balance between chemistry and the prevailing conditions in the universe that permit complex chemical networks and life-supporting structures to exist. In this book, biologist Christian de Duve writes, “We live in a biofriendly world. Were it otherwise, we wouldn’t be around. The question is, therefore, how biofriendly is it? Physicists have addressed this question and have come to the conclusion that if any of the fundamental physical constants were a little smaller or a little larger than they are, the universe would be very different from what it is and unable to produce or harbor living organisms.” Concepts such as fitness and fine-tuning are related to the idea of an engineered universe, and can be reframed in terms of engineered affordances that exhibit a nested configuration in nature.
Also from *The Fitness of the Cosmos for Life*, biologist Simon Conway Morris writes, “[Microscopic] organisms appear on the whole as though they had been precisely engineered. They operate as though aware of their environment, and invariably they are able to modify it…In addition, they are capable of sophisticated computational exercises…No matter how familiar we are with these factors, we too easily take them for granted. Yet the fine-tuning of organisms is entirely extraordinary, as even a glance at a living cell and its biochemical intricacies will confirm: machine-like, but unlike any machine we can build.” The emergence of machine-like biostructures and organisms that exhibit nested affordances speaks of an engineering influence that underlies the cosmos. These discoveries carry with them the important connotations of ingenuity and purpose.

Affordances are signs of Ingenuity and Purpose

In his contribution to *The Fitness of the Cosmos for Life*, theologian John Haught writes, “What purpose means, at the very minimum, is ‘the actualizing of value’ – that is, of what appears self-evidently good…Thus a universe that appears to be in the process of bringing about such value-laden actualities as life, consciousness, freedom, creativity, and [the appreciation of ] beauty, along with beings endowed with a capacity for reasonableness, selfless love, and promise keeping, could be said to have an overarching purpose, provided, of course, that these achievements have been intended.” Notice that his list of valuable actualities are affordances; good things that are afforded by the makeup and interaction of the elements of our universe.

It should be clear that the force of this evidence from engineering does not proceed from a few specific instances (although detailed examples help to illustrate the idea), but permeate the entire fabric of the cosmos. Theologian F. R. Tennant writes, “The forcibleness of Nature’s suggestion that she is the outcome of intelligent design lies not in particular cases of adaptedness in the world…[but] consists rather in the conspiration of innumerable causes to produce, by their united and reciprocal action, and to maintain, a general order of nature.” This order of nature seems to be for the purpose of producing valuable affordances such as life.

The force of the evidence is compounded when the general quality of these ingenious affordances is considered. Ingenuity is defined as skill or cleverness in devising or combining, and this is evident in nature. An engineering design is considered to be ingenious when a few simple elements are skillfully combined to produce something that may be complex, but is still functional, elegant, efficient and beautiful. Due largely to discoveries of the twentieth century, scientists, engineers, and mathematicians generally agree that our universe exhibits this characteristic, as described in the ground-breaking work, *The Anthropic Cosmological Principle*, by physicists John Barrow and Frank Tipler.

They write, “One of the most important results of twentieth-century physics has been the gradual realization that there exist invariant properties of the natural world and its elementary components which render the gross size and structure of virtually all its constituents quite inevitable. The size of stars and planets, and even people, are neither random nor the result of any Darwinian selection process from a myriad of possibilities. These, and other gross features of the universe are the consequences of necessity; they are manifestations of the possible equilibrium states between competing forces of attraction and compulsion. The intrinsic
strengths of these controlling forces of nature are determined by a mysterious collection of pure numbers that we call the constants of nature.\textsuperscript{22} There are only a few of these constants, and the mathematical equations that govern all the various phenomena in the universe can easily fit on one side of an 8.5x11 inch sheet of paper. The impression of incredible ingenuity is striking.

In discussing the superb performance of feedback control systems within the living cell, engineer Bryant Shiller writes, “The fact that all of this works so well (and at all) speaks to the issue of ‘excellence’ of applied form and function as we perceive it. Indeed, as amateur engineers (the role each of you assumed when you began this inquiry) the fathoming of just some of the complex functioning of, what is after all, just your average (and dirt cheap) eukaryotic cell has to be a humbling experience. No less so for experienced engineers (and biologists) for whom just grasping and appreciating the feat of miniaturization that is the living cell represents a formidable challenge. Then, of course, couple all this wonder with the economies and efficiencies involved and one is left literally breathless – what human engineers can only envy.”\textsuperscript{23} Hence the positive affordances associated with life processes exhibit an amazing ingenuity. The implication is of a Maker who possesses exquisite engineering expertise.

The Invitational Nature of Affordances

Several researchers have picked up on the idea that affordances not only provide action possibilities, but can also invite behavior.\textsuperscript{24} Psychologist Rob Withagen writes, “When actively exploring the environment, the agent is attracted or repelled by some of its affordances, and the ensuing behavior is partly the result of these invitations.”\textsuperscript{25} Julian Kiverstein expands on this theme in recognizing the continuous process of maintaining positive affordances as the basis for purposeful behavior in a meaningful environment. He writes, “Affordances are in flux and unfold in the landscape through the ongoing patterns of activity of individuals responding to the invitation of relevant affordances. Through these patterns of activity affordances set up the conditions for their own continuation. Molar [or purposeful] behavior should be thought of as fundamentally anticipatory – individuals are responsive to the direction of the process which they help to sustain, and keep alive through their activities.”\textsuperscript{26} At least for human beings, this state-of-affairs is a direct result of free will and our ability to reflect on possibilities (reflexivity), but the environment also plays a critical role in presenting these invitations.

Pickering illustrates this point when he writes, “The characteristic reflexivity of human cognition means that we are not only able to perceive the world as it is, that is, to perceive the affordances that actually surround us, but also to perceive affordances that do not yet exist, that is, to perceive the world as if it were otherwise. When we take a rock and modify it with blows until it functions as a blade, we do just that. We not only perceive what is, but also what may be and hence we may take meaningful, intentional action to bring it about if we so choose.”\textsuperscript{27} This ability to use creativity, resourcefulness, knowledge and wisdom to make improvements to our environment is consistent with the Judeo-Christian understanding that we bear the image of God. We can engineer things (at least to some degree) because God is the ultimate engineer, and we are made in His image.

Think about the incredible string of nested affordances that exist in the mind-body system that allows human beings to engage in engineering activities. A variety of sense organs (eyes,
ears, nose, and skin) afford an enormous amount of valuable information about the outside world. A powerful information processor (brain) receives this information and affords the ability to form beliefs about the nature of the world. Part of the brain serves as a memory bank that, based on these beliefs, affords conscious reasoning about past, present and future events. Other parts of the brain afford our ability to have desires and purposes, which we reason to sometimes be good, but sometimes be evil. Another part of the brain serves as a processor to turn these desires and purposes into limb and other voluntary movements, which afford our ability to impact the world around us, for good or for ill.\textsuperscript{28}

Beyond this, recent discoveries in the field of epigenetics show that the decisions we make about how to live our lives not only end up affecting who we become as people, but also affect the lives and tendencies of our children and future descendants.\textsuperscript{29} Even without getting into the nitty-gritty biological details that make all this possible, it seems clear that this is an amazing set of nested affordances. Figure 2 illustrates the feedback nature of these affordances. As we believe the truth and pursue the good, we perceive that the actions we are taking tend to have a positive influence on who we become, and how we affect others and the world. This has the effect of inviting us to continue on in this positive direction.

![Figure 2. The Feedback Nature of the Mind/Body/World System](image)

At this point, philosopher of religion Richard Swinburne asks a very good question: “Why are there not just any laws of nature, but [instead we discover] laws of a particular kind such that together with the initial matter-energy at the time of the ‘Big Bang’ would lead to the evolution of human bodies?”\textsuperscript{30} He argues that such laws and initial conditions facilitating the emergence of human bodies with such a remarkable set of affordances is “very improbable \textit{a priori}, but fairly probable if there is a God who brought it about.”\textsuperscript{31} One of the most remarkable things about these affordances is that they invite us to choose; choose between good or evil, love or hate, care or neglect, activism or apathy, wisdom or foolishness, faith or unbelief.\textsuperscript{32} And the life that results is a testimony to the wisdom of those choices, and a legacy for the lives that will follow in that person’s biological wake.
As a husband and father of four adult children, and now three grandchildren, I know a little bit about love and the handing down of a legacy. Like nearly all married couples, my wife and I have had to make some hard choices over the years. Often, we have to deny our own selfish desires in order to choose love and care for each other instead of something (or someone) that may seem more gratifying or comforting at the moment. In so doing, over time we have “engineered” a healthy environment that affords love and security for the family as a whole. When we are successful at making such wise choices, it seems that our love grows deeper and more beautiful. As a result, we sense an invitation to invest in each other more fully, get to know each other even better, and enjoy each other all the more. It seems that mankind’s experience of the universe offers an interesting parallel to our family situation.

The layers of positive affordances embedded in the universe provide us with the gifts of life and love that we celebrate and enjoy. To be fair, we should also acknowledge the existence of negative affordances such as evil and suffering. But according to philosophers Benjamin Wiker and Jonathan Witt, “one can recognize the hand of genius without turning a blind eye to disease and deformity, pain and suffering.” As discussed previously, the freedom of the creation and human free will may entail a necessary amount of adversity. But as we learn more about the universe, nature has a way of drawing us deeper into her secrets.

Recall how unreasonably effective mathematics is in describing the physical world. But Wiker and Witt further observe, “if we look back over the history of science, we find that the effectiveness is layered in a kind of tutorial fashion; that is, in regard to earlier science, relatively simple mathematics was very effective in illuminating significant aspects of nature…Further penetration into the natural order has required more and more complex mathematics…if we keep finding that multiple mathematical systems ‘map onto’ nature – calling us from one steppingstone of discovery to the next – then it is certainly reasonable to suspect a conspiracy of reasoned order.” As a university professor, this situation is reminiscent of good teachers whose love for their students demands that they do their best to facilitate an optimum learning experience.

In their book, *A Meaningful World*, Wiker and Witt describe four criteria for recognizing works of genius. They are depth, clarity, harmony and elegance. They argue that nature possesses these qualities to a striking degree, and conclude, “The layer upon layer of complexity and beauty, the ingenious designs and the majestic integration all point beyond pointlessness to a meaningful world and, more than this, to the genius of nature.” Chemist Marcos Eberlin, in his book, *Foresight: How the Chemistry of Life Reveals Planning and Purpose*, extends this list of criteria for recognizing ingenious engineering by adding a fifth element: foresight. He writes, “All of those marvels depend on deeper levels of foresight. Science has revealed that Earth and the cosmos display layer upon layer of features essential to life.” Because of the way these valuable and high-quality affordances seem to be directed specifically at human beings, I argue that they are the expression of a loving Mastermind who desires to share his love with all people.
And this masterful Maker invites us into a deeper knowledge of who he is and what he does through the affordances he provides.

4 Halsmer, *Hacking the Cosmos*.
10 Pickering, “Affordances are Signs,” 72.
11 www.dictionary.com
12 Pickering, “Affordances are Signs,” 72.
14 Pickering, “Affordances are Signs,” 73.
15 Pickering, “Affordances are Signs,” 74.
27 Pickering, “Affordances are Signs,” 73.
32 According to the rock band, Rush, “If you choose not to decide, you still have made a choice,” from “Freewill,” *Permanent Waves* (1980).
A Biblical View of Sustainability in Engineering Education

Joseph Lyon*

Abstract

The grand challenges of engineering have obvious focus on sustainability of processes; the challenges emphasizing ideas such as renewable energy sources and the ability to limit the impact of carbon emissions through carbon sequestration. This paper investigates a philosophical view on the role sustainability should play in engineering education from a biblical viewpoint. In order to orient the paper into a frame of reference, the paper will start by looking at how sustainability is currently taught in the engineering classroom with challenges to implementation highlighted. From there, the paper will look at what the Bible has to say about sustainability. Finally, the paper will layout design principles in which these biblical viewpoints can be integrated into engineering education, providing biblical motivations for the prescribed pedagogy.

Introduction

A central conviction of those who follow Jesus is to know and be known by the Creator. In this relationship with the Creator, we have the opportunity to align ourselves with His redemptive mission for the world and ultimately all of creation. John writes in Revelation 21:5:

He who was seated on the throne said, “Behold, I am making all things new.”

As engineers, engineering educators, and Christians, how can we come alongside this renewal mission that God the Creator has for His good world in making all things new? A focus on sustainability within our own lives, within our influence as educators, and within our engineering practice is one way in which to emphasize this redemptive mission of the Creator, and care for all of creation, both the materialistic world and the people within it. A focus on sustainability helps in this redemptive mission by retaining and prioritizing the goodness of creation rather than human progress.

There is growing national and global focus on the role and importance of sustainability and sustainable processes. The National Academy of Engineering has listed many grand challenges that are considered of importance to the world at large, including: making solar energy economical, providing energy from fusion, and developing carbon sequestration methods (Engineering). All three of these challenges emphasize the importance of energy and sustainable processes within the world economy. This means that sustainability is a core topic that aligns with both the mission of Christians as agents of our Creator and a current compelling need in the field of engineering and engineering education.

Additionally, the Bible itself has quite a bit to say about sustainability, environmental stewardship, and caretaking of the earth. From the beginning of Genesis, to the law in Exodus, Leviticus, and Deuteronomy, to the teachings of Jesus himself, the Creator’s compassion and love for creation is evident. This care for creation can be illuminated in our work by distilling

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what the Bible has to say about sustainability into intervention design principles that can be implemented and used within the engineering classroom and within our own engineering work.

This paper will take a look at the current state of sustainability in engineering education. From there, a discussion will follow on what the Bible has to say about sustainability and environmental stewardship. Finally, this will all lead to the development of design principles to use within the engineering classroom in order to prioritize sustainability. This paper seeks to primarily answer the question: How can a biblical view of the world impact and prioritize the idea of sustainability within the engineering classroom?

**Sustainability in Engineering Education**

A definition of sustainability can be elusive as each industry sector and discipline may often have their own definitions for what sustainability means (Little). These definitions may solely look at environmental impacts or more broadly. One of the more common definitions for sustainability used is from the United Nation’s World Commission on Environment and Development report titled *Our common future*, who write that sustainability is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” ([WCED]). While this is a good definition, it should be added that sustainability means not only not compromising future generations from meeting their needs, but also others within the current generation from meeting their own needs.

Sustainability is of importance to engineering education but also broader society. There have been national and global calls for an increased focus on sustainability and environmental stewardship within education, society, and engineering broadly (Potts, Van der Meer, and Daitchman). The National Academy of Engineering has listed many of the greatest challenges for engineers in the future, or grand challenges, as related to sustainability, specifically in relation to the environment (Engineering). In response to this, there has been growing literature as to the presence and effects of sustainability within the engineer’s education. Sustainable engineering is currently a growing field and has access to large amounts of research funding through agencies such as the National Science Foundation (Murphy et al.). Yet, even with access to research funding there is quite a distance to effectively implementing sustainability into engineering education and developing engineers that prioritize sustainable processes.

There are multiple ways to integrate sustainability education into the engineering curriculum, such as having separate sustainable engineering courses (courses specifically focusing on sustainability within engineering) or integrating sustainability into already existing traditional engineering courses (Murphy et al.). Sustainability can also be incorporated as an engineering focus at the graduate level or as an area of specialization at the undergraduate level (Glavič; Kamp). Sustainability being integrated across the curriculum of multiple engineering disciplines is possible, as sustainability has been successfully infused into existing curriculum within disciplines such as mechanical engineering and civil engineering (Chau; Gershenson et al.). However, one of the biggest barriers to implementation of sustainability into engineering is the already crowded curricula (Chau). Unless prioritization of sustainability and sustainable
processes is made by individual engineering departments and programs, barriers to implementation may continue to persist throughout the engineering education field.

Sustainability has many aspects to it and is not a simple idea. This has led to many issues with understanding how to teach sustainability within higher education. There is still needed work for standards in what sustainable engineering looks like within education circles (Murphy et al.). Research has shown that there are four sustainability scales in engineering broadly: gate-to-gate, cradle-to-grave, inter-industry, and extra-industry (Murphy et al.). How these different scales are balanced and trade-offs analyzed are important to having a holistic view of sustainability within the larger national and global economy. Additionally, sustainability in engineering education can also focus on different types of sustainability. Research into sustainability has highlighted taxonomies of sustainability in education, with four main categories of sustainability: environmental, social, economic, and institutional (Segalàs, Ferrer-Balas, and Mulder). Students needing to understand these complexities at both the level of scale as well as the different ways in which a process needs to be sustainable highlights the difficult task engineering educators have in creating effective sustainability pedagogy.

Sustainability education has been used in engineering or education more broadly and has had mixed results. When implemented, many engineering students are not developing expert understandings of sustainability even when going through interventions designed to promote sustainability education (Carew and Mitchell). Students often are holding incomplete knowledge of what sustainability is or have extremely oversimplified views of sustainability (Carew and Mitchell). These oversimplified views of sustainability can either pertain to the scale at which the sustainable process impacts or to the complexity in which sustainability can be considered within a process. For example, students often do not emphasize the social aspects of sustainability as much as experts do, considering aspects such as: quality of life, health, fair use of resources, among others. Students often opt to focus on technological aspects of sustainability (Segalàs, Ferrer-Balas, and Mulder). While all types of sustainability are important, an equal consideration of all four types and understanding tradeoffs and costs are important in developing deep understandings of sustainability and sustainable processes.

**Biblical teaching on sustainability**

The bible much to say regarding sustainability and caretaking of the earth. This dialogue starts as early as Genesis 1:4-31, with God declaring that all of creation is good. Additionally, Genesis 2:15 states one of the main aims of humankind:

>The Lord God took the man and put him in the Garden of Eden to work it and take care of it.

While the context of the verse is explicitly referring to the Garden of Eden, this idea of caretaking of the land and not merely using it to exhaust it of all resources can be seen in the laws given in Exodus and Leviticus regarding the Sabbath year and resting portions of the land (Exodus 23:10-11):
For six years you shall sow your land and gather in its yield, but the seventh year you shall let it rest and lie fallow, that the poor of your people may eat; and what they leave the beasts of the field may eat.

This idea of allowing the land to rest focuses on care in our interactions with creation as opposed to brute force as an exercise of dominion over the earth. Additionally, it is worth pointing out that this passage in Exodus not only talks about sustainability in terms of the earth but also sustainability in terms of the social structures in which society is built, such as allowing the poorest of the people to eat from the field. Social sustainability is found other places in the bible, such as Deuteronomy 15:

At the end of every seven years you must cancel debts.

Rather than creating unsustainable socioeconomic conditions for people under crippling debt, Deuteronomy shows societal structures that aim to help the poorest and neediest in society. Ultimately, this positionality towards caretaking is a function of understanding that creation is not ours to do with whatever we wish. The land is ultimately the possession of the Creator from whom we have been given residency. This principle is demonstrated in Leviticus 25:23:

The land must not be sold permanently, because the land is mine and you reside in my land as foreigners and strangers.

Additionally, the writer of Psalm 89:11 describes this mindset of possession of the creation by the Creator when writing:

The heavens are yours, and yours also the earth; you founded the world and all that is in it.

With this residency humans have traditionally not done well, opting instead to seize autonomy for ourselves rather than seeing ourselves as foreigners in a creation that is not under our possession. This theme can be seen in Jeremiah 2:7 with God condemning how the Israelites treated their inherited land:

I brought you into a fertile land to eat its fruit and rich produce. But you came and defiled my land and made my inheritance detestable.

While only a single case, the Bible is full of examples of people trying to rise above their role as caretakers, the tower of Babel story (Genesis 11:1-9) being a prime example.

Additionally, creation as a whole is positioned as having a difference in status from that of humans. This difference is seen in Deuteronomy 20:19, when the fate of a city and the fate of the trees around it is described:

When you besiege a city for a long time, making war against it in order to take it, you shall not destroy its trees by wielding an axe against them. You may eat from them, but you shall not cut them down. Are the trees in the field human, that they should be besieged by you?
This highlights a fundamental stance through which to view creation and nature. Although we are to have dominion over the land, a careless attitude of destruction is unbiblical. This is again seen in Proverbs 12:10:

\[
\text{The righteous care for the needs of their animals, but the kindest acts of the wicked are cruel.}
\]

The needs of creation should be under consideration when engaging in the development of human systems. Whether considering the needs of nature or the needs of animals, human systems should not result in the intentional destruction of nature, animals, and all of creation.

Just because people have the capability of utilizing creation in certain ways for creating these human systems doesn’t mean that we should. An example of this would be the tree of knowledge of good and evil in the Genesis narrative (Genesis 2:17):

\[
\text{But of the tree of the knowledge of good and evil you shall not eat, for in the day that you eat of it you shall surely die.}
\]

God has created some structures or capabilities (such as the tree of knowledge of good and evil) that are not to be utilized by people. When looking at sustainability this means that just because we are able to progress and harvest creation in a certain way, we should always be looking through a lens of one of our original purposes, to take care of creation.

In order to understand how the Creator feels about creation, we can look to a point Jesus made regarding nature in Matthew’s gospel (Matthew 6:26):

\[
\text{Look at the birds of the air: they neither sow nor reap nor gather into barns, and yet your heavenly Father feeds them. Are you not of more value than they?}
\]

While the point being made is that people are of ultimately higher value, the point still stands that the Creator cares for His creation. The Creator cares for the birds and cares for the flowers of the field. And with that mindset, we as caretakers of this creation, should make it our aim, specifically in engineering, to align our work with this calling.

**Design principles for the engineering classroom**

This biblical viewpoint of sustainability ultimately leads to multiple design principles, three of which I will detail below. The first is that in our engineering work, sustainability should be a consideration at the start as a primary goal of any engineering or design process. The second, is to frame sustainability as more than just environmental friendliness, having sustainable social process to our work is imperative by injecting the needs of humanity back into the engineering process. And finally, sustainability can only be achieved through a lens of love and care for creation.

(1) **Start with sustainability**

Often sustainability is an added piece, being a specialization for undergraduates or a graduate degree (Glavič; Kamp). However, a focus on anything but sustainability detracts from the goodness of creation. Without sustainability of processes as a lens with which to view all engineering work, we fail to achieve our initial goal from the Creator as caretakers of creation.
Thus, when teaching engineering, sustainability should be a focus from the start of any design project or educational unit. To assume that sustainability is the primary aim of only a few who specialize in sustainability is to defer our responsibility as caretakers of the resources of the earth to others.

Much like the builders of the tower of Babel, it is easy for us as engineers to get caught up in the whirlwind and pride of human progress neglecting the effects of our efforts on the world around us in terms of resources, nature, and the creatures with which we share this planet. This neglect leads to one of the biggest hurdles to implementation, which is that the engineering curriculum is already crowded (Chau). However, a biblical focus on sustainability starts from a place that creation is not ours to do with whatever we wish, but rather, we are residents with the charge of caring for creation. When this is a starting point, it becomes a function of fitting everything around a core goal of sustainability rather than adding sustainability education into the curriculum post hoc.

Practically, on an engineering assignment or project in the classroom, this may involve setting a sustainability goal as the primary aim of projects. This could be by creating the main mission of a design project as limiting resource consumption, promoting reuse of waste products, or use of alternative energies. Rather than having students focus primarily on financial impacts or gains, the project can focus on impacts to elements external to the engineered system.

(2) Have a holistic view of sustainability
There are many aspects to sustainability beyond just that of environmental stewardship, such as social and economic sustainability (Segalàs, Ferrer-Balas, and Mulder). However, students rarely have a holistic view of sustainability after educational intervention, often focusing solely on one aspect of sustainability (Segalàs, Ferrer-Balas, and Mulder). Without a holistic view of sustainability, we risk losing an important aspect of caretaking for all of creation, such as neglecting the environment or neglecting the people within it.

Our Creator has shown us that although environmental stewardship is important, people are of immense value, as we are called to love people. A biblical view of sustainability injects humanity back into the engineering design process. The Bible has multiple instances of social sustainability including allowing the poor to eat from the fields on the Sabbath year (Exodus 23:10-11), allowing people to be forgiven of their debts (Deuteronomy 15), or allowing the poorest of the poor to not be taken advantage of by the moneylenders (Exodus 22:25). This emphasizes the role people have in human systems; leading to engineering education that aims to treat people as more than mere resources to be exhausted, but as images of God (Genesis 1:27).

In an engineering education environment, this could include discussing the impacts that a work schedule has on people during a design process or considering the dangers of a manufacturing process on the individuals tasked with running the operation. Additionally, considering fair compensation or adequate benefits when solving engineering problems would inject the humanity back into the design process. This allows students to understand the importance of people over solely the importance of profit.

(3) Sustainability must begin with and care
Sustainability is integral to many of the grand challenges of engineering (Engineering). Yet, many of these grand challenges can seem focused on self-preservation by avoiding catastrophic outcomes for humanity in exhaustion of resources or impact to the environment. Jesus points out in the gospel of Matthew:

For where your treasure is, there your heart will be also.

A focus on self-preservation makes ourselves and human progress the treasure and thus, means our heart will follow. It creates an inward focus and expects society to act quickly on energy and environmental issues that they may never see come to pass; neglecting the allure of power and opportunity today.

However, a biblical focus of sustainability turns our treasure externally to creation and the welfare of other people as opposed to ourselves, making care for creation and sustainability a function of selflessness as opposed to potential selfishness. As with most things, this becomes not a change in knowledge but rather a change of heart that will motivate a change in action. As engineering educators we must first foster a love for other people and a care for creation as prime over love for ourselves and care for human progress. Only then will we be successful in fostering an educative environment that promotes all forms of sustainability. Our love for creation stems not from our own self-interest but from the Creators care for creation and its goodness.

One practical way to do this is to discuss the motivations and intention behind our engineering work with students. When looking through our motivations we can find all of the ways that our motives impact our work. Altering the engineering narrative from motivations of technological progress to motivations of caring for people and creation around us may allow for engineering work and the incorporation of sustainability to begin with love and care.

Conclusion

Currently, many have called for increases in sustainability education within both engineering and society at large. This has led many to look at how sustainability can be incorporated in the engineering classroom. However, results of these educational interventions have sometimes produced students that have incomplete views of sustainability and sustainable processes. Additionally, sustainability has often been included as an add-on rather than as a primary aim. The bible makes a primary aim of people to be caretakers of creation. This biblical focus has major ramifications for how sustainability is taught in the engineering classroom.

As one of the primary aims of humankind is to care for the earth, engineering education should start with sustainability. From there, we should aim to teach our students to have a holistic view of sustainability by injecting humanity back into the engineering education by treating people as images of God as opposed to resources to be exhausted. Finally, a biblical focus allows us to frame sustainability from a standpoint of love and care as opposed to self-preservation to motivate our students. The Creator cares for His creation, and has made it His mission to restore His good world. By focusing on sustainability in our engineering education endeavors we have the unique opportunity to be sources of renewal and restoration towards creation.
Acknowledgements

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References

An Agile Classroom: An Experiment in Interdisciplinary Curriculum Development to Better Prepare College Undergraduate Students for the Modern Cross-Functional Work Environment

Kyle Agee*, Todd Goehner*, Sam Heinrich*, and Ted Song*

Abstract
For higher education to better prepare graduates for the changing modern work environment, it must begin exploring methods to escape the discipline silos that perpetuate the deficiencies often associated with recent college graduates. Also, with a Christ-centered mission, Christian institutions are committed to equipping students to show Christ’s characters as they go out and serve God in a variety of vocations. In the Spring 2018 and 2019 semesters, three courses from different disciplines at John Brown University collaborated to provide undergraduate students with a new classroom experience. This experiment sought (1) to prepare students with an analog for the modern workforce and (2) to provide an opportunity for them to assess how their biblical faith and worldview impact their relationship with others in a setting where people must work with others who have different backgrounds and cultures.

Introduction
In 2014, a faculty member observed an engineering student in an attempt to collaborate with a visual art student. The interaction was painful to watch as it became increasingly obvious that neither student was adequately prepared to collaborate effectively. Neither student would qualify as unintelligent, and both students were making a sincere attempt to work together and understand one another. However, they did not know how to communicate with each other.

In 2015, Hart Research Associates conducted a study for the Association of American Colleges and Universities (AACU) in which recent college graduates and their employers were asked to assess workplace readiness [1]. The four hundred employers surveyed revealed that college graduates lack in seventeen essential workplace skills.

Additionally, as Christians, we are called to glorify God wherever we are and whatever we do (1 Cor. 10:31). Often at work, opportunities to glorify God occur in interactions with colleagues, thus, it is critical that Christian institutions intentionally foster an environment where students of various backgrounds work together and practice showing Christ’s love and humility.

Therefore, this experiment has sought to answer the following question: How might college departments collaborate to develop a curriculum that increases students’ cross-functional capacities and equips them for showing Christ’s characters in the workplace?

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Context and Relevance

The modern work environment is and has been shifting in operational theory. Tim Hird, the executive director of the accounting and finance staffing firm Robert Half Management Resources describes this shift:

Before, these (specific business or organization) functions were run as silos. But business has become more complex... a few years ago it wasn’t necessary to work together – now it’s essential. [2]

These shifts have caused organizations to seek out new management techniques and mechanisms to adapt to this shift for some time. A study conducted by Deloitte Global Human Capital Trends in 2017 suggests in light of this shift “for the last five years, companies have been experimenting with new performance management approaches” [3]. One of these performance management approaches is cross-functional teams. Cross-functional teams can be described as teams of individuals representing different disciplines and departments within an organization who are tasked with solving complex problems that span multiple departments and considerations. These teams have many benefits, including “improved coordination, integration, and communication across functional boundaries” [4]. They serve as an important part of effective project management as multiple departments or disciplines may be involved simultaneously, reducing the back-and-forth nature often experienced in linear organizational structures. Cross, Rebele, and Grant explain in their article Collaboration Overload that:

As business becomes increasingly global and cross-functional, silos are breaking down, connectivity is increasing, and teamwork is seen as a key to organizational success. According to data we have collected over the past two decades, the time spent by managers and employees in collaborative activities has ballooned by 50% or more. [5]

Considering the wide adoption of cross-functional teams, the perpetuation of the siloed model of education presents a significant departure from the skillsets necessary and expected of today’s college graduates. When considering the connection between potential failure points in cross-functional teams and the findings of the AACU study, the authors contend that not only does higher education continue to not adequately their students, they may be contributing to such project failures.

While the importance of having a capability to work in cross-functional teams continues to be emphasized in the secular world, this is not a new topic to Christian educators. Christian education is not just to provide information or professional skill sets to students, but it is to educate the whole person so that people who receive this education could integrate their faith in a variety of situations and places. For example, Vander Werff, Sikkema, and Brue from Dordt University made the following comment:

Equipping students with specialized knowledge is the tendency of many engineering programs. While this knowledge is important, it is critical that a curriculum does not become too narrowly focused or isolated. Such reductionism fails to appreciate the cross-disciplinary nature of contemporary engineering problems and hides the fact that no problem can be solved by engineering alone. The proposed solution must meet standards in areas such as cultural appropriateness, stewardship, and justice to those impacted. Furthermore, a broad curriculum will
also cultivate a healthy respect and awareness of other disciplines, a respect that will be highly valued when addressing needs in this fallen world. [6]

As shown, a broad curriculum that would equip students not only in their major but in other areas could be one of the distinctions of Christian higher education.

Even though collaboration between multiple departments for the whole person education is emphasized in Christian institutions, John Brown University could not avoid the common tendency for college or university disciplines to operate apart from other disciplines. For example, in the first planning meeting for this initiative, of the four faculty members taking part in this experiment, only one faculty member knew all of the remaining participants. This is significant as John Brown University has approximately 1,400 traditional undergraduate students and approximately 90 full-time faculty members. Additionally, all faculty attend monthly faculty meetings and annual faculty workshops that provide opportunities to meet faculty outside of their respective disciplines.

In order for higher education to better prepare graduates for the changing modern work environment, it must begin exploring methods to escape the discipline silos that perpetuate the deficiencies associated with recent college graduates. The original survey conducted for the AACU surveyed employers from all industries, not specifically one discipline. Considering the substantial gap between the student’s and employer’s perspective, a likely conclusion is that the discipline does not matter at all. Even the best-prepared students, the ones most likely to succeed in their particular field, are likely to fail equally in another. For these students to be better prepared for the cross-functional workplace environment that exists currently, they must not only master a single discipline but also learn from other discipline’s strength(s). In their article for the American Journal of Business Education, Scott, Derrick, and Hoadley made the following conclusion:

The issue is the lack of understanding of the interrelationships among the separate fields of business on which most majors are based. The ability to combine disparate information to draw insight is an important skill, especially for CEOs. [7]

Scott, Derrick, and Hoadley identified a major problem with the siloed model of education in that it assumes that the silo is self-sufficient instead of recognizing the deficiencies inherent to the discipline with the intention of eradication or at least individual student growth. When discussing the findings in the AACU study around the campus of John Brown University, neither faculty nor administration was surprised by the study’s findings. This awareness indicates a widespread understanding of a deficiency found in higher education, one that merited further investigation.

**Project Design**

A primary concern for the authors was the heavy modification of existing courses. Instead of re-writing course curriculums to fit the experiment, the authors hoped to provide a mechanism in which existing classes could collaborate with minimal modification to course objectives. Additionally, the authors wanted to be very careful not to interject or set the final goal for the collaboration.
From the initial research, the Engineering Design Lab course seemed to be a prime candidate to facilitate this project. This class had previously established requirements that reached outside of their disciplines such as a branding package, user manual, marketing plan, and business plan. These requirements made identifying subsequent departments for collaboration very straightforward.

Once the requirements of the engineering course were understood, the project coordinator studied the university course catalog to find courses that pertained to these objectives. The branding packages and marketing plans could be addressed in Graphic Design III. Additionally, this course serves as an introduction to design thinking, which has direct application potential for the engineering class. The business and marketing plans could fit into several different classes in the business department. The final course involved studies the necessary steps to developing the organizational structure and financial analysis for startups.

These courses are the mechanisms by which this study would be conducted; they do not constitute the entirety of the study, however. This project required not only classes that could be linked or merged, but also faculty that value the potential benefit for the students. Therefore, final parameters would be set by the faculty, that allowed each faculty member to give perspective and understanding of the proclivities of their students.

Additionally, to maximize the diversity in each group, faculty intentionally chose members of each team. Gender, ethnicity, nationality, and personal background were carefully reviewed before assigning students in teams, and faculty attempted to put close friends in different groups so that each student would work with relatively a new group of people. This team assignment was one of the critical efforts to allow students to get to know people in a professional setting and practice showing Christ’s love in the workplace.

The authors’ choice to not set the final parameters of the project was in response to knowing that the project would need to change benefitting from the faculty perspectives. Furthermore, it would change in ways that would not be imaginable for four individuals.

**Project Goals**

The mechanism of the experiment would be the three classes working collectively to produce a functional prototype of a saleable item meeting a real market need. Through this mechanism, both faculty and students would be working toward a series of goals that are as follows.

1. **Goals for Students**

The study conducted for the AACU indicates two overarching problems for students transitioning from higher education to the workplace. First, students are categorically unaware of their deficiencies. Second, students are drastically under-prepared in key performance areas. The student goals for the research phase will seek to:

   a. Increase student capabilities in eight deficient skills as identified in the AACU study.
   
   b. Increase student’s awareness of their actual level of capability.
This study makes no predictions and sets no threshold about the qualifications for what constitutes student success. Any increase in these areas constitutes success as it better prepares students for the workplace. Additionally, because of the status of the involved students, growth at this point in their education will likely benefit them in subsequent years of education. The eight key performance areas were chosen from the AACU study because of their relevance to the project as well as their alignment with pre-established course objectives. They are as follows:

1. Working in teams
2. Locating, organizing, and evaluating information
3. Oral communication
4. Written communication
5. Apply knowledge, skills, education to real-world project
6. Intercultural awareness
7. Critical thinking
8. Innovative and creative thinking

2. Goals for Faculty

In a summary of his research, Behnam Tabrizi explains, “…the reason why most cross-functional teams fail is that silos tend to perpetuate themselves: for example, engineers do not work well with designers, and so on” [8]. Considering the faculty in this experiment also constitute a cross-functional team, their ability to align course objectives and personal visions is a hurdle that must be navigated. While each faculty member has expressed and demonstrated their willingness to be flexible in this process, each brings their understanding and expectations of what the collaborative process should look like. Because all associated faculty are not only educators but are also previous industry professionals, they view collaboration through the lens of their experiences. Therefore, the faculty goals for the research phase are:

a. Successfully align course objectives across disciplines.

b. Begin the process of understanding the potential of true collaborative design.

c. Develop a framework that allows for future collaboration to perpetuate and expand.

d. Foster an environment where students can practice their integration of faith and work.

Project Execution

This project’s success would hang on the ability of the associated faculty to align course objectives. Therefore, the logical starting place was to conduct a series of meetings in which those faculty members explained the role of their course in the department’s curriculum, outlined the key deliverables, and discussed each course’s schedule. These meetings took place starting in the latter half of the Fall semester.

After the initial onboarding meetings, students enrolled in the three classes were then placed into four teams by the project coordinator. The students were introduced to their teams before the fall semester completed. During that meeting, the scope and goal of the project were explained to the students, and the faculty were allowed to introduce themselves and explain why this project is important to their discipline. Students were then broken into teams and asked to identify a team leader from the group. The students were then instructed to exchange contact information and given the mandate to think about real market needs over Christmas break and communicate them with their teams.
Before the commencement of the Spring semester, the faculty and coordinator met to finalize the milestone map for the semester. This document outlined the deliverables outlined in previous years syllabi and offered a firm foundation for aligning the course requirements. While this document was necessary, it represented something that would become far more important to the overall process. This document was one of the first indications that the faculty members had begun taking over the direction of the project rather than waiting for the coordinator to direct the next steps.

The faculty also discussed the deliverables, the natural breakpoints, the time necessary to complete each deliverable and the order they should occur in. This conversation eventually led to the development of the final milestone document and ultimately, the structure of the project. The students would have four presentations, one for each month of the spring semester.

Given the numerous deficiencies listed in the AACU study, the student teams would likely require oversight, intervention, and guidance. Each team chose their respective team leaders, and each team leader was made aware of the expectations for their roles in the project. One role would be a weekly meeting on Wednesday afternoons with the project coordinator. These meetings would not have a set agenda, but instead, serve as an opportunity to discuss the problems occurring throughout the experiment. In the first few weeks of the team leader meetings, a great portion of conversations centered around the practical approaches to managing a large group. These conversations included advice on conflict management, scheduling tools, document sharing platforms, and group task management.

As expected, throughout the semester, most teams had some conflict in making decisions or simply working together. Many times, conflicts arose when students of a certain discipline did not take into account the other disciplines’ needs or challenges, or when they saw their work more valuable than the work of the others. These moments were some of the highlights of the course since students could recognize the challenge of integrating their biblical worldview and their thoughts and actions in a professional setting. When conflicts arose, faculty carefully monitored each group’s situation and attempted to guide them through encouragement, rather than giving a direct recommendation.

Additionally, through the course of the semester, students were asked to attend one evening event per month. This meeting took the place of a regularly scheduled meeting time during that week. Each meeting had a preselected set of milestones, and all students shared the responsibility for some milestones. The responsibility for other milestones that required more specific skillsets fell to the appropriate discipline’s students. The instruction necessary to complete the discipline-specific milestones would be addressed in the intermediate class times between presentations. Students were expected to meet outside of class to prepare for these meetings as part of their homework load.

These meetings served as opportunities for the faculty to address all students at one time, rather than relying on disseminating information through the students to their respective teams. Three of the four meetings had a presentation component as well to allow the students to develop their oral and visual presentation skills. Additionally, each meeting had an agenda item such as choosing a final project idea, how to craft a problems statement, and so on.
The last of the meetings served as a final presentation where the functional prototype, the market need and marketing materials, and the financial validations would be presented to a panel of faculty, and industry representatives. Each student group was given 15 minutes to present and 5 minutes for questions and answers.

**Results**

Assessment data was gathered by several different methods from both faculty and students. Various methodologies were used to address the different outcomes for each group in an attempt to gather the most specific data possible.

1. **Students Goals**

The assessment of student goals was completed through two main mechanisms.

1. Student interviews and final survey questions would provide information on student growth in capability in individual areas.
2. Survey questions would be used to assess any changes in a student’s perception of their abilities. Students were asked to compare their level of ability at the beginning of the semester with their level at the end of the project.

The student learning goals were:

a. Increase student capabilities in eight deficient skills as identified in the AACU study.

The students reported the following results when asked whether their abilities had improved throughout the semester:

![Bar chart showing student improvement in working with others and locating and evaluating information.](chart.png)
3. Have your oral communication skills significantly improved?

4. Have your written communication skills significantly improved?

5. Has your ability to apply skills in real-world situations significantly improved?

6. Has your intercultural awareness significantly improved?
Overall, the involved students identified growth in all eight areas in the survey data. Furthermore, the student interviews indicated a largely positive experience with most interviewed students indicating recognizable growth in each of these areas.

b. Increase student’s awareness of their actual level of capability.
The students were surveyed at the beginning of the project and at the end and asked to assess their actual level of ability at the beginning compared to the end.
10. How would you rate your ability to gather and evaluate information?

![Bar chart showing the percentage of students that answered the question.](chart10)

11. How would you rate your oral communication skills?

![Bar chart showing the percentage of students that answered the question.](chart11)

12. How would you rate your written communication?

![Bar chart showing the percentage of students that answered the question.](chart12)

**Scaled answer from questionnaire**
- **Pre**
- **Post**
13. How would you rate your ability to apply your education in real world projects?

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14. How would you rate your cultural awareness?

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15. How proficient were you at critical or analytical thinking?

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Overall, the students were able to identify the inaccurate assessment of their abilities at the beginning of the semester when compared to the end.

2. Faculty Goals
The goals for the faculty were:

a. Successfully align course objectives across disciplines.
All faculty indicated success in aligning existent course objectives. Furthermore, several faculty indicated that while the workload and expectations for students increased, that increase produced “the superior outcomes that are possible from eclectic teams.” All faculty acknowledged the potential for further organization and alignment but described the process a success.

b. Begin the process of understanding the potential of true collaborative design.
All faculty reported recognizing the benefits of collaborative course design. Furthermore, the faculty reported that by working with other disciplines, assumptions could be removed. For example, the finance professor explained that in the past, many students made wide assumptions of product feasibility in order to make financial data work. This process forced them to operate in the real world.

c. Develop a framework that allows for future collaboration to perpetuate and expand.
All faculty reported success in developing a framework for future collaboration. As one faculty member explained, “There was much working out of the processes and structure that which will not have to be repeated in the future.” Each faculty member expressed a desire to continue collaborating in the future, and conversations have already taken place to identify opportunities for smoother collaboration in the future. One faculty member explained, “these processes can be messy and need guiding structure. The adults all need to be on the same page in terms of desired outcomes.”

d. Foster an environment where students can practice their integration of faith and work.
All faculty agreed that this collaboration course not only allowed students to integrate their faith and work but also gave faculty a greater chance to incorporate their faith in their teaching. The design of the course allowed faculty to invest more in mentorship and coaching, and, as a result, both faculty and students had

![Bar chart showing percentage of students who answered questions about their innovation and creativity.](chart.png)
more time to process what it means to be a Christian at a workplace. Additionally, like students, for faculty of multiple disciplines to work together, we all needed humility and empathy in our discussions, which was a great reminder that this is something that we want to share with students.

Conclusion

Three departments at John Brown University collaborated to create a design course that would include teams made up of engineering, graphic design, and business students. The goal was to prepare students to perform well in cross-functional teams that the modern work environment needs and to equip them to integrate their biblical world view and faith at work. Blending three courses in order to provide a setting that is similar to the current work environment allowed students to fail, adjust, and learn how it can be challenging to work with others who might have a different background. Additionally, this collaborative course allowed students to reflect on ways of integrating faith and showing Christlike characters in the workplace. While the course still has much room to improve upon, based on students’ survey, authors strongly suggest that the students who participated in this new course are better prepared to perform in cross-functional teams and to integrate their faith and work.

References

Perspectives and Possibilities for Online Engineering Education
at Christian Institutions

Norman Reese* and David Dittenber*

Abstract
Digital technologies are rapidly disrupting areas of entertainment, commerce, and transportation, among others. Perhaps the biggest change occurring in the field of education is the growth of computer based and online education. However, engineering education, with complex math concepts and the need for laboratory experiences has adopted these technologies more slowly. Among Christian engineering faculty, there is the additional question of how students can be assisted spiritually over an internet line.

Meanwhile the benefits of online learning are promising. In a time of great questioning on the value of a college education, online education offers the potential for cost reductions, broader access, and greater flexibility for a larger variety of students. Furthermore, the possibilities of individualized focus and pacing may offer improved learning outcomes over traditional classroom settings. It could be argued as well that with the trend toward globalization, students need to be prepared for more online teamwork and training.

While much has been published on the benefits and disadvantages of online education, this paper and accompanying survey describe how engineering faculty in America’s Christian colleges view online engineering education. A survey was done of 335 faculty of 30 universities and colleges that offer engineering degrees and openly claim a position of Christian faith, with approximately 52% of faculty responding.

Results of the survey show that faculty believe the main advantages of online engineering education are improved accessibility and lower costs for students. They largely agree the biggest disadvantage is the difficulty of providing “hands-on” experiences and labs. 72% of respondents haven’t taught an online course, and 37% are not interested in teaching an online course. Regarding outlook, 59% mildly or strongly believe online engineering programs will expand, and 90% believe there is economic opportunity in developing more online engineering options. 86% of respondents agree that there is opportunity to collaborate with other Christian colleges on co-developing online engineering options. A multitude of concerns with online education were cited, such as student engagement and motivation, learning outcomes, cheating, spiritual formation, character development, increased teaching load, quality assurance, how to teach teamwork, teaching “hands-on” and troubleshooting, personal relationship and mentoring of students, financial arrangements.

Finally, phone interviews or additional surveys were conducted with leaders of the larger Christian engineering programs to ascertain interest in more online education and collaboration. The views ranged from low interest in online engineering education at Cedarville and Calvin, to high interest at California Baptist and Baylor, with development of entire online engineering degrees in progress at Liberty University.

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Background
While many educators may have mixed feelings about the appropriate place for online learning amidst the historic structure of higher education, the consistent student demand for access to the online medium ensures that it will continue to develop as a central part of the educational process. While some might point to the economic decline of several notable for-profit institutions that specialized in online delivery as an indicator of declining interest, the reality is that accessibility to higher quality courses from a greater variety of sources has been primarily responsible for their troubles, rather than a cultural trend away from online education. According to the Babson Survey Research Group\(^1\), which has been monitoring trends in online education for over 16 years, overall enrollment in U.S. institutions of higher education decreased by 3.8% from 2012 to 2016, but the number of students taking distance courses for some or all of their education increased by 17.2% over the same time period. This growth is due to successes at public and private non-profit institutions, experiencing 22% and 50% growth respectively in distance learning enrollment, while private for-profit institutions experienced a 22% loss in their distance learning enrollment\(^1\). As of fall 2016, there were over 6 million students taking at least one distance education course in the U.S., which is around 31.6% of overall higher education enrollment\(^1\). Approximately half of those students take all their courses online, while the other half take a combination of online and traditional courses\(^1\). For comparison, only 25.9% of higher education students were taking at least one distance education course in 2012\(^1\). The reasons for this increase are various, but most are related to economic and practical considerations.

In addition to students’ increasing interest in taking online courses at public or private non-profit institutions, it is also an interesting trend to see that despite not needing to be physically present on campus, many students prefer to take their online courses at an institution located within their same state. Over 61% of undergraduate students taking exclusively online courses choose to take them at an institution within their own state\(^1\). While some in-state tuition requirements might be partly responsible for this localized approach, it would also appear that online learners place some significant value in the familiarity and culture of their institution, rather than simply searching for opportunities to get the easiest access to courses for the lowest dollar, as some might assume. Additionally, the international market for online education at U.S. Institutions has been slow to develop, with only 0.7% of distance learning students taking courses while living outside of the U.S.; despite attracting over a million international students overall, it is clear that online programs at U.S. institutions are not of interest internationally (<50,000 students)\(^1\). Therefore, while online courses may offer the opportunity to attract students from a broader population, the greatest market for online enrollment at U.S. institutions is essentially the same geographic market as for traditional enrollment.

One interesting trend in online education is that engineering, which might seem to be naturally suited to being adapted to the latest and greatest technology of the day, tends to be under-represented. This has been the case since at least 2007, when engineering was found to offer far fewer online educational options among major disciplines, including psychology, social sciences/history, computer/information sciences, education, health, liberal arts and sciences, and business\(^2\). Despite this relative inaccessibility, students are still highly interested in studying engineering through online delivery; nearly 1/4 of engineering students take some online courses\(^3\). While the opportunity to take at least some online engineering courses has grown considerably, the overall state of online engineering education can be best understood by looking
at program accreditation. America’s main engineering accrediting board, ABET, has accredited over 4000 programs across its various commissions. However, they have accredited only two fully-online bachelor’s engineering programs. Part of the explanation for this small number of programs is related to an ambiguous definition of what constitutes an “online program;” many that claim that title require students to complete extensive prerequisites at on-ground institutions before enrolling and some require students to commit several weeks a year to intensive learning on-campus. A few others offer an online version of a degree that shares its accreditation status with an on-campus program, which ABET does not differentiate. A non-exhaustive summary of the currently offered, fully-online engineering degrees available in the U.S. is summarized in Table 1 below (based on a review of the institutions’ own websites).

Table 1 – A Review of “Fully Online” Engineering Degrees at U.S. Institutions

<table>
<thead>
<tr>
<th>Institution</th>
<th>Degrees</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona State University</td>
<td>Electrical Engineering</td>
<td>Accredited as online program by ABET</td>
</tr>
<tr>
<td>Stony Brook University</td>
<td>Electrical Engineering</td>
<td>Accredited as online program by ABET</td>
</tr>
<tr>
<td>Florida International University</td>
<td>Electrical Engineering</td>
<td>Accreditation shared with on-campus</td>
</tr>
<tr>
<td></td>
<td>Computer Engineering</td>
<td>programs</td>
</tr>
<tr>
<td>University of North Dakota</td>
<td>Electrical Engineering</td>
<td>Accreditation shared with on-campus</td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td>program</td>
</tr>
<tr>
<td>Clemson University</td>
<td>Electrical Engineering</td>
<td>Not fully online; heavy pre-req requirement</td>
</tr>
<tr>
<td>Lamar University</td>
<td>Industrial Engineering</td>
<td>Not fully online; 2+2</td>
</tr>
<tr>
<td>Morgan State University</td>
<td>Electrical Engineering</td>
<td>Not fully online; 2+2</td>
</tr>
</tbody>
</table>

One possible reason for slow online adoption in engineering programs is the need to provide students with lab experiences and practical learning. A well-developed online engineering course must provide these same sorts of experiences to students, which often requires an extra measure of creativity and effort. Some common approaches to providing students with lab experiences in an online engineering course include:

- a requirement for students to perform lab exercises at another institution or to spend a short period on campus for a condensed lab experience
- the use of simulations or remote labs
- providing students with kits they can use to do experimental work at home

There are pros and cons associated with each of the above approaches, and realistically each engineering course has its own demands that may make it better suited to one approach over another. It is also the authors’ experiences that developing online courses with appropriate learning activities is a laborious and time-consuming process. What is abundantly clear, however, is that improvements to technology have created new channels for communication and learning, offering opportunities for students to approach online engineering education in ways
that have not been available in the past. Video conferencing allows group or one-on-one conversations, as well as a mode for off-campus students to participate in classroom or lab discussions and “virtual” office hours. Additionally, these interactions can be recorded for later review or participation by absent students. Online discussion boards and simultaneous group editing of online documents allow teams to debate and collaborate effectively. Online journaling and reflections provide an opportunity for faculty to discuss personal matters and do mentoring on an individualized basis. With creative effort, it’s conceivable that student engagement and learning outcomes could be even higher than live lecture delivery methods.

A Current Model of Collaboration
Online flexibility also allows a new level of course collaboration between schools which may prove to be revolutionary. Thanks to online delivery, programs of similar philosophy can work together to build content and share courses with each other. The Council for Christian Colleges and Universities recently developed such a systematic arrangement by teaming up with the organization College Consortium®. The authors interviewed leaders at College Consortium to understand this model of collaboration. College Consortium arranges agreements between colleges that have spare seats in an online class and “home” colleges that have students needing that particular course. Since the course at the “teaching” institution presumably has their costs met with existing students, they can “sell” available seats at discounted costs ($300 to $1000). The home college of the student can either pay the fee as part of the student’s tuition block or charge the student extra for the special course. College Consortium provides some initial student support and gets a cut of the course price. The class would be accessed through the home school’s learning management system and would result in a grade on the student’s transcript.

This kind of arrangement offers significant benefits. The additional course availability could really help students that need a class out of sequence, or to cover a pre-requisite, or take developmental courses for college entrance. Student athletes could have an additional option to maintain full time status and grade point requirements. Universities could benefit from this option when having faculty shortages, filling under-enrolled courses, growing new programs, or offering special electives. Meanwhile, schools can actually earn revenue from a partnered online class, rather than sending students to other institutions for transfer credit.

Interestingly, the College Consortium has no engineering courses available currently. There are some engineering management type courses available from a larger related consortium called “the Council of Independent Colleges” (CIC). This dearth of online engineering courses raises questions. Why are few students taking online engineering courses? Why are few online engineering courses being offered? Are the hesitations related to educational quality, job security, or financial sustainability? For faith-based institutions, are the main hurdles related to spiritual influence or adjusting to the changing world of higher-ed? Can they benefit from working together or will it be better to maintain separation and protect market distinctives in the competition for students?

This paper is intended to address some of these questions from the faculty member’s perspective. More specifically, what do professors see as the challenges and benefits of online engineering education and is there interest to collaborate in this area?
The Survey
To get faculty perspectives, a survey tool was developed and administered online via Limesurvey. The Institutional Review Board at LeTourneau University approved the faculty survey and the Dean interview questions. Lists of Christian engineering programs and faculty were developed from online searches, personal contacts, and conference attendee lists. The list of schools and engineering faculty are shown in Table 2, with the number responding from each school. Total numbers of faculty surveyed may not match actual number of faculty at the school due to inability to obtain contact information.

Table 2. Schools surveyed and respondents

<table>
<thead>
<tr>
<th>School</th>
<th>Faculty</th>
<th>School</th>
<th>Faculty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abilene</td>
<td>8</td>
<td>LeTourneau</td>
<td>30</td>
</tr>
<tr>
<td>Anderson</td>
<td>6</td>
<td>Liberty</td>
<td>15</td>
</tr>
<tr>
<td>Andrews</td>
<td>4</td>
<td>Lipscomb</td>
<td>12*</td>
</tr>
<tr>
<td>Baylor</td>
<td>38</td>
<td>Messiah</td>
<td>11</td>
</tr>
<tr>
<td>Bob Jones</td>
<td>5</td>
<td>Northwest St.Paul</td>
<td>4</td>
</tr>
<tr>
<td>Cal Baptist</td>
<td>39</td>
<td>Northwest Nazarene</td>
<td>5</td>
</tr>
<tr>
<td>Calvin</td>
<td>17</td>
<td>Oklahoma Christian</td>
<td>12</td>
</tr>
<tr>
<td>Cedarville</td>
<td>22</td>
<td>Olivet Nazarene</td>
<td>9</td>
</tr>
<tr>
<td>College of Ozarks</td>
<td>2*</td>
<td>Oral Roberts</td>
<td>7</td>
</tr>
<tr>
<td>Dordt</td>
<td>11</td>
<td>Pensacola</td>
<td>5</td>
</tr>
<tr>
<td>Geneva</td>
<td>9</td>
<td>Seattle Pac</td>
<td>7</td>
</tr>
<tr>
<td>George Fox</td>
<td>12</td>
<td>Taylor</td>
<td>5</td>
</tr>
<tr>
<td>Grove City</td>
<td>13</td>
<td>Union</td>
<td>4</td>
</tr>
<tr>
<td>Houston Baptist</td>
<td>2</td>
<td>Walla Walla</td>
<td>10</td>
</tr>
<tr>
<td>John Brown</td>
<td>7</td>
<td>Whitworth</td>
<td>4</td>
</tr>
</tbody>
</table>

* Could not obtain contact for all faculty

The survey asked faculty to select potential advantages and disadvantages of online engineering education (see Appendix A for full survey). It then asked what involvement they have had with teaching and developing online courses and what interest they have in doing so in the future. They are then asked to rate their belief about various outlook statements, provide open comments, and select current modes that have been effective for spiritual formation. The survey ended with demographic information on school, field of teaching, length of teaching and typical teaching load.

After this survey of individual teaching faculty, a phone interview was attempted with leaders of the larger Christian engineering programs. Some preferred answering the questions via email, while others did not respond after several requests. Interview questions addressed the online
engineering courses currently offered by these institutions and what their plans and interests are for the future (see Appendix B for the Dean’s interview form). Results of both surveys follow.

Results of Faculty Survey
Response rates are shown for each question, with a brief discussion following.

1. Pick two statements that you believe are the greatest advantages of online engineering education:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved learning outcomes for students</td>
<td>3%</td>
</tr>
<tr>
<td>Improved accessibility for students</td>
<td>91%</td>
</tr>
<tr>
<td>Improved spiritual impact on students</td>
<td>0%</td>
</tr>
<tr>
<td>Lower cost for students</td>
<td>77%</td>
</tr>
<tr>
<td>Improved work efficiency for instructors</td>
<td>19%</td>
</tr>
<tr>
<td>Other</td>
<td>10%</td>
</tr>
</tbody>
</table>

Clearly two advantages faculty most agree with are improved accessibility and lower cost for students. Comments provided in the “Other” category included flexibility of scheduling and lower costs for those who can’t afford full time education. They also noted that some students prefer online, and online provides the possibility of reaching students that don’t attend Christian institutions.

2. Pick two statements that you believe are the greatest disadvantages of online engineering education:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>More difficult to communicate principles of engineering online</td>
<td>22%</td>
</tr>
<tr>
<td>More difficult to give students “hands-on” experiences and labs online</td>
<td>79%</td>
</tr>
<tr>
<td>More difficult to adjust teaching to student response</td>
<td>27%</td>
</tr>
<tr>
<td>More difficult to impact students spiritually online</td>
<td>36%</td>
</tr>
<tr>
<td>More difficult for students to manage their time without face to face accountability</td>
<td>23%</td>
</tr>
<tr>
<td>More difficult to advise students academically online</td>
<td>5%</td>
</tr>
<tr>
<td>Other</td>
<td>8%</td>
</tr>
</tbody>
</table>

While the outstanding disadvantage faculty note is the difficulty of providing “hands-on” experiences, all the other issues are of significant concern except academic advising. Comments in the “Other” category included concerns about cheating, reliance on student self-discipline,
lack of student-faculty interaction and relationship, difficulty of modeling responsibility and engaging the whole person. Additionally, some are concerned with difficulties with providing problem-solving teamwork and ensuring online courses support other courses in the program.

3. What is your level of involvement with teaching online courses (engineering or otherwise)? Check any that apply:

Adding the first two categories reveals that 71% have never taught an online course. Summing the last four options indicates that 22% have taught at least one online course.

4. To what level have you been involved in developing online courses (engineering or otherwise)? Check any that apply:

Adding the first two categories reveals that 65% have not been involved in developing an online course.
The conclusion is clear on this question – 2/3 of faculty surveyed have not been involved in developing an online class. Comments mentioned in “Other” include some faculty incorporating video elements for classroom “flipping”. Also several have taken online classes on how to teach online, but haven’t done it yet.

5. What interest do you have in teaching engineering courses online? (check any that apply)

<table>
<thead>
<tr>
<th>Interest</th>
<th>Strongly Disagree</th>
<th>Mildly Disagree</th>
<th>Mildly Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am generally against teaching engineering</td>
<td>15%</td>
<td>22%</td>
<td>41%</td>
<td></td>
</tr>
<tr>
<td>I am not interested in teaching online</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am interested in learning more about online classes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am interested in teaching at least one online class</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am interested in developing more online</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am interested in teaching all my classes</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In adding the categories of various interest, it is found that 2/3 of faculty are interested in considering online teaching, while 29% are interested in teaching at least one class online. Fewer are interested in developing online classes than teaching online classes.

6. Please rate from strongly disagree (1) to strongly agree (4):

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Mildly Disagree</th>
<th>Mildly Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning outcomes for engineering courses are more difficult to achieve online</td>
<td>1%</td>
<td>23%</td>
<td>55%</td>
<td>20%</td>
</tr>
<tr>
<td>I believe spiritual formation can be done effectively in an online class</td>
<td>12%</td>
<td>51%</td>
<td>33%</td>
<td>2%</td>
</tr>
<tr>
<td>Online engineering programs will expand indefinitely</td>
<td>9%</td>
<td>31%</td>
<td>49%</td>
<td>10%</td>
</tr>
<tr>
<td>I believe online engineering courses will become less popular in the long term</td>
<td>18%</td>
<td>62%</td>
<td>19%</td>
<td>2%</td>
</tr>
<tr>
<td>There is economic opportunity in developing more online engineering options</td>
<td>1%</td>
<td>8%</td>
<td>61%</td>
<td>29%</td>
</tr>
<tr>
<td>There is opportunity to collaborate with other Christian colleges on co-developing online engineering options</td>
<td>2%</td>
<td>12%</td>
<td>54%</td>
<td>32%</td>
</tr>
</tbody>
</table>

If both “Mildly Agree” and “Strongly Agree” categories are summed, 3/4 of faculty agree that learning outcomes are more difficult to achieve online, and almost that many are skeptical that spiritual formation can be done online. Most faculty believe online engineering will continue to grow in popularity. Approximately 90% believe there is economic opportunity and potential to collaborate with other Christian colleges with online engineering options.

7. What other thoughts and concerns do you have about online engineering courses?

Almost half of the respondents (82) entered perspectives to this open question, adding up to almost six pages of comments. They were grouped into similar themes and are summarized in Table 3 with number of responses of that category and several typical comments.
### Table 3. Thoughts and concerns about online engineering courses:

<table>
<thead>
<tr>
<th>Category (number of responses)</th>
<th>Typical comments</th>
</tr>
</thead>
</table>
| **In-person interaction** (21) | • ...developing character is something that online courses do not do well  
• Can't see their faces to see if they're understanding the material  
• It is much harder to note a student's obstacle to learning, and much harder to approach the student to increase their efficiency.  
• Hard to get to know the students, their interests, their struggles, their spiritual life  
• I believe our culture has the misperception that education is about information transfer. True education is primarily about relationship. |
| **The Future** (14) | • It's a growing trend. Go with it or get left behind  
• It's inevitable that a few professionally created video courses will be used by most of the nation. We will need to provide skilled tutoring instead of professors.  
• I believe online engineering degrees ....due to their lower cost they will become dominant and eventually they will make residential colleges cost prohibitive. (Much like online shopping is hurting big-box stores...). |
| **Hands-on and labs** (13) | • Hands-on is difficult although not impossible; consider PC-based simulations and/or shipping the hardware to students as part of the course.  
• Some classes are more conducive to online than others. [Classes needing] power supplies, oscilloscopes, motors, sensors, etc, are more challenging.  
• There is no substitute for the "real thing" -- it's hard to appreciate making "magic smoke" with a virtual LED. |
| **Course Quality** (7) | • I don't believe technology and software is advanced enough to accommodate for the type of intensive equation and problem solving that is required for teaching and learning engineering.  
• I noticed that their level of understanding of that [online] class is from average to poor despite the high grades they received. |
| **College Collaboration** (7) | • I see the opportunity to help serve a broader population of students through collaboration, but I have a hard time envisioning advantages for all the programs that would be involved  
• I believe that shared online classes between our CCCU engineering programs may be an increasingly necessary way ...when it seems increasingly difficult to hire the necessary faculty to staff and develop some of the more specialized courses independently.  
• How to share costs/credit for student hours covered between host institutions and course delivery institutions |
Table 3 cont’d. Thoughts and concerns about online engineering courses:

<table>
<thead>
<tr>
<th>Category (number of responses)</th>
<th>Typical comments</th>
</tr>
</thead>
</table>
| **Student Self-Discipline (5)** | • Research from MOOCs has shown that 18 year olds have no business in online classes. They need a community of embodied persons to hold them accountable  
• The online classes really only work if the online student is highly motivated and mature. |
| **Cheating (5)** | • I am most concerned about identity falsification and cheating  
• Security...certainty that the person getting credit for the course is truly the one doing the work. |
| **Faculty Workload (5)** | • I have found teaching online to be more labor intensive, not less.  
• ...extra resources and faculty they have to have for facilitating online labs and online design projects  
• Time and video experience to create quality presentations |
| **Benefits of Online (5)** | • I find that I can cover more material because I am not limited in time. I am also not afraid to go faster in my lectures because I know students can slow them down or repeat them. This is freeing because I don't have to worry about leaving someone behind (or boring others by going to slow).  
• Online courses provide flexibility for both students and faculty (e.g. summer courses while student is working at an internship or faculty is working on research project or with family). - They also allow students to take courses that their primary school doesn't offer. - Developing an online course requires one to think carefully about course outcomes and structure. This is a good thing that will benefit the traditional course as well.  
• A major economic advantage is in being able to collect a larger class size across geographic barriers. |
| **Teamwork / Group Interaction (3)** | • Spiritual formation is doable, but again the advantage of group interaction is pretty high over individual "reflection"" memos."  
• Teamwork among engineering students need to be considered carefully when delivering a course online. |
| **Mix with live classes (3)** | • I think online content has a place in non-online courses. Teaching an entire course online is trickier.  
• I think there are benefits in online tools to supplement classroom instruction." |
| **General (17)** | • It is not for everyone and not for every course.  
• Our engineering programs have been extremely effective and our graduates very well received. I am deeply skeptical of the ability to achieve widespread success with online models, and fear it will dilute our brand.  
• One on one customization and spiritual impact  
• ABET |
There were many comments related to the future of online learning. There was one comment that was especially interesting that is quoted in full here:

“I see a new kind of university, one that radically lowers costs and increases access to education around the globe by curating the best online coursework for students, while also bringing students and professionals into communities for project-based learning. These communities will need project and meeting spaces, but otherwise will be financially unburdened from the need for manicured grounds, gyms, dining halls, etc. Intergenerational project teams will get real work done for clients, and clients will have great insight into the capabilities of team members by the time they graduate. Experienced professionals will give back to the next generation as player-coaches, and the next generation will give back in their turn, creating a virtuous cycle that further lower costs by making higher education everybody’s business.”

8. What have been two of the most effective ways you have impacted students spiritually in face-to-face courses?

Educating students spiritually is a top priority at the schools surveyed, so considering how this influence would change with online education is important. All of these categories had meaningful response rates, but “Living the example” and “Informal conversations” were much more frequent. While it is conceivable that many informal conversations can take place from a distance, it is unclear how students will be able to see professors exhibiting godly character through the internet. Involvement with student groups and attending trips with students will also be quite limited. “Other” categories included praying with students, assigned reading and discussions, providing background of Christians of influence in the field, tying chapel messages to course content, and having Bible studies at faculty homes. A couple responses noted the need to embed spiritual themes in the course and “integrating spiritual/physical realities.”

Demographic Correlation

Demographic questions identified the respondent’s institution, teaching field, years of teaching, and teaching load.

Various demographic groupings were correlated to the responses of question 5, “What interest do you have in teaching engineering courses online?” Faculty teaching in the fields of electrical/computer, civil, and mechanical engineering were the most interested in teaching one or more of their courses online. Those who had been teaching for the shortest period of time (0-2 years) were by far the least interested in teaching courses online (only 7% interested, as...
compared to 29% interested on average). Those with higher teaching loads were generally more interested in teaching some or all of their courses online. As conjecture, it’s possible those newer to teaching are too overwhelmed to be interested in the additional work of converting courses to an online format, while those teaching higher loads are hopeful an online format could provide some preparation efficiencies over the long term.

Correlating demographic information to question 6 (part e) gave insight into interest in collaborating with other colleges. On average, respondents mildly agreed that there is an opportunity to collaborate with other Christian colleges on co-developing online engineering options. Respondents from 3 institutions mildly disagreed on average (Anderson, Lipscomb, and Pensacola Christian), while respondents from 8 institutions strongly agreed on average (College of the Ozarks, Dordt, Geneva, John Brown, Liberty, Northwest Nazarene, Union, and Walla Walla). Typically, those who had been teaching for the shortest period of time (0-2 years) viewed the opportunity to collaborate with other colleges less positively than those who had more teaching experience.

Dean Interviews
In addition to the survey of faculty around the nation, attempts were made to interview leaders of the larger engineering schools. Some preferred to answer the questions by email (See form in Appendix B) while one did not respond at all. While all the schools had general education courses available online, like Calculus, Chemistry and Physics, few offer online engineering courses currently. California Baptist offers some computer science courses and they are working on Circuits 1 and 2. Cedarville offers an Engineering Graphics class in the summer. LeTourneau offers Statics, Dynamics, Circuits 1, and Mechanics of Materials during the summer. Baylor also offers Thermodynamics, Dynamics, Circuits, and Python over the summer. Liberty has plans to develop several online engineering degrees.

When asked about courses these leaders would be interested in having available for their students, there was frequent interest in upper level specialized electives, like Finite Element Analysis or Aero focused courses. One respondent mentioned a need for core engineering courses for students who take a semester abroad. Another need was making the freshmen introductory engineering courses available to dual credit high school and community college students. Several schools are planning more online courses for master’s degree requirements. Cal Baptist already offers an online master’s degree in Information Technology Management.

Most of these leaders believe there is economic opportunity in developing more online engineering options and that online engineering programs will expand for the foreseeable future. However, most aren’t offering such courses and have no such plans. Most of them did respond with mild or strong belief that there is opportunity for collaboration in this field with other Christian colleges. Of concern, most of them also had some doubt about the effectiveness of spiritual formation online.

Next steps
This paper and conference is timely when considering the state of online engineering education. It is time for schools of similar philosophy to begin conversations about how collaboration in online engineering can benefit participants. The next step will be to begin such conversations at
this summer’s CEC conference. As part of this conference presentation, discussion will address particular courses faculty feel are needed, which ones they might be interested in developing, and what hurdles will need to be overcome. A small working group will be identified to have further discussions on needed courses, interested faculty, financial needs, and possible funding sources. Guidelines need to be drafted for guaranteeing quality of collaborative courses and clarifying practical issues related to registration and access to learning management systems. With all this in mind, it may be best to just “try it”. The benefits and hurdles will remain uncertain until two or three schools get together and build a course they can all use and work through the challenges. In addition, a catalog of online courses currently offered by Christian colleges needs to be maintained and disseminated. Eventually, collaborating schools will need to agree on quality standards for shared courses as well as financial arrangements.

As the number of high school students is expected to decrease nationally, and the number of engineering programs increases every year, there is a need to do more with less. As with bookstores, educational institutions will not be able to survive by selling books and knowledge. Book stores brought in coffee shops and comfortable furniture and toys for the children and made buying a book an “experience”. Higher education has been providing more toys and comforts for some time. It’s logical that trend will continue. So what’s the role of the professor? It probably won’t be selling knowledge. However, there will continue to be a need for an expert to guide the student to the right knowledge - to identify where a student’s thoughts and strengths are, and provide the coaching and tools to bridge the gaps. Whether that can be done over an internet line remains to be seen.
APPENDIX A
Perceptions of Online Engineering Education

1. Pick two statements that you believe are the greatest advantages of online engineering education:
   _____ Improved learning outcomes for students
   _____ Improved accessibility for students
   _____ Improved spiritual impact on students
   _____ Lower cost for students
   _____ Improved work efficiency for instructors
   _____ Other: _________________________

2. Pick two statements that you believe are the greatest disadvantages of online engineering education:
   _____ More difficult to communicate principles of engineering online
   _____ More difficult to give students “hands-on” experiences and labs online
   _____ More difficult to adjust teaching to student response
   _____ More difficult to impact students spiritually online
   _____ More difficult for students to manage their time without face to face accountability
   _____ More difficult to advise students academically online
   _____ Other:
   ________________________________________________________________

3. What is your level of involvement with teaching online courses (engineering or otherwise)?
   O I never taught or have taken an online course
   O I never taught an online course, but I have taken at least one
   O I have utilized video methods for hybrid or "flipped" classroom experiences
   O I taught one online course 1-2 times
   O I taught one online course three times or more
O I taught multiple online courses 1-2 times
O I taught multiple online courses many times
O Other:_____________________________________________________________

4. To what level have you been involved in developing online courses (engineering or otherwise)?
   O Have not been involved in developing an online course
   O Helped modify an existing online course
   O Did significant modification to an existing online course
   O Did most of the development for one new online course
   O Did most of the development for two or more online courses
   O Other:_____________________________________________________________

5. What interest do you have in teaching engineering courses online? (check all that apply)
   O I am generally against teaching engineering online
   O I am not interested in teaching online
   O I am interested in learning more about online learning
   O I am interested in teaching at least one online class
   O I am interested in developing more online classes
   O I am interested in teaching all my classes online

6. Please rate from strongly disagree (1) to strongly agree (4):
   1 2 3 4 Learning outcomes for engineering courses are more difficult to achieve online
   1 2 3 4 I believe spiritual formation can be done effectively in an online class
   1 2 3 4 Online engineering programs will expand indefinitely
   1 2 3 4 I believe online engineering courses will become less popular in the long term
   1 2 3 4 There is economic opportunity in developing more online engineering options
   1 2 3 4 There is opportunity to collaborate with other Christian colleges on co-developing online engineering options
7. What other thoughts and concerns do you have about online engineering courses?

8. What have been two of the most effective ways you have impacted students spiritually in face-to-face courses?
   O Living the example   O In-class devotional talks   O Informal conversations
   O Conversations as academic advisor   O Involvement with student groups
   O Trips/service learning projects with students   O Other: ______

9. Choose your institution.
APPENDIX B

Engineering leadership survey
(To be completed by Dean’s office of larger schools)

Number of undergrad students in engineering program: ______________________

1. Which engineering related courses do you currently offer online:

2. Which online engineering courses do you plan to add in the next two years?

3. Which engineering courses (online or face to face) would you most like to add if you had the resources?

4. Please rate from strongly doubt (1) to strongly believe (4):

    1  2  3  4  There is economic opportunity in developing more online engineering options
    1  2  3  4  Online engineering programs will expand indefinitely
    1  2  3  4  Online engineering courses will become less popular in the long term
    1  2  3  4  Spiritual formation can be done effectively in an online class
    1  2  3  4  There is opportunity to collaborate with other Christian colleges on co-developing online engineering options
1 Seaman, Julia E. et al. *Grade Increase: Tracking Distance Education in the United States*. Babson Survey Research Group, 2018.


