2009 CEEC Proceedings

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Foreword

Welcome to the 2009 Christian Engineering Education Conference! In this volume of proceedings you will find the 13 papers that were presented at the conference. Many thanks are due to the authors who did such a fine job of preparing them. The conference also featured 2 panel discussions, and numerous informal discussions with colleagues from industry, public universities, and other Christian institutions.

This is the first time we have had back-to-back Christian Engineering Education Conferences. Since 2002 the conference has been a biannual event, but beginning this year the CEEC will be held on odd numbered years to avoid conflicts with other events. The next CEEC will be in 2011 in or around Vancouver, BC. As always, the Christian Engineering Education Conference web page (http://www.calvin.edu/academic/engineering/ces/ceec/) will have details for 2011 when they become available. In 2010 we will meet for dinner and discussion during the ASEE conference in Louisville, Kentucky. Again, see the web page for details or to sign up for email notification via the CEEC listserv.

One of the reasons for switching to odd numbered years in 2009 was to take advantage of the opportunity to have the conference hosted at Baylor University. Special thanks are due to Bill Jordan, Ben Kelley, and Minnie Simcik for their work on the local arrangements. Thanks are also due to Steve VanderLeest (general chair), Matthew Green (program co-chair), and organizing committee members Gayle Ermer, Murat Tanyel, and Bill Jordan (the chair for local arrangements). Thanks to Michelle Krul for her help in preparing these proceedings and to the 39 reviewers who reviewed the papers herein.

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# Table of Contents

Putting the ‘And’ Back into Genesis 2:15 ................................................................. 3  
Kevin J. Timmer, Dordt College

Biblical Principles for a Christian Engineering Entrepreneur ........................................ 10  
Steven H. VanderLeest, Calvin College

Common Grace: A Key to Integrating Faith and Engineering ........................................ 23  
Max Deffenbaugh

Deus Machinator: God the Engineer........................................................................... 30  
Stephen Frezza

Christian Engineers or Engineering Christians? ........................................................... 37  
Andrew J. Blauch, Charleston Southern University

Guiding Technological Development: An Analysis of Borgmann’s Device Paradigm ........ 44  
Gayle E. Ermer, Calvin College

Can Design for the “Poor” Result in Better Designs for Everyone? .............................. 57  
Matthew G. Green, LeTourneau University

Enhancing Student Learning through Interaction on Service-Based Projects ............... 68  
Michael R. Foster, George Fox University

Technological Justice by Intentional Design ................................................................ 74  
Steven H. VanderLeest, Calvin College

Curriculum Development for Training in Basic Energy Concepts for Developing Countries .... 84  
Dominic Halsmer, Sean Estes, Nathan Fansler, Joshua Glesener, Nic Halsmer, Jennifer Luth, Evn Presson, Kevin Stark, Oral Roberts University

Lifecycle Design and Christian Viewpoint in Technology Development for Developing Agrarian and Rural Economics ................................................................. 97  
Israel Dunmade, Mount Royal College

Calling and Motivation for International Engineering Pursuits .................................. 108  
Benjamin Kelley and William Jordan, Baylor University

Serving Developing Countries: From Senior Design Projects to Career Decisions ........ 117  
J. Aubrey Sykes, Calvin College
Putting the ‘And’ Back into Genesis 2:15
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Abstract
As our consumeristic society bumps up against creational limits, technological and economic progress is often pitted against environmental stewardship. Those opposed to governmental regulation of pollution and resource use claim that these restrictions hinder the growth of the economy, while those in favor of additional control, acknowledge that we will likely have to make sacrifices as a result. The adversarial relationship between humankind and the rest of the creation has a long history with many ramifications. This paper begins to explore how this twisted relationship has distorted the engineering design process by narrowing the definition of the engineer’s stewardship task. By revisiting the garden and our original mandate, our understanding of our stewardship task is broadened from one of “doing less harm” to one of “enabling creation to flourish”. A richer understanding of our proper relationship to the rest of creation has the potential to spur creative solutions to meet the needs of our world while pointing to Christ’s kingdom of shalom.

Introduction
In the last few decades societies have become increasingly aware of the planetary limits of our cultural activities. These limits threaten the consumeristic lifestyle that many in the West have become accustomed to and others in the world are striving to achieve. Concern for the environment is often seen as a threat to economic growth and therefore progress. Automobile manufacturers bemoan CAFÉ standards which they predict will threaten their economic competitiveness. The U.S. drags its feet on committing to climate change reform, fearing it will hurt the economy. Environmental groups fight to keep the thirsty petroleum industry out of the Arctic National Wildlife Refuge. The livelihood of people like loggers is pitted against the lives of other creatures like the spotted owl. Through these examples and countless others we see technological and economic growth seemingly at odds with environmental stewardship. Many have recognized our path as unsustainable and warn of future catastrophe. Lester Brown, president of the Earth Policy Institute, writes “We are crossing natural thresholds that we cannot see and violating deadlines that we do not recognize. Nature is the time keeper, but we cannot see the clock.” Richard Wright of Gorden College introduces his environmental science text with this warning “However, if we fail to achieve sustainability by our deliberate actions, the natural world will impose it on us in highly undesirable ways…” However, others continue to proclaim salvation through increased technology as demonstrated in this quote from Freeman Dyson, “Three huge revolutionary forces are being harnessed just in time for the new century: the sun, the genome, and the Internet. These three forces are strong enough to reverse some of the worst evils of our time...(like) poverty.” The realities of the tension between creation development and creation care suggest that we are living as if Genesis 2:15 read “…. to till it or keep it.” rather than by the original mandate “…. to till it and keep it” (RSV). This paper is an initial attempt at understanding the implications of the tension between technology and the environment for engineering and how embracing the comprehensive scope of our stewardship task might free us to design in ways that allow all of God’s creation to flourish. A brief background to the issue is provided followed by an exploration of the biblical foundation for a holistic call to stewardship. The paper concludes with three examples meant to illustrate comprehensive stewardship at work and some potential responses to our stewardship call which are meant to stimulate further creativity.

Background
Of course the tension between humans and the rest of creation, including the environment, is as old as the “thistle curse” of Genesis 3:18. The original harmonious relationship between humanity and the rest of
creation became a struggle after Adam and Eve’s fall into sin and an all-out assault after the Renaissance and Enlightenment (see Chapters 5-9 of Earthkeeping in the Nineties for a brief history of this progression). Intoxicated with the prospect of controlling its own destiny through the power of human reason, western culture has abandoned God and his call to serve and has instead sought autonomy through technological power and economic accumulation. In this context, progress has come to be defined as that which expands technology and grows the economy and the rest of creation becomes raw material for this end. As faith in technology and the economy has grown, it has given rise to consumerism. Alan Durning argues in his book How Much is Enough that western societies have moved beyond materialism to consumerism. In contrast to materialism which places its faith in the accumulation of wealth, consumerism is anchored in the act of selling, buying, and throwing. Consumption itself becomes the sought after source of happiness. Quality takes a back seat to price and people welcome planned obsolescence, which frees them to upgrade without guilt. Consumeristic-based economics, at its extreme, seeks to maximize profit at nearly any cost. Loss of ecosystems and extinction of species is only a concern if there is an immediate impact on human well being in terms of higher prices or loss of a potentially useful genetic resource. This anthropogenic attitude has triggered a counter, preservationist movement which puts the needs of the rest of the creation ahead of humans and at its extreme, as expressed by some in the Deep Ecology movement for example, celebrates the death of humans as a measure of liberation for the rest of nature. These two ideologies serve as the poles for the tension between technological development and environmental preservation.

In the last few years many Christians concerned about large scale destruction of the environment have authored books drawing attention to God’s expressed love for the creation and his call to man to preserve and take care of it. However, there is a tendency in some of these writings to apply the cultural mandate of Genesis 2:15 as two separate mandates: to develop and to preserve, that must somehow be balanced, rather than a single rich call to stewardship in all that we do. These texts emphasize the importance of creation preservation with little or no mention of our call to unfold the creation. For example Scott Hoezee writes about the creation, “As image bearers, it is our holy vocation to notice it, love it, and preserve it.” Given the wide scale destruction of species and ecosystems and the general ambivalence of the church to creation care, a one-sided presentation may be warranted. However, a one-sided presentation, while effectively calling attention to our God given responsibility to care for the environment, also tends to propagate a distorted view of our stewardship task. This distorted view has us trying to balance human needs and development against the needs of the rest of the creation. The authors of Earthkeeping in the Nineties and Responsible Technology give a more holistic description of our stewardship task, but in its application, they tend to emphasize either the preservation of creation or the unfolding of creation to meet human needs, respectively.

While framing our discussion of our stewardship task as primarily either a process of unfolding creation or of preserving creation may serve a valuable role in particular contexts, it can also limit our understanding of the richness of the cultural mandate and the potential design alternatives that may flow from it. When the cultural mandate is incorrectly understood as “development or preservation,” the responsible designer is asked to choose sides and is often frustrated by this dichotomy. Technological development is seen as being at odds with creation preservation. So for example, the civil engineer would feel compelled to choose to either practice the profession of highway building or to preserve habitat important to the health of a particular ecosystem. In this context exercising stewardship during design is often practiced as a process of minimizing damage. While minimizing creational damage by reducing harmful emissions, fossil fuel use, construction site soil erosion, or the rate of species extinction is often the best that we can do, these efforts fall short of our singular task of enabling the whole of creation to flourish to God’s glory and toward the restoration of shalom. A designer that appreciates the full scope of God’s call to stewardship may be able to see alternative solutions to problems that simultaneously serve mankind and the rest of the creation.
Identifying creationally sound alternative designs is only part of the challenge. The engineering design process is often driven by a consumeristic worldview. Alternative designs compete based on profit margins and the result is “an attractive product that is affordable, meets regulations, performs well enough, and lasts long enough to meet market expectations.”  In this setting creation care often becomes an unaffordable luxury but for a splash of “green paint” as portioned by a consumer survey. The whole scale exploitation of the material world to feed the economy is assumed, and even as Christian engineers we are often content to embrace “do-less-harm” as the full expression of our stewardship calling. We have allowed our stewardship task to be reshaped into the space provided for it by the consumeristic mission. In a world in which economies are bumping up against creational limits, consumerism eagerly accepts a “do-less-harm” stewardship ethic, particularly when human well being is a concern or when green technology positively affects the bottom line.

The straight-jacketing of the design process by consumerism has troubled me for a long time, particularly with regard to environmental concerns. My formal introduction to environmental conservation and ecology in high school resonated with an adolescence spent outdoors on the family acreage. For a variety of reasons I choose to pursue a technical degree (engineering actually chose me but that is another story) in college in lieu of ecology. However, as I earned an engineering degree, I also developed my outdoor interests and began to study native prairies as a hobby. For many years as I taught and practiced engineering I saw firsthand the rift between environmental stewardship and technological development, knowing in my heart that it was not the way God had intended it. During my early years of teaching I felt like the engineering curriculum adequately addressed energy and materials stewardship but there was little room or place to discuss ecology and the stewarding the whole of creation. And as an HVAC engineer I often consulted building owners and architects unwilling to consider energy conservation measures unless simple payback periods were less than two years, despite their hope that the building would last longer than that. The day-to-day world of technique seemed far removed from the biblical call to creation care. During those years I felt paralyzed by the enormity of the problem and was compelled instead to live with the duality by doing engineering during the week and exploring prairies on the weekends. However, my recent doctoral studies in utilizing biomass as a renewable source of energy and materials allowed me to combine my interest in prairies and energy conservation and gave me a renewed vigor to explore the biblical relationship between technological development and the environment.

**Biblical Foundation**

In the New Testament Christ teaches that through him the law is fulfilled and that God’s kingdom has come, although it is not fully revealed. He then calls each of us to be his disciples by seeking first his kingdom, a kingdom of shalom. Shalom is an Old Testament word which refers to the restfulness, contentment, and harmony of a life lived in perfect obedience to God’s will. Shalom is a condition in which everyone and everything is in right relationship all the time. Human and non-human creation are enabled to flourish by becoming everything God created them to be. This condition existed before Adam and Eve’s fall into sin and its complete restoration through Christ was envisioned by Isaiah (Isaiah 11) and John (Revelation 21). While we, as whole beings, seek God’s kingdom it can be helpful for us to think of our sanctification as a process of restoring shalom in our relationship with God, with others, and with the rest of creation. The need to seek a restored relationship with God and with others is often very clear to Christians. Brokenness in personal relationships can make us aware of our failure to live obediently before God, and of our need for forgiveness and restoration through Christ. God’s call to us to seek a restored relationship with the rest of creation has not always been as obvious to many Christians, but is no less real. God’s love for his creation is proclaimed throughout scripture as Cal DeWitt and others have made clear. The apostle Paul proclaims Christ’s mission to “reconcile to himself all things” (Colossians 1:20). Ezekiel gives us a wonderful vision of a restored relationship between humanity and the rest of creation (Ezekiel 36:6-12), and we read in Romans 8:18-22 that the creation groans as in childbirth for this restoration. Indeed, even our response to Christ’s call to love our neighbor, current and
future is woefully inadequate if we are polluting our neighbor’s drinking water or destroying the earth’s fruitfulness.

Creation knew this perfect relationship before the fall. In Genesis 1:28 we read that mankind was not given the earth but was given dominion or authority over the rest of creation. Our relationship to the rest of creation in light of this authority is further clarified in Genesis 2:15, where we read, “The Lord God took the man and put him in the garden of Eden to till it and keep it” (RSV). Cal DeWitt has explored the details of this mandate and the following discussion is based on his efforts. The Hebrew word for till is ‘abad which can also be translated as “to work”, “to dress”, or “to serve”. “Keep” is the Hebrew word shamar which is also used in the Aaronic blessing, “The Lord bless you and keep you” (Numbers 6:24, RSV). That is, the Lord bless you and sustain you, prosper you, or cause you to flourish. In this context DeWitt understands our creation to the keeping task as a dynamic, human involved, prospering rather than a preserving or set-aside type of keeping. Therefore our mandate “to till and to keep” can be understood as two different ways of stating the same thing, “to serve and to prosper the garden”, rather than two separate tasks. In the initial chapters of Genesis, God is calling us to be stewards or managers of his creation and is asking us to bear his image by ruling it as loving servants. God expects us to serve creation by enabling it to flourish in every conceivable way. Flourishing here certainly means biological flourishing, but it also includes responsible unfolding or development of the creation through our technological activities. Through obedient development we enable the creation to bring praise to God in ways that it couldn’t without human involvement. In keeping with God’s plan of shalom, obedient design unfolds creation so that the whole of creation, including humanity, flourishes. In other words we are to enable all of creation to flourish through time as a growing chorus of praise with ever increasing diversity. When we steward or serve creation in this way, we cultivate shalom. The authors of Responsible Technology describe our technological task “as a form of service to our fellow human beings and to the natural creation. This means that we are to develop technology in such a way that the blessings, riches, and potentials God has put in creation are allowed to flower. We are called to do technology in such a way that the creativity and joy for which God created men and women can exist in abundance, the riches of the physical world can be uncovered and utilized, and the plant and animal worlds can be perceived and used for what they are and for what God intends them to be.”

I would modify this quote slightly to include the physical world as part of what we are called to help flourish and not just see it as something to be uncovered and utilized. Consider the following as an example of the comprehensive way in which we can serve the rest of the creation.

As members of particular ecosystems oak trees biologically flourish and have for a long time. They grow, reproduce, collect solar energy, and, by providing food and shelter for a host of plants and animals, give back to their ecosystems. But oaks are also enabled to flourish in ways they could not on their own when humans selectively harvest some oaks and skillfully manufacture them into beautifully grained veneered tables and desks. Through this unfolding the oak’s voice in the chorus of praise has been enhanced. Mankind serves oak trees in this way. We enable them to become what God had intended. In doing this, I believe we go beyond Cal DeWitt’s stewardship goal of “enjoying creation’s fruit without destroying its fruitfulness” to actually increasing creation’s fruitfulness. God intends mankind to unfold and develop creation, to get their hands dirty, to add voices to the choir, but not at the expense of other voices. Oaks must also be allowed to continue to flourish in their biological calling by producing more oaks as well as food and shelter for other creatures in their ecosystem. Obedient stewardship enables the entirety of creation to flower in every conceivable way while building up just, harmonious, and delightful relationships between God, mankind, and the rest of creation.

Of course the simultaneous realization of this comprehensive potential has been seriously crippled by the work of Satan and the distortion of sin since Adam and Eve’s fall. In the absence of God’s grace, the misdirected heart of mankind flees from obedient, loving, selfless service and instead embraces self-centered autonomy from God at the expense of everything else. However, Christ’s victory over Satan sets us free to once again serve as God had intended. Christ’s work restores the possibility of a right
relationship with God but also with each other and the rest of the creation. By the ongoing work of the Holy Spirit we are prodded and enabled to seek Christ’s kingdom first and to find it. His kingdom is a kingdom of right relationships. It is a kingdom of shalom. Although the victory is won, believers are called to continue to wage war against the powers of evil by proclaiming the good news until Christ returns. Engineers witness by verbally proclaiming the gospel when appropriate, but also by helping others to glimpse Christ’s kingdom by revealing the way things are supposed to be in all areas of life, including technological development. We are called to bring healing in and through all of our lives, including our design work, “erecting signposts of the kingdom,” as Goudzwaard says.\textsuperscript{17}

Designers, tasked with the original mandate to enable creation to flourish and now the additional mission of bringing healing to a broken world, need to be properly equipped. To be an effective manager and agent of reconciliation, an engineer requires knowledge of or at least sensitivity to all of the diverse aspects of the creation. The engineering student’s ability to serve effectively is enhanced with course work in ecology, sociology, environmental studies, etc. Engineers must know enough to recognize brokenness and to prescribe healing. The engineer must consider the whole in order to chart a path toward true progress, universal flourishing, and shalom. This type of holistic design generally requires breadth of expertise and therefore is facilitated by the involvement of a community of diverse individuals, all contributing insight from their unique disciplines or perspectives.

\textbf{Examples}

While we often see tension between concern for the environment and technological development we can also point to examples of tilling and keeping that at least seem to have the potential to bring some measure of shalom and flourishing. The first example comes from my own experience and served as the impetus for writing this paper. While working on my doctorate degree in biorenewable resources, I was introduced to the idea of growing switchgrass as a source of renewable energy and chemicals. This idea piqued my interest, but rather than just a monoculture of switchgrass, I envision the reestablishment of whole prairie ecosystems. A diverse prairie ecosystem of grasses and forbs has the potential to simultaneously provide a sustainable source of cellulose without the need for fertilizer, build the soil, and provide habitat for numerous animals, insects, and microbes. In this way mankind and the rest of creation may both be allowed to flourish in harmony.

William McDonough and Michael Braungart propose a number of intriguing ideas in their book \textit{Cradle to Cradle: Remaking the Way We Make Things}\textsuperscript{18}. Many of their suggestions comport well with the stewardship ideal laid out in this paper. They argue for redirecting our technological goals away from economic efficiency and toward human and ecological health. Their catch phrase, “waste equals food”, captures their concept of complete cycling of both manmade as well as naturally occurring materials. They maintain that materials and products should be designed so that they easily become biological food or technological “food” after their useful life. They describe the retooling of an upholstery manufacturer in which all the toxic dyes and chemicals were removed from the product and process. The result was furniture fabrics that no longer off-gassed toxins and fabric trimmings that were no longer considered hazardous waste but rather food for compost. Redesigning holistically resulted in a safe and competitively priced product for the user, a safe process for the workers, and a net benefit for the environment.

This last example illustrates how seeking flourishing and shalom may bring to light non-technical solutions to problems. Many North Americans take pride in keeping a well manicured lawn around their home. While restricting the height of urban grass may help control rodents and wild fires, current practice can tread heavily on creation. Traditionally an assortment of herbicides, pesticides, fertilizers, and water are applied to a cool season grass in order to encourage its growth, and a gasoline powered
mower whacks it off when it does. Gasoline lawn mowers have some of the highest pollution rates of all combustion engines. The herbicides eliminate plant diversity, the pesticides reduce insect and worm numbers, watering consumes a valuable resource, and we are told that when it rains a portion of the applied chemicals make their way into the local stream, disrupting those ecosystems. The situation cries out for a steward. However, when stewardship is explored within the confines of economic efficiency and a technological mindset, the potential for full flourishing is restricted. The least radical solution to the identified problem might be to improve the fuel efficiency and emissions controls of a gasoline mower. Alternatively, an engineer could really go “green” and design a battery powered mower packaged with a photovoltaic recharging system. While both of these designs represent improvements over the status quo, they are both “do-less-harm” options and have limited potential to increase flourishing. If instead we approach the problem holistically while seeking to serve the entire creation, we arrive at a radically different solution; plant buffalo grass. Buffalo grass is a perennial, warm season, native prairie plant that grows slowly to a maximum height of four to six inches. It is very drought resistant, forms a dense sod which controls weeds and builds the soil, and it does not require fertilizer or pesticides. Mowing could be completely avoided or reduced to a monthly trimming with a manual unit. Elimination of the chemicals decreases the cost to care for the lawn but would also be healthier for the residents and neighbors. The number and diversity of insects’ life would likely increase, attracting birds and other wildlife to the property.

These examples illustrate that efforts to redirect technology toward flourishing and shalom are most fruitful when they begin at the root. Unfortunately by the time a project reaches the designer’s desk, the problem and what constitutes a solution have often already been determined. So while the engineer may set her sights on kingdom design, the narrow drive toward minimizing first costs often sets the technological path and denies holistic thinking the freedom to bear much fruit. Even as engineers move into management positions, they are often constrained by the mission of the corporation. Indeed, it would be difficult for a company that produces and sells lawn mowers to accept buffalo grass as a feasible solution. Clearly, given humanity’s finite and fallen nature, it is unrealistic for us to expect to witness complete shalom before Christ’s return. But this should not keep us from striving to bring the kingdom to light in all that we do.

The call to serve the creation is given to everyone not just engineers. It is part of our larger call to bear witness to Christ’s kingdom of shalom in all that we do and requires us to individually and collectively respond within each of our spheres of influence. As engineering faculty we should nurture a longing in our students for shalom and perfect stewardship, but we should also temper that idealism with the realities of practicing engineering in a broken world. We should design curriculum with sufficient breadth to equip our students to recognize all forms of flourishing. As faculty we might also consider teaching an energy stewardship course to the broader student body. Perhaps as church members there may be opportunities to be involved in the education of fellow Christians regarding the idolatry of consumerism and its threat to shalom. As members of residential communities we can persuade local governments to encourage stewardly behavior through codes and ordinances. For example, I live in a small but growing community that is concerned about energy conservation but could benefit by being made aware of the significant energy savings that can be realized by designing new housing developments that encourage construction of homes with southern exposures. At home too we should be seeking whole creation stewardship and be open to alternatives that may not necessarily be the most cost effective. I believe through these and countless other ways we can by God’s grace shine light on a path of obedience.

Conclusion

In our broken world technological development is often pitted against creation care, but antagonism between these ends is not the way God intended it to be. God created mankind to reflect him through their loving service to each other and the rest of the creation. This stewardship call requires engineers to till and to keep creation in such a way that all things are enabled to flourish in accordance with God’s will.
and to his glory. This is a difficult goal to achieve but if we become content with "do-less-harm" stewardship, we may miss opportunities to be salt and light.

References


Biblical Principles for a Christian Engineering Entrepreneur

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Abstract

Perhaps not surprisingly, many entrepreneurs are engineers. Equally unsurprising, many engineering entrepreneurs are Christians. How do these three roles interact and support each other? In this paper, I will use my sabbatical experience at an engineering start-up company as the context to explore how one's faith can provide a foundation for pursuing engineering entrepreneurship. My premise is that entrepreneurship and engineering are complementary – a natural combination that can be informed by a foundation of faith. The paper introduces the topic by first describing why engineering educators should take an interest in entrepreneurship. Second, a sample of some the important literature in this area will be explored. Third, we will review some commonly identified characteristics of entrepreneurs. Some of the characteristics lend themselves well to engineering; some are good fits with Christian faith. But some can cause a tension which must be addressed. Fourth, a number of important Biblical principles will be enumerated that are applicable to entrepreneurial activities. Examples include stewardship, caring, honesty, the imago dei, and planning for good while trusting in God. Finally, the paper will conclude with a number of small case studies applying these principles in specific situations such as product development, human resources, and project management.

The Need

Entrepreneurship is the discipline and art of innovation – creating new products, new businesses, new organizations, new approaches. The word itself derives from the French verb entreprendre which means “to begin” or “to undertake”. Engineering is also the discipline and art of innovation – creating new products, new approaches, and new processes. Both the entrepreneur and the engineer focus on practical application of ideas and inventions. Such similarities in focus and goals lead many engineers to become entrepreneurs. It is not uncommon to find engineers running large businesses. For example, the most frequent undergraduate degree for CEOs of the S&P top 500 corporations is engineering (accounting for 23% of the CEO undergrad degrees, followed by Economics at 13%)¹. Even more engineers are found in entrepreneurial enterprises related to technology (which itself accounts for a large number of businesses): “About two-thirds of the technical entrepreneurs have degrees in engineering, 30 percent in science, and 3 percent in other fields.”²

Are engineering students who are Christians also interested in entrepreneurship? To find out, I recruited several faculty at a number of Christian colleges and universities to survey students in their courses. The survey began with a brief definition of entrepreneurship: “Entrepreneurship is the discipline and art of innovation – creating new products, new businesses, new organizations, new approaches. Entrepreneurs can be found inside large and small companies, but often they start their own businesses. The Merriam-Webster Dictionary defines entrepreneur as one who organizes, manages, and assumes the risks of a business or enterprise.” Following this definition, students were asked if they agreed with the statement (1) “I am interested in pursuing entrepreneurship in some form after graduation.” and (2) “I am interested in starting my own business after graduation.” The survey was administered in engineering courses with class sizes ranging from 11 to 23 students, with students ranging from first year to seniors, and included a variety of engineering disciplines. Of the 141 students surveyed across five institutions, 82% agreed with the first statement and 33% agreed with the second statement.
Even if many engineering students are interested in entrepreneurship, it may be that this is an inappropriate goal that should not be encouraged. Engineers who are Christians and also considering entrepreneurship might be concerned that such an endeavor is incompatible with their faith. Entrepreneurs are often perceived not so much as creative as greedy, not so much interested in creating new jobs as getting rich quick. For example, the film *The Call of the Entrepreneur* notes the common attitude that entrepreneurs are greedy (and then dispels this notion). Alexander Hill makes a similar remark: “Mark Twain's observation... that 'an ethical man is a Christian holding four aces' reflects the widely held notion that personal Christian ethics is a luxury few can afford in competitive professional environments such as the marketplace.” Christian Day notes in his opening line that “Speculators are often portrayed in literature, film and the media as evil businessmen who prey upon markets.” If “the love of money is a root of all kinds of evil” (1 Timothy 6:10) and entrepreneurship is the art of making money, then in practice, if not by definition, is entrepreneurship evil? On the contrary – I intend to make the case that entrepreneurship is redeemable. God's sovereignty claims entrepreneurs as well as every other part of creation. Entrepreneurship can be a kingdom calling guided by Biblical principles. The focus of this paper will be the interplay of engineering, entrepreneurship, and Christian faith. In some cases, the traits and skills common for one of these roles is quite helpful for the other roles. In other cases, there is a certain tension that must be addressed. For example, the engineers and entrepreneurs both need a certain creativity. On the other hand, engineers are risk averse, while entrepreneurs must be willing to live with a certain level of (calculated) risk. As another example, a Biblical understanding of justice or mercy might be colored differently by the engineer than by the entrepreneur. For Christian engineering educators who may not be interested in entrepreneurship *per se*, there is still much to be learned from this triple combination that can be applied in other contexts. My topic is germane to this conference because (1) entrepreneurship is a common aspiration for many of our students, (2) it is a topic that is complementary to engineering and can enrich our curriculum, (3) it is a calling that can benefit from Christian principles and perspective.

During the 2008-9 academic year, I had the privilege of taking a sabbatical leave from my faculty position at Calvin College to pursue some entrepreneurial activities at a small but growing engineering start-up company. This was an opportunity to see entrepreneurship in practice and think through some potential Biblical principles that might apply. My proposal for such a sabbatical grew out of participation in a entrepreneurship faculty reading group, which was funded in part first by a National Collegiate Inventors and Innovators Alliance (NCIIA) faculty grant and then by a start-up grant from the Kern Entrepreneurship Education Network (KEEN). My sabbatical has given me a chance to participate in the executive management of an engineering company, including strategic planning, day-to-day operational decisions, and the opportunity to tackle the significant challenges of an economic downturn. The company is DornerWorks, founded by the company president, David Dorner. David was a student in a couple of the first courses I taught at Calvin College at the beginning of my career. We kept in touch over the year and I became a partner with DornerWorks in 2005, consulting on a part-time basis while maintaining my full-time teaching position. At the time I joined the company, we had 12 employees. The intervening years have seen tremendous growth – today we have 72 employees. During my one year sabbatical leave, I have the position of Vice-President of Research and Development at the company, focusing on product development, technological innovation, and engaging as an active member of the executive management team.

The remainder of the paper is structured as an exploration of some of the literature, an examination of the characteristics of an entrepreneur, an enumeration of some Biblical principles that could be considered for the engineering entrepreneur, and an elicitation of a few practical applications as case studies from my sabbatical experience.

**Literature Review**

This section provides a brief sampling of the literature – brief because the available resources are few.
There are a number of publications that explore the impact of Christian faith on entrepreneurship and there are also a number of works that explore the impact of faith on engineering. Nevertheless, finding examples of the combination of all three (faith, entrepreneurship, and engineering) is much more difficult. Occasionally the topic is touched on, such as where an author writing about entrepreneurs warns against a human-centered point of view: “In the realm of technology, the inventor and the entrepreneur are the image of success. It is always assumed that man is the creator of man-machine systems: the designer invents ideas; the entrepreneur makes things happen. Thus, man takes all the credit for himself.”

One important book that discusses faith principles for business (and in part address the specific sub-domain of entrepreneurship) are the collaboration of Chewning, Eby, and Roels for the “through the eyes of faith” series commissioned by the Christian College Coalition. A second book (less academic, but more practical and personal) is from Max Depree, the former CEO of the Herman Miller Corporation: *Leadership is an Art*. Both books make the case that business is an area where Christians can and do work from a faith perspective. Chewning identifies the “…real reasons Christians are in business: to do the will of God and to serve their neighbors.” Depree declares that “corporations can and should have a redemptive purpose.” Further insights from these books will be interleaved in the discussions in the following sections.

The literature on the relationship of engineering and entrepreneurship is extensive. There are studies of curriculum and pedagogy for building entrepreneurship into engineering education. Others focus on the education of the engineering educators in order to teach entrepreneurial concepts, e.g., Gassert.

### The Context: Characteristics of the Entrepreneur

For many, the stereotypical view of the entrepreneur is a money-hungry, greedy capitalist: “Why do their stories matter? Because how we view entrepreneurs—as greedy or altruistic, as virtuous or vicious—shapes the destinies of individuals and nations.” Entrepreneurs are sometimes viewed as unscrupulous, unprincipled, shady, and selfish. They are in it for themselves. They are looking to make a quick buck. For others, entrepreneurs are the innovative engines that drive our economy and provide opportunity. They are the modern day Thomas Edisons who “bring good things to life”. Entrepreneurs are engaging, proactive, forward-thinking, and driven. They provide jobs and new products.

The real entrepreneur breaks both of these stereotypical molds and may be simultaneously saint and sinner. While there may be no certain set of universal characteristics that define the entrepreneur, in this section I identify a few traits that seem to be common to many entrepreneurs.

There are many lists of entrepreneurial traits in the common media as well as in the professional literature. Rather than generate a definitive description, my purpose is to outline a summary characterization so that we can explore the interplay between the two disciplines of entrepreneurship and engineering. Thus one example will suffice, such as Glick-Smith, who identifies twelve characteristics of entrepreneurs:

- Good health
- A Need to Control and Direct
- Self-confidence
- Sense of Urgency
- Comprehensive Awareness
- Realistic Outlook
- Conceptual Ability
- Low Need for Status
- Objective Approach
Emotional Stability

Attraction to Challenges

Describing with Numbers

Many of these characteristics could also describe engineers, such as a realistic outlook, a need to control and direct, an objective approach, attraction to challenges, or an aptitude for describing things with numbers.

Many entrepreneurs are not born but are made by their circumstances. Many find themselves nudged (and sometimes pushed) into entrepreneurship because of difficulties with their current jobs. At some point they find themselves in disagreement with their employers on one or more ethical questions, leading them to make some attempt to influence the tone and disposition of the company. The ethical quandaries vary from the fair treatment of employees to the honest assessment of risk to the justice of strategic corporate decisions. Sometimes the corporation is so big and its tired, old approaches are so entrenched that the nascent entrepreneur is unsuccessful in winning hearts and minds to make a difference in the business decisions. Sometimes the issue is not an ethical dilemma but rather, the company is stifling creativity and slowing innovation. The budding entrepreneur feels stymied from performing and progressing to the best of their ability. She is not allowed to pursue her vocation and calling fully; she is bogged down with boring details that seem unrelated to her expertise and a waste of her talent. Whether due to ethical quagmires or innovation hurdles, at this point the entrepreneur is born – she begins to realize that she could create a new business that would “do it right”. Eventually the entrepreneur breaks away from traditional corporate employment and ventures out on her own.

Once started down this path, many entrepreneurs suffer an identity crisis as their business grows. The first crisis has already been noted: transforming from employee to self-employed. The second is the transformation to an employer. Their previous experiences often influence their choices in setting the vision, tone, and approach of their own company when it comes to treating their own employees properly. As the company grows, they must learn to delegate some responsibilities and must trust their employees to carry out some of the key tasks of the business. This does not come easily because they have often started the business on the belief that they could do it better themselves than anyone else. Giving up that control and admitting that someone else could do it better than themselves is a big step to take. An engineering background can help here because team approaches to large undertakings are common. Those that cannot make the leap to delegation are unable to grow their company because everything continues to depend on them. Those that hire “people smarter than they are” and invest their trust and confidence in others provide the infrastructure needed to grow the business. A maturing process occurs as they begin to take on more responsibility: “I don't want to take myself too seriously, but I want to be taken seriously.” As time progresses, they find that their priorities shift and their time is spent on new, higher level tasks and issues to keep the company going and growing. Rather than performing the detailed, day-to-day tasks that keep the wheels turning, they now are pursuing the broader vision of the company and putting the resources together to make it happen. They must regularly reinvent themselves as their business evolves. As they define the key strengths of their business – the niche that the company fulfills in the economic environment – they also define their own role in leading the organization to capitalize on those strengths. In becoming a good manager, they must move from doing to enabling: “…the leader is the ‘servant’ of his followers in that he removes the obstacles that prevent them from doing their jobs.”

Entrepreneurs are sometimes viewed as gamblers – taking big risks for big returns. But entrepreneurs are not foolhardy. They carefully analyze the risks and work to minimize them. Neither are they timid – when the opportunity arises, they have the courage to take a calculated risk. Sometimes they put a lot on the line – they may need to invest all the cash they have, or mortgage their homes, or take a chance with a new direction that if unsuccessful could be disastrous for their current business. But they are driven because avoiding change can also be deadly. Companies that cannot adapt to a changing environment can quickly wither and die. So the entrepreneur must carefully judge the times and steer the company in a
Many entrepreneurs are non-linear thinkers and sometimes seem a bit scattered in their thinking to more sequentially-minded observers. Their planning takes into account all the aspects of a project simultaneously, rather than moving methodically and incrementally from the first to last step. Their reading style is more suited to hyper-linked articles on the web than traditional printed tomes. This characteristic can be helpful when making tough choices under pressure. The entrepreneur must quickly and effectively assess all the relevant points and make a decision.

Entrepreneurship appeals to many engineers. The creative, innovative spirit of the entrepreneur attracts the engineer who is also inventive and creative. The freedom to design and build one’s own ideas (rather than someone else’s) is also a magnet for some engineers. Despite the similarities, there are also some tensions between engineering and entrepreneurship. For example, engineers often continue to refine and polish their designs, improving the performance and reliability bit by bit over time – until the manager steps in, stops the “fiddling”, and ships the product. This balance between getting it right and getting it shipped is not an easy line. It can be the difference between profit and bankruptcy for the entrepreneur. It can be the difference between pleasant operation and customer injury for the engineer. Engineering as a discipline has continued to refine and formalize approaches to design (in part to address the trade-offs discussed above). For example, Voland describes the engineering design process as an iterative cycle through stages of needs assessment, problem formulation, abstraction and synthesis, analysis, and implementation.

**Biblical Principles to Guide Entrepreneurship**

While examining business from a Christian perspective, Chewning proposes a number of norms for economic systems including providing quality of life, provisioning for the basic needs of the disadvantaged, stewardship, justice, and human rights (among others). Chewning later identifies some norms for specific businesses, which better fit with the more narrower focus of this paper, such as treating employees well, using natural resources frugally, and developing products that lead to a better life for the consumer. Each of these norms finds a basis in scripture, and conversely, certainly many scriptural precepts are applicable to entrepreneurial engineering. In this section, we'll consider a number of promising candidates – but this is just a starting exploration and by no means meant to be a comprehensive list.

**Love Your Neighbor**

“Love your neighbor as yourself.”
Matthew 22:39

But the greatest of these is love.
1 Corinthians 13:13

Jesus summarized the law with a call to love God first and secondly to love neighbors equal to ourselves. The entrepreneur loves his neighbors by providing solutions to their problems, giving them good value for their money, and providing meaningful employment in the community. Contrary to the stereotypical view of the selfish capitalist who puts “me” first, the Christian entrepreneurial engineer chooses which problems to solve on the basis of loving the customer with a kingdom vision. Contrary to greed for worldly wealth, the Christian entrepreneurial engineer puts people before profit, balancing the bottom line so that his business is sustainable through modest margins that do not gouge the buyer.

It is the command to love our neighbor that puts wealth into its proper context and to its proper use. Deuteronomy 8:18 tells us that the ability to make money is a gift from God: “But remember the LORD...
Honesty

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

Deuteronomy 25:14-16

Surely you desire truth in the inner parts...
Psalm 51:6

Speak the truth to each other...
Zechariah 8:16

The Lord repeatedly admonishes us in scripture to seek honesty – often in terms of financial transactions. Dishonest gain is a sin that the Bible repeatedly condemns. For the entrepreneur engineer, this plays out in decisions about how to advertise the features, functions, reliability, and safety of a product. Engineers often develop complex technology that requires significant expertise to design and can therefore be difficult to understand by some stakeholders. The engineer has an obligation to design so that the risks of the product are clear. If the end user can easily abuse a product so that it produces injury, the engineer might be culpable. The entrepreneur mindset might attempt to minimize risk of injury because it implies a liability risk or perhaps a risk of lost customers. Faith provides a stronger and clearer basis for seeking honesty in a technological product.

Honesty extends beyond the technology itself to the design activities surrounding the product. For entrepreneurial engineers who offer services rather than products, they must be honest with their price quotes and their methods of measuring time when they charge for their hours. The temptation to pad hours for an easy increase in profit is certainly a form of using “two differing measures”.

Is there ever a limit to the extent of our honesty? Is the entrepreneurial engineer obligated to enumerate every blemish and shortcoming of the product to each prospective customer? Just as one might be self-constrained in responding to the question “Does this make me look fat?” I suspect that there is some legitimate point where restraint is ethically allowable. Careful judgment is necessary to discern which information is necessary and proper for the customer to receive and which information can be properly omitted.

Caring

“Which of these three do you think was a neighbor to the man who fell into the hands of robbers? The expert in the law replied, 'The one who had mercy on him.' ”

Luke 10:36-37

However, there should be no poor among you, for in the land the LORD your God is giving you to possess as your inheritance, he will richly bless you...

Deuteronomy 15:4

...do not be hardhearted or tightfisted toward your poor brother.

Deuteronomy 15:7

"Go, sell everything you have and give to the poor, and you will have treasure in heaven. Then

1 Scripture taken from the HOLY BIBLE. NEW INTERNATIONAL VERSION®. Copyright © 1973, 1978, 1984 International Bible Society. Used by permission of Zondervan. All rights reserved.
come, follow me."
Mark 10:21

God calls us to care for our neighbor and furthermore, to pay special attention to the poor and disadvantaged. Engineers on their own, might not think through the implications of their designs as they relate to the poor (because they might not think the poor can afford a product and thus are unaffected). But as engineering entrepreneurs, they may think more broadly about how they could design affordable products, or products targeted at the disadvantaged, or perhaps development of new businesses in economically depressed areas. Consider this point made to businessmen (but certainly with implications for engineers): “Product should do something positive…consider whether or not a product has substantial potential for harm…product’s primary intention should not be the creation of status for the buyers…we must be concerned about products that use resources inefficiently or create problems because of difficulties in disposing of them.”

The entrepreneur has an additional obligation with respect to this principle, because she often has employees – and as an employer, she is in a position of power over them. Caring for employees can take many forms. Depree puts it in terms of enabling: “….the art of leadership: liberating people to do what is required of them in the most effective and humane way possible.” Chewning puts it even more broadly, speaking of “ways to extend God's shalom in business…provide goods and services that enhance the lives of individuals and society…create and maintain jobs…provide a fair return for committed investors and owners…allocation of business resources to community projects.”

Entrepreneurs often experience God's blessings in producing wealth: “The blessing of the LORD brings wealth, and he adds no trouble to it.” (Proverbs 10:22) This puts them in the happy position of having resources to share with the poor and in so doing, share God's special concern for the less fortunate.

**Spiritual Gifts**

It was he who gave some to be apostles, some to be prophets, some to be evangelists, and some to be pastors and teachers, to prepare God's people for works of service, so that the body of Christ may be built up until we all reach unity in the faith and in the knowledge of the Son of God and become mature, attaining to the whole measure of the fullness of Christ.

Ephesians 4:11-13

Now you are the body of Christ, and each one of you is a part of it.
1 Corinthians 12:27

If work is a calling, then it is likely that our spiritual gifts are beneficial to our vocational pursuit. Our faith should infuse every part of our life, including our work life, and thus talents for entrepreneurship and engineering should be seen as God-given gifts to be used for his glory by serving the community. This community is not exclusively the church (though special attention must be paid here), as Galatians 6:10 indicates: “Therefore, as we have opportunity, let us do good to all people, especially to those who belong to the family of believers.”

**Respect for Image Bearers**

So God created man in his own image, in the image of God he created him; male and female he created them.

Genesis 1:27

Whoever sheds the blood of man, by man shall his blood be shed; for in the image of God has God made man. As for you, be fruitful and increase in number; multiply on the earth and increase upon it.
Genesis 9:6-7

As image bearers, each person must be respected as a whole person. Depree explains: “…it is fundamental that leaders endorse a concept of persons. This begins with an understanding of the diversity of people’s gifts and talents and skills. Understanding and accepting diversity enables us to see that each of us is needed. It also enables us to begin to think about being abandoned to the strengths of others, of admitting that we cannot know or do everything.” The Latin phrase *imago dei* literally means “image of God” and is often used to describe the idea that fundamental human nature reflects the Creator. Entrepreneurism and engineering alike are enriched by understanding *imago dei* and that our own creativity is part of that reflection.

Stewardship

The earth is the LORD's, and everything in it, the world, and all who live in it;

Psalm 24:1

If anyone has material possessions and sees his brother in need but has no pity on him, how can the love of God be in him? Dear children, let us not love with words or tongue but with actions and in truth.

1 John 3:17-18

It is easy to imagine that the business that you built from the ground up with your own hands is yours and no one can lay claim on it. But scriptures tell us everything is God’s – we are merely the stewards of those resources. In scripture, from the Old Testament (such as the cultural mandate of Genesis 1:28) and the New Testament (such as the parable of the talents in Matthew 25), we are reminded that God gives us resources to use to his glory, not for our personal benefit alone. The admonishment to tithe (e.g., Leviticus 27:30) tells us that God expects us to return some resources back to him rather directly – but this does not release us from using the rest responsibly. The engineering mindset can be frugal with resources in optimizing a design, but it can also be wasteful in pursuing new technology for its own sake without considering the real need to be addressed. Thus, the entrepreneurial mindset may be a useful corrective to keep creative energy focused, so that resources are expended to maximum benefit – where benefit is measured by a higher metric than simply profit & loss statements, but against kingdom standards. These two measures are not (necessarily) in tension – a profitable business implies a sustainable means to provide good products for a community as well as good jobs for community members.

Plan for Good while Trusting in God

But those who plan what is good find love and faithfulness.

Proverbs 14:22

Go to the ant, you sluggard; consider its ways and be wise! It has no commander, no overseer or ruler, yet it stores its provisions in summer and gathers its food at harvest.

Proverbs 6:6-8

Some trust in chariots and some in horses, but we trust in the name of the LORD our God.

Psalm 20:7

Does placing one's trust in God obviate the need for planning? The first two passages above counter that notion. God calls us to make plans that result in good things for God's people. The planning does not flow out of a fear that we are on our own, without God's help. Rather, the planning is an outgrowth of our faith in God resulting in good deeds (James 1:14-26). Chewning suggests that good planning is a prerequisite to seeking justice through business: “Planning is vitally important for Christians who want to act justly in business. We must anticipate decisions in order to ensure a variety of options…Doing justice – doing what is right – requires good planning that involves everyone in the business and that is based on
broad counsel and advice."²⁷

Although planning may be an essential component of Christian pursuit of entrepreneurship, there is the danger that the success from well-laid plans will be attributed to the plans rather than to God. Careful planning may be perceived as taking hold of one's own destiny, leading to less trust in God. An engineering education also stresses planning and can easily tempt one to believe a product is solely one's own. Furthermore, technological design is often about control – control of electricity, control of forces, control of processes, control of information, even control of nature. An engineer can easily delude himself that he is in control of his own destiny. So the entrepreneurial engineer must be doubly careful to trust in God.

Case Studies and Examples

In the previous section, we examined a number of Biblical principles that could guide a Christian engineering entrepreneur. This section starts from the other direction, taking some examples of typical tasks or issues encountered by the entrepreneur and looking for guidance based on the principles elicited earlier.

Product Screening

Engineering entrepreneurs have lots of bright ideas for new products. The important task of filtering these ideas down to a few that will be pursued in earnest is called product screening. This is not an easy job – for every 100 ideas, perhaps only ten are pursued. Of every 10 pursued, perhaps only one actually becomes a profitable product. This pipeline of ideas can be the lifeblood of a business and the filtering process is essential. One approach to product evaluation is the NABC method from Carlson and Wilmot²⁸, who base their approach on experiences at SRI International (a business responsible for HDTV and robotic surgery innovations, among others). NABC evaluation is a four-step process. First, a customer-centric Need is described. This step carefully defines the problem to be solved with a clear focus on the potential buyer. Other innovation experts have also pointed out the need to focus on the need: “The product innovation activities of a business are greatly enhanced by the adoption of a market orientation... [meaning] that all business activities are focused on meeting the needs of customers in identified market segments.”²⁹ Second, a possible Approach is developed. This is the step where the engineer makes plans and invents novel methods of solving the problem. Third, the Benefit of the approach in filling the need is elaborated and quantified. This is where the so-called “value-proposition” is detailed, building the case for why the buyer will be convinced to purchase the proposed product. Finally, the Competition is identified. The entrepreneur must be aware of what other businesses are doing to fill the same need before taking the risk of using development resources to pursue a new approach.

Focus on the customer is not only a good business idea, but it is also a good spiritual principle if we see the customer as our neighbor. The principle of loving your neighbor as yourself is congenial with the customer-centric approach of the entrepreneur. By focusing on the customer's need and how the proposed solution best solves that need, we are caring for the customer.

A second principle important for product screening is stewardship. Engineers tend to spend too much time on the Approach step and not enough time analyzing the Need. The entrepreneurial mindset can act as a corrective here, channeling the engineering energy to the most valuable solutions, where “valuable” is measured by the customer. Terminating the pursuit of a product idea because a competitor has a strong product in that domain already is not only good for business, but it is also compatible with the scriptural call to stewardship. While competition can spur one to develop better products that provide good value to customers at reasonable costs, it can also create waste through if development and production resources are expended for a duplicate product that has nothing distinct to offer.

Finally, the principles of honesty and caring influence our communication with the customer. Sometimes we may assume that we know what is best for them, but the only way to determine their needs effectively
is by honest and open communication about the project and the goals of the client.

**Hiring Employees**

One of the great joys of entrepreneurship is creating jobs. Work is a God-given calling. It is part of our human identity and a reflection of our Creator. Created in God's image, we are made for work – just as God worked for six days and rested on the seventh day after his creative work was done, he calls us to work. This calling is also part of our role as stewards, mandated to cultivate the resources with which we are entrusted.

When considering whether to hire, sometimes it is not clear if the opening is because of a temporary need or part of a long-term growth trend. What first appears as a “blip” may actually be one step in a growth curve. In the moment of decision it is not clear what the future holds. I have seen this challenge during my sabbatical. Once we have hired someone, we have a strong obligation to continue providing work for them. Their livelihood now depends on the company. This has sometimes led to a hesitancy to hire because we couldn't be sure that business would remain good. Of course the failure to hire might mean lost opportunity and business, which could impact the existing employees. Failure to hire might require existing employees to work longer hours to fill the gap. The principle of caring for the poor is important here, but it may be applicable to both the potential employee looking for work and also to the current employees impacted by the decision. The principle of planning for good while trusting in God may also provide the courage to move ahead with hiring even when the future is uncertain.

Part of our hiring process has included a “red flag” system. Several members of the current staff participate in the interviewing of a potential new employee. If any one of the interviewers finds a problem during the interview or even has an intuition that the applicant would not fit in well with the company, we treat this red flag seriously and normally do not make an offer. Jim Collins discusses the practice of hiring the best people for the job in his book *Good to Great*. He terms it “getting the right people on the bus.” The idea is that some people just don't fit in with the direction a company is heading. Sitting on that bus is bad for the rest of the bus riders and bad for that person. Collins notes that it may be the case that a particular employee is on the right bus (belongs in the company), but is simply in the wrong seat. This is a recognition of the gifts of each person. God gives each Christian spiritual gifts that surely are visible during their working hours. These gifts are a complement to the gifts of others and should be used in the proper place in the community. Part of the hiring and interviewing process should recognize that not everyone (even talented individuals) are necessarily the right match for a particular company.

Once hired, the entrepreneur has obligations and responsibilities towards the new employee. For example, as image bearers of God, every employee deserves respect. Management should listen to employees and provide for their needs. The first goal of personnel managers should be to enable the people they supervise to do their jobs well, to help them flourish in their roles. Caring for employees includes providing transparency of communication, opportunity to interact and collaborate, and a pleasant physical environment. For example, during my sabbatical, part of the evaluation process in selecting a new building for the company was the criterion that every employee would be able to see the outside from their workstation and thus have some measure of natural lighting.

Even when it is necessary to terminate someone's employment, this must be done with respect and caring. Firing an employee should be one of the hardest, most gut-wrenching tasks a manager performs. The decision should be made with one's head, but it must be carried out with one's heart. The principles of caring and honesty are important for the manager to observe. Honesty with an employee who isn't fitting in or cannot perform their expected duties is also caring for them because they may need to do some self-evaluation and introspection about their own needs, wants, talents, and abilities. God surely has a place and a plan for them, even if it is not in that particular company.
Project management

Choosing the right number of engineers to staff a project is a difficult task. During my sabbatical, this issue often arose. Family is important to our company and we aim to keep the work week at 40 to 45 hours to allow all employees to spend time with their loved ones. We believe that requiring heavy overtime for extended periods of time is a sign of poor planning. Project managers should anticipate the staffing needs of a project so that each member of the team can work a normal week most of the time. An occasional end-of-project push that requires extra time is acceptable, but not as a long-term strategy. Some hurdles to implementing the goal of reasonable hours for staff include occasional difficulties in finding the right people to hire in order to augment the staff as needed, the difficulty in predicting changes in project needs, and even the psychology of the project. This last one is related to the old 90-10 rule. We tend to choose the easiest parts to work on first, leaving the most difficult tasks as the last 10% of the project, which then take 90% of the time. This leads to a misperception that “we’re almost done” even though the project continues to drag on for weeks or months. Principles of honesty and integrity demand that managers learn from past projects and find ways to better predict the actual completion of the project. This may include a requirement that the more difficult parts of the project are not left to the end (this is one of the principles of Agile software development, for example).

Project managers must be excellent communicators. Everyone interprets and sees things from a different angle. Thus the manager must be able to put themselves in someone else's shoes and understand how they might translate the same words in different ways. Active listening skills (such as asking questions and providing regular feedback to check understanding) are essential. The manager does not always necessarily know who will receive their communication. A memo, report, or email might land in the hands of someone far removed from the manager. This unseen audience will interpret the report from their own point of view, so the manager should over-communicate the context and background in anticipation of this wider audience.

Communication to an employee about their performance must be done with care. Milton Kuyers, a long-time Christian entrepreneur and businessman has described the balance succinctly: “Praise in public, but discipline in private.” Employees who are complimented in front of their peers will be grateful for the encouragement and continue to take pride in their work; employees who are publicly reprimanded will be so shamed and embarrassed that they may not recover for months or even years. The principle of loving one's neighbor is present here in two forms: tough love that understands discipline is necessary and caring love that does not use humiliation as discipline.

Another dilemma managers face is the proper approach to bidding on a project. The customer wants the lowest price. But lower price on a firm, fixed-price bid may come at the cost of lowered quality, increased risk, or cutting corners in some way. On a time & materials quote, an unscrupulous bidder may purposely bid low, knowing full well that the actual number of hours will be far more than they quoted. The principles of honesty and justice are important here: “Doing justice in the marketplace means there is an honest relationship between the quality of products and their prices.”

Conclusion

This paper is an initial foray into identifying some Biblical principles for engineering entrepreneurs. Just as in engineering, discernment is essential, as often there are no clear cut answers. Having established a starting point, a natural extension of this topic would be an exploration of some pedagogical and curricular techniques for the engineering classroom. For example, many educators already use real-world projects with actual customers. But students often view these projects (often part of a senior design capstone course) as a single-point solution. They might be designing a clean water system for a third-world village, but the students only consider this single customer. An business vision of the project would consider how a design could be replicated and distributed, becoming a small business that organically disseminates the benefits of the engineering product to many villages, not just one. This approach might
not only be considered an entrepreneurial approach but also an engineering systems approach – widening the definition of the problem to provide the best overall solution.

Many engineers aspire to be entrepreneurs. The arts and disciplines of entrepreneurship and engineering are a complementary combination which ought to be informed by our faith. Christian engineering educators should be aware that many of their students will pursue entrepreneurship and thus should equip them with Biblical principles that are helpful to the life and practice of this dual vocation.

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References

[22] ibid, p. 15.
[27] Chewning, p. 120, 123.


[31] Chewning, p. 29.
Abstract
Finding significance in the practice of engineering requires, for Christians, coming to terms with how engineering relates to their faith. Yet, there is little difference between how Christians and those of other faiths or no faith do engineering. The science they apply is the same; their design process is the same; even their design norms and engineering ethics are quite similar. Does this mean that faith is irrelevant to engineering? Or, have Christians in engineering been so little influenced by their faith that their practice is like those of no faith? This paper suggests a different answer, one based on the doctrine of common grace. Common grace refers to the gifts God gives to all humanity and not preferentially to those who also receive special or saving grace. Examples include rain, reason, a moral sense, and engineering. Viewing engineering as a common grace activity explains the similarity of engineering practice among people of all faiths. This explanation offers perspective on certain approaches to integrating faith and engineering and can help Christian engineers to work effectively as part of diverse teams. Common grace also brings about the similarity of engineering ethics among people of all faiths, but the role of common grace is sometimes overlooked in Christian discussions of engineering ethics. While the doctrine of common grace explains the remarkable similarities between engineers of all faiths, it also suggests a distinctively Christian motivation for engineering. It is through common grace activities like engineering that Christians serve Christ as we also serve our neighbors.

Introduction
Christians believe and teach that matters of world view are vitally important to how we live our lives, yet these matters seem to make little difference in the practice of engineering. Shaw writes,

> The prevailing worldview of engineering designers does not often lead to radically different engineering practice when compared to that resulting from a Christian worldview. This raises some important questions of its own. How is it that Christian and non-Christian engineers can agree that engineering is an important endeavor, that we do need moral standards, and why do they reach similar final designs when several presuppositions about the nature of the world and the nature of man are quite different?¹

Shaw answers this question in terms of the doctrine of common grace. This paper expands on the connection between engineering and common grace by considering how the doctrine offers insight into three questions about the relationship between faith and engineering:

1) Why does the engineering method seem to be the same among people of all faiths?
2) Why are engineering ethics largely the same among people of all faiths?
3) What distinguishes a Christian engineer from engineers of other faiths or no faith?

Common Grace
The doctrine of “Common Grace” is based on the Biblical teaching and empirical observation that, despite the fall, God sustains creation and restrains in part the falleness of mankind from coming to its full expression. Berkof describes the two components of common grace.
When we speak of “common grace”, we have in mind, either (a) those general operations of the Holy Spirit whereby He, without renewing the heart, exercises such a moral influence on man through His general or special revelation, that sin is restrained, order is maintained in social life, and civil righteousness is promoted; or (b) those general blessings, such as rain and sunshine, food and drink, clothing and shelter, which God imparts to all men indiscriminately where and in what measure it seems good to Him. References to the former aspect of common grace in Scripture include Romans 2:14-15 and to the latter Matthew 5:43-45.

Common grace is distinguished from “special” or “saving” grace based on those to whom the grace is given. The gifts of common grace are given to all humankind, while those of special grace only to those who are saved. Some examples of each are given in Table 1.

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<th>Special</th>
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<td>Salvation</td>
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<td>Gift of the Holy Spirit</td>
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<td>New Heaven and Earth</td>
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<td>Food, clothing, shelter</td>
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<td>Sense of right and wrong</td>
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<td>An orderly creation and the capacity to control it</td>
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<td>The Bible</td>
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Table 1: Examples of Common and Special Grace

The Similarity of Engineering Practice

This paper suggests that the similarity of engineering practice between Christian engineers and engineers of other faiths is not due to a fundamental independence or mutual irrelevance between engineering and Christian faith, but rather is due to the nature of engineering as a common grace activity. Gidley writes “Good engineering makes real provision against real evils, bringing by God’s common grace longer life, ease of toil, and pleasurable recreation.” To call engineering a common grace activity is to say that it is a gift of God, given both to those who do receive and to those who do not receive special grace. Both groups receive the same gift from the same Giver, so no substantial difference in the operation of the gift is expected. This proposition has several corollaries which are illustrated in the following examples.

Coexistence of Christian faith and engineering

At a Christian college, engineering students take Bible survey classes, engineering classes begin with a short devotional or prayer, famous Christians in science and engineering are identified, and faculty model Christian values. These are all valuable components of a college-level Christian education, and each is an example of coexistence of faith and engineering: at the same college, within the same class period, within the life of the same individual.

Understanding engineering as a common grace activity and therefore as God’s gift means that there is nothing contradictory between being a Christian and being an engineer. We expect to find the practice of engineering among Christians. However, recognizing both engineering and Christian faith as gifts from
the same Giver draws us to look for a deeper connection between the two, beyond a mere coexistence. As Berkhof writes, “there are not two kinds of Grace in God, but only one”.

Collaborating with unbelievers
A Christian engineer is sent on a six month training assignment to work at a company facility in an Islamic country. His colleagues in country are warm and hospitable and he is learning a great deal from their experience and technical insight. They make a sincere effort to include him in all their engineering tasks and the recreational activities they enjoy. He appreciates their warm reception of him, but their open practice of their faith throughout the day makes him uncomfortable.

Although the Christian engineer in this case is learning from engineers of a different faith, it doesn’t make the engineering subject matter or even the engineering abilities of his colleagues any less a common grace gift of God. Matthew 5:45 states the obvious, “the rain falls on the just and the unjust”. In providing students with numerous role models of the coexistence of Christian faith and engineering excellence, there is a risk of implying that perhaps the rain does not fall as freely on people of other faiths. Referring to ancient Greek writers whose work he admired, Calvin writes,

We should let that admirable light of truth shining in them teach us that the mind of man, though fallen, and perverted from its wholeness, is nevertheless clothed and ornamented with God’s excellent gifts. If we regard the Spirit of God as the sole foundation of truth, we shall neither reject the truth itself, nor despise it where it shall appear, unless we wish to dishonor the Spirit of God. Those men whom scripture calls natural men, were indeed sharp and penetrating in their investigation of inferior things, let us accordingly learn by their example how many gifts the Lord left to human nature even after it was despoiled of its true good.

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

Christianized forms of engineering
Exploration for oil and gas involves forming integrated histories of the biological, chemical, and geological processes that have acted in a region of interest over millions of years. From these histories, geoscientists evaluate whether the conditions have been favorable to produce and accumulate economic quantities of hydrocarbons. One oil company has a different approach to such regional geology studies,

Following continued assessment of all geological and geophysical data, renowned petroleum engineers, geologists and geophysicists continue to ask … “where is the most logical place to drill where we can be sure of ‘tapping’ those vast reservoirs of oil?” Yet, there is an “ANSWER”, and it is found in the most “overlooked” source of geological information available to mankind today... the Bible! The archaeologists have found the Bible to be their unerring guide to hidden treasures ... Why cannot the geologists utilize the same “tool” to find this oil? So we searched the Bible and found numerous occasions where, I believe, the Bible … makes direct reference to the existence of OIL in Israel.
For this discussion, let us leave aside exegetical questions about the specific passages in view; the interested reader will find these addressed in the cited reference. Consider instead the question of whether or not the process of finding oil is made more “Christian” by replacing, in part, its foundation of evolutionary science with Biblical information.

An important corollary of common grace is that all truth is God’s truth, so that the application of scientific truth is no less God’s gift and no less sacred than the application of Biblical truth. Thus, oil exploration which incorporates Biblical information is not ipso facto more Christian than oil exploration which does not. The value of both approaches for humankind and in the eyes of God must be reckoned according to their motivations and outcomes, not according to the source of their information.

The Similarity of Engineering Ethics

There does not seem to be a Christian version of engineering ethics which is distinct from the general ethics of the profession. Jordan, et al review the N.S.P.E. code of ethics from a Christian perspective and find few points of disagreement. Eisenbarth and Van Treuren comment on the relationship between Jesus’ greatest commandments and engineering codes of ethics,

Although these two commandments are central to the Christian faith and extremely rich compared to all secular and non-Christian moral codes, many of their practical aspects are present in the Codes of Ethics adopted by most engineering societies. Additionally, these normative principles focus on the human element and do not specifically address the broader aspects of creation, i.e. issues dealing with animals or the environment.

The similarity between engineering codes of ethics and Biblical ethical norms seems to be due to two aspects of common grace. First, there has been significant influence of Judeo-Christian values in western society. Such influence of special revelation in society generally is an aspect of common grace. Mitcham finds British influence in the ethical codes of engineering societies in Asia. However, influence on the content of society ethical codes is not the same as influence on the underlying moral values that pre-date and motivate the writing of codes. Martin and Schinzinger observe,

Early cultural anthropologists tended to overemphasize the extent of moral differences between cultures… More recent anthropologists have drawn attention to underlying similarities… They have noted that virtually all cultures show some commitment to promoting social cooperation and to protecting their members against needless death and suffering. And beneath moral differences often lie differences in circumstances and in beliefs about facts, rather than differences in moral attitude.

The impact of general revelation in producing a similarity of “moral attitude” is also an aspect of common grace. Common grace as the source of the similarity in engineering ethics has certain practical corollaries which are explored in the following examples.

The role of common grace in engineering ethics

In explicitly Christian developments of engineering ethics, there is a tendency to provide Biblical texts to support each ethical principle. For example, Swearengen writes,

God’s desire that biodiversity be maintained is codified in the Noahic covenant. In the book of Job, we read of God’s delight in creatures that have no apparent usefulness to humans—thereby discrediting a purely utilitarian worldview. Human activity that results
in extinction of species is not only a biological concern for the ecosystems that support human life, it is in opposition to God’s intent. So our theology of technology must elevate maintenance of biodiversity to obedience to God.\textsuperscript{12}

We understand today the benefits for disease resistance of a diverse gene pool in farm plants and animals and the loss of potential scientific knowledge when an endangered species is lost. However, it seems anachronistic to read into Genesis 8:20-9:17 (where we find the Noahic covenant) the modern concerns of protecting genetic diversity within a species or the maintenance of every species. In Job, the parade of creatures serves to contrast the omniscience and omnipotence of God with the finite perspective of Job more so than to establish an ethical imperative for maintaining biodiversity. It is not so much Biblical information as it is ecological research, a common grace product from scientists of all faiths, that has compelled—and should compel—Christians to agree with Swearengen’s elevation of maintaining biodiversity to obedience to God.

In presentation of engineering ethics from a Christian perspective, a distinction should be made between those points which historically were derived from Biblical ethics, those which can be derived from Biblical ethics, and those which extend beyond the scope of special revelation. Attempting to validate the last category by proof-texts or implying that the second category is part of the first denies the importance of God’s common grace. By common grace, people of all cultures have a similar moral sense and therefore adopt similar ethical standards for engineering. By common grace, new dimensions of ethical understanding may develop which are not prominent in the Bible, such as care for the environment. A Christian perspective on engineering ethics must recognize the dependence of engineering ethics on God’s common grace, not just on special revelation, and therefore value and recognize the contributions that God has enabled people of all faiths to make to a Christian understanding of engineering ethics.

**What does Christian faith have to offer?**

If we feel some disappointment that Biblical ethics does not seem to have made a clear and distinctive contribution to engineering ethics in our secular society, it is worth recalling that the Christian faith is not a new ethical system and does not offer complete prescriptions for all of life. Indeed, measured by volume of regulations for all aspects of life, it is quite inferior to the 1\textsuperscript{st} century Judaism from which it emerged. According to Galatians 5:13-14,

\begin{quote}
For you, brethren, have been called to freedom (from the Law), only do not use your freedom as an opportunity for the flesh, but through love serve one another. For all the law is fulfilled in one word, ‘You shall love your neighbor as yourself.’
\end{quote}

So, while Christians are set free from the obligations of the Law, and thus the New Testament does not contain extensive or systematic ethical instruction, we must seek to understand how to live ethically so that we can more effectively show love to our neighbors. This leaves a significant place for common grace and therefore insight from people of other faiths and no faith in developing a Christian understanding of what it means to love our neighbors through the practice of engineering.

It should be noted that Christians who teach engineering have heeded the Biblical mandate to love their neighbors through engineering practice and there is a far greater emphasis on teaching engineering ethics and the value dimensions of engineering design at Christian colleges than is typically found in secular universities.\textsuperscript{13}
Distinctively Christian Engineering

The doctrine of common grace explains the similarities in technical methods and ethical norms between engineers of all faiths. It also assists in identifying distinctives which Christian engineers should embrace.

**Common grace ministries**

As graduation approaches, an engineering major is wrestling with whether to accept a job offer from a large high-tech company or to prepare for full-time Christian ministry by attending seminary. She questions whether the improvements to computers that she would develop at the high-tech company have any value or purpose in God’s plan for Creation.

Although the Bible has little to say specifically about engineering, it says a great deal about common grace activities. God’s purpose for engineering can be understood in the context of a general purpose for all common grace activities. In the Genesis creation accounts we find that humankind was created to multiply, fill the earth, subdue the earth, rule over it, and tend the earth to raise food to eat. These common grace activities find their value and purpose as our way to fulfill God’s command to love one another and become God’s providential means of caring for humanity. Hardy describes Luther’s concept of vocation:

> Thus the call to love one’s neighbor goes out to all, but what this call requires of me in particular is discovered in those stations which I presently occupy: as a parent I am called to care for my children, as a teacher, to provide an education for my students, as a member of a Christian congregation, to exercise my spiritual gifts in order to build up the community of faith… Through the human pursuit of vocations across the array of earthly stations the hungry are fed, the naked are clothed, the sick are healed, the ignorant are enlightened, and the weak are protected. That is, by working we actually participate in God’s ongoing providence for the human race.”

Luther seems to focus on the exterior working of common grace in providing for physical needs, while Mouw emphasizes that the spectrum of common grace also includes interior transformation of people to a better state. He offers the useful term “common grace ministries” to refer to those activities which “promote the goodness associated with common grace”. People of all faiths can be common grace ministers, however there is a uniquely Christian motivation for common grace ministry. This is found in the New Testament equation of common grace activities with service to Christ (Matt. 25:40; Col. 3:23-24).

**Conclusion**

The doctrine of common grace explains the similarity of engineering practice and engineering ethics among people of all faiths or no faith. It also provides useful insights for a Christian perspective on the nature of engineering and on the integration of Christian faith with engineering. Discussion of these issues can help students understand more clearly God’s gift of engineering to humankind, and to appreciate more fully the words of the hymn writer: “O to grace, how great a debtor daily I’m constrained to be.”
References


[3] The Bible, or “special revelation” is available to all humankind, which makes it a gift of common grace. Berkhof identifies special revelation (presumably the ethical teaching in the Bible) as one of the influences by which God restrains the sinfulness of humankind.


[15] Richard J. Mouw, He Shines In All That’s Fair, Eerdmans: Grand Rapids, 2001., p. 81
Deus Machinator: God the Engineer

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Abstract

This essay reflects on the traits of God that reflect the ideal traits of engineers. Engineers apply their intellect to subdue and control the forces of nature, not as an end in itself, but rather, like God, this is accomplished for the greater good, particularly for the good of other human beings. In this sense, seeing the engineer in God helps us to see the good and proper role of engineering. Essentially, God is the “ideal” engineer, and provides a model for the ideal engineer for which we strive. Rooted in the pre-Fall commands to create and subdue (cf. Genesis 1:28), comes the distinct realization that our engineering work is a participation in God’s continuing work in the world.

This assessment of Deus Machinator has another, more fundamental aspect. If properly understood in its pre-Fall roots, this call to be an engineer is an aspect of our nature, and call to all people. These calls to create, to subdue, and to tend, are fundamental to the very nature of each person. In this work we must apply the free will, as independent agents that God created us with. This is truly ‘Engineering’ in the modern sense of the term: not just an understanding or a search for truth, as with the sciences (both Theological and Natural), but using understanding to do, to act, to build – in imitation of God [Ephesians 5.1]. In this sense, we have much to learn from the nature of “God the Engineer,” in the necessity of imitating God in our doing in accordance with His Will [cf. Is 55:11].

Defining the Engineer

Engineers are individuals who combine knowledge of science, mathematics, and economics to solve technical problems that confront society; “…a person who applies science, mathematics, and economics to meet the needs of humankind”(Reece & Hooltapple, p. 2); alternatively defined, “Engineering is the art of directing the great sources of power in nature for the use and convenience of man”(Florman, p. 66).

Individually, engineers are those who engage in the practice of engineering. The root of the word engineer derives from engine and ingenious, both of which come from the Latin root in generare, meaning “to create.” In early English, the verb engine meant “to contrive” or “to create.” The word engineer traces to around A.D. 200, when the Christian author Tertullian described a Roman attack on the Carthaginians using a battering ram described by him as ingenium, an ingenious invention. Hence an engineer is a person responsible for developing such ingenious engines [of war](Reece & Hooltapple, p. 3). At their roots, engineers are problem solvers – ingenious problem solvers. Engineers create products and processes to improve and to enhance the convenience and beauty of our everyday lives(Schinzinger & Martin, p. 1). Thus, engineers are civilizers, since civilization in its most elemental sense means bringing humans physically out of the state of primitive savagery(Florman, p. 180).

Engineering knowledge is rooted in scientific knowledge; however they appear to be separate spheres of knowledge that are both man-made(Wise). Historically, each engineering sub-discipline has developed its own body of knowledge, whether codified or not (IEEE, INCOSE, ASCE). Among engineering educators, it is commonly accepted that engineering knowledge, however much based on the study of mathematics, science and engineering science, is insufficient. “…there is a big gap between scientific research and the engineering product which has to be bridged by the art of the engineer. The creative, constructive knowledge of the engineer is the knowledge needed to implement that art.”(Vincenti, p. 4)

Beyond engineering knowledge and skill, there are the behaviors that help engineers succeed, bring honor to their profession, and make technology a force for good in the world. Engineers are expected to link effectiveness and creativity, where conscientiousness is the virtue suggested to be the most valuable for
engineers. In sum, engineers identify problems, construct solutions, and use their knowledge and skill to change the status quo into a new situation that is better for mankind.

**Deus Machinator – God the Engineer**

Given the view of Engineering outlined above, God can be viewed as an engineer – identifying problems, constructing solutions – wielding His power over creation for the good of Man. In this sense, seeing the engineer in God helps us to see the good and proper role of engineering. Essentially, God is the “ideal” engineer, and provides a model for the ideal engineer for which we strive.

Consider the first acts of God in history: In the beginning, according to His Wisdom (cf Wisdom 9:9, Revelations 4:11), the very first thing that God does is to recognize a ‘problem,’ and solve it: “The earth was a formless wasteland...” (Genesis 1:2). He addresses this ‘problem’ by giving the world form (Genesis 1:3-13) and then fills the “wasteland” and makes it good (Genesis 1:14-31). God’s ‘engineering’ is creation – even the very laws that govern its operation, were made with his omnipotent power, made out of love for the creatures made in His image. His creation is perfect love, wielding omnipotent power in creation.

Another aspect of this view of God is to recognize Him as the accountable, effective actor. When God sets out to accomplish a task, it is accomplished in an exemplary fashion.

“For just as from the heavens the rain and snow come down and do not return there till they have watered the earth, making it fertile and fruitful, giving seed to him who sows and bread to him who eats, so shall My word be that goes forth from My mouth; it shall not return to Me void, but shall do My will, achieving the end for which I sent it.” (Is 55:10-11)

This reflects one of the great gifts to mankind – the ability and will to act and work. As engineers, we act to formulate requirements and designs that, when constructed, are intended to achieve the end for which they were created. While imperfect, these requirements and designs both record and reflect human will applied to a purpose. The assertion is that this is an act of creation (or sub-creation); that when we, through our work and actions, take things and engineer them into something that was not, we are in fact creating, making a ‘new nature’ for the thing.

These human efforts to engineer only manipulate the gift of creation. But when faced with the intricacy of the created world, we humans can only marvel at the wonder of God’s creation, and of our own place therein. “When I behold your heavens, the work of your fingers, the moon and the stars which you set in place - what is man that you should be mindful of him, or the son of man that you should care for him?” (cf. Psalm 8: 4-5) Similarly, the effort to step back and examine the work is itself an imitation of God, for “God saw all that He had made and behold, it was very good.” (cf. Genesis 1:31) In imitation of God the engineer, engineers should preserve a sense of wonder for His creation and this wonder should also extend to the own work of our hands, our engineering creations.

We model God in our creations, wielding our limited power, with imperfect (fallen) love over ourselves and nature. Our creations are made using the gifts and talents He bestows – both the material and our talent for creating new things for some purpose. What we make out of our imperfect love – changes the status quo into a new situation that is (when rightly ordered) better for mankind. When creating to rightly, or better order our now fallen world, we are acting (cooperating) with, and helping to restore, the Kingdom which Jesus inaugurated (cf. Mark 1:15). Those called to engineering should see themselves in the image of Deus Machinator, collaborating with creation, actively responding to our call to work as co-creators with Christ in building up the Kingdom.

The impact of this view is subtle – it begins with the recognition that created beauty includes that which is created by the workings of creation, including people. The impact includes recognition that we, in
working in the world with the limited powers He has bestowed, model God in whose image and likeness (Genesis 1:27) we are made. The observation needs to be made that this ‘power’ to participate in creation – in our actions and our work (cf. Genesis 2:8) is part of who God made us to be before the Fall, and like other aspects of the Human Person (e.g., our sexuality, marriage) have a right ordering innate to who God has made us to be. In employing these gifts of who we are, we must also collaborate with Grace in recognizing Whose we are – that we allow ourselves to be actively guided by the Holy Spirit (Acts 1:8). Thus we have, by Grace, the ability to collaborate with Grace in the continuation of creation.

Collaborating with Creation

Genesis 2:8 is a key passage worthy of reflection. Herein, God commands Adam to “keep and to till” the Garden of Eden. This can be seen in a more fundamental way by considering familiarity Adam and Eve shared with God prior to The Fall. The sign of man’s familiarity with God is that God places them in the garden where they lives, “to keep and till” the garden (cf. Genesis 2:8). At this point, work is “not yet a burden (Genesis 2:15, cf. Genesis 3:17-18), but rather the collaboration of man and woman with God in perfecting the visible creation.” Through sin, man broke this relationship with God, yet God in His mercy renews this relationship through His Son, forgives us, and restores mankind to relationship with Him. Yet the responsibility of collaborating with God in perfecting the visible creation remains.

A reasonable view of this is that we are called to work on solving human problems, but without arbitrary or destructive domination. We participate with God in His work of creation, but unlike His authority over creation, our authority is not absolute. While we work to direct or subdue the forces of Nature, we must act in a moral manner: for the good of our fellow humans, and not to the abuse of the natural order. As we work to ‘keep and to till’ today we need to collaborate with Our Creator in manipulating and controlling the forces of Creation. In the image of God, the engineer applies his or her intellect to subdue and control the forces of nature. But this is not the end in itself. The engineer does this, like God, for the greater good, particularly for the good of other human beings. Therefore the engineer, being called to change and improve the world in which they work, should always be conscious of the impact of his work on others and on creation.“Man is the image of God partly through the mandate received from his creator to subdue, to dominate, the earth. In carrying out this mandate, man, every human being, reflects the very action of the creator of the universe. Work understood as a “transitive” activity, that is to say an activity beginning in the human subject and directed toward an external object, presupposes a specific dominion by man over “the earth”, and in its turn it confirms and develops this dominion.”

Engineering is continually concerned with exercising dominion on the environment or external object. Fundamentally engineering has as its focus the creation, modification and disposal of things for the purpose of solving problems – people’s problems. Real engineering problems are about creating ‘machines’ processes, devices or systems that change the environment in which people live and work, as that environment is now different with the new process, device or system installed. The various levels of development process may focus specifically on the technology of the ‘machine’ needed, but the end for which it is built, and the effect for which it is created is for people, and changing the environment they value. Hence engineering work is almost always directed by human subject(s), and this direction can take on multiple dimensions (e.g., viewpoints in requirements analysis). This call to work with and for people, in creating, and harnessing nature constructively is thus both the secular and Christian call of the engineer.

The Call to Work

Inspired by the teaching of Christ and His Church, the Christian engineer is even more aware of his responsibility in this regard, seeing his work as a participation in the work of God the engineer. “The word of God’s revelation is profoundly marked by the fundamental truth that man, created in the image of God, shares by his work in the activity of the Creator and that, within the limits of his own human
capabilities, man in a sense continues to develop that activity and perfects it as he advances further and further in the discovery of the resources and values contained in the whole of creation.”

In this sense, God is a laborer working in the world - “My Father is at work in the world” (cf. John 5:17), with whom we, made in His “image and likeness” (cf. Genesis 1:26-27) are called to participate. Before the Fall, God commands Man to subdue the earth (cf. Genesis 1:28), and He commands the First Man to tend the garden (cf. Genesis 2:15). This injunction was repeated to Noah and his descendants (Genesis 9:1-7). Christians have long interpreted this in that God wills Man to share in His providential care for all of creation, voiced in Catholic teaching that we are to act as “stewards of God,” and “called to share in his providence toward other creatures.” While acting as stewards, with power over nature, we also have much to learn from nature as well. For “by the very circumstance of their having been created, all things are endowed with their own stability, truth, goodness, proper laws and order. Man must respect these as he isolates them by the appropriate methods of the individual sciences or arts.”

We can see this in the life of our Redeemer, who was called to live most of his life as an artisan under the tutelage of his foster-father. The importance of valuing Jesus as an artisan should not be downplayed. Study of medieval scholars indicates that while assimilating Greek philosophy into the Christian worldview during the Middle Ages, Catholic monks rejected notion that the artisans of the world – Blacksmiths, builders and such, were to be valued, as was their labor. This position lies in stark contrast with the esteemed Greek philosophy of Plato and Aristotle which overvalued thinking person over the “Mechanical Arts” One thousand years later, it is not hard to see God’s hand at work – many other religions devalued the role of technology and technological development and innovation, much to their detriment, while in Christendom, particularly after the period of the Crusades, scientific and technological developments flourished.

The importance of scientific development was sustained and institutional. It was in religious monasteries where early developments in pharmaceuticals, water wheels, metallurgy, medicine and other technologies came about. It was through these same monasteries that these technological developments were disseminated among other monasteries and into the community. Specifically, the sacredness of work, including these developments, was repeatedly acknowledged. For example, St. Benedict urged his monks to take care of the farm implements with the same reverence given to the altar vessels, as these were part of the monks’ sanctification. Several commentators on the Benedictine spirituality have noted that the bells in the Benedictine monastery do not so much demarcate times for worship, manual labor, study, and recreation as they serve to call the monks to different forms of worship expressed by these activities. Human work, inclusive of engineering work, is a divinely ordained activity and the foundational human vocation.

Co-Creators with Christ

This fundamentally theological view of engineering, intertwining labor and redemption, dates back to at least the 12th Century. Hugh of St. Victor (d. 1142) wrote a significant theological work to form a synergy among the arguments elevating theoretical over practical arts, not unlike the issues in understanding where engineering fits in a Liberal Arts education. In his work Didascalicon, he presents a theological argument that the ‘mechanical arts’ yield artifacts (and processes) that are inherently sacramental because they render visible the end of mechanical reasoning. Here, mechanical reasoning is simultaneously natural (namely, the alleviation of physical weakness) and supernatural (namely the journeying toward reunion with Divine Wisdom). These actions are sacramental because, as fallen creatures, human beings have forgotten who they are and Whose they are. Nevertheless, Hugh writes, "we are restored through instruction, so that we may recognize our nature." God in his redemptive grace and wisdom has intended the very condition of human fallenness as the impetus for human pursuit of Wisdom, a quest which is the "highest curative in life."
And so arose the pursuit of that Wisdom we are required to seek—a pursuit called ‘philosophy’—so that knowledge of truth might enlighten our ignorance, so that love of virtue might do away with wicked desire, and so that the quest for necessary conveniences might alleviate our weaknesses. These three pursuits first comprised philosophy. The one which sought truth was called theoretical; the one which furthered virtue men were pleased to call ethics; the one devised to seek conveniences custom called mechanical.” 18

Here Hugh asserts that the redemption of the soul is assisted by the practice of "arts" that correspond with all the powers of the soul. Corresponding to the understanding (intelligentia) are both the theoretical arts (i.e., the contemplation of necessary truths; here Hugh intends theology, physics, and mathematics) and the practical arts (namely, the practice of morality and the cultivation of virtue). Corresponding to knowledge (scientia) are all the mechanical arts, e.g., feeding, fortifying the body against harm, and the contrivance of "remedies" for alleviating physical weakness. The latter are accomplished through work.

Our primordial call in Genesis 2:8 is to subdue the earth. These words refer to all the resources contained in the visible world and placed at man's disposal. “However, these resources can serve man only through work. From the beginning there is also linked with work the question of ownership, for the only means that man has for causing the resources hidden in nature to serve himself and others is his work. And to be able through his work to make these resources bear fruit, man takes over ownership of small parts of the various riches of nature: those beneath the ground, those in the sea, on land, or in space. He takes all these things over by making them his workbench. He takes them over through work and for work.”

Divine action of creativity is interrelated with human work. “Sweat and toil, which work necessarily involves the present condition of the human race, present the Christian and everyone who is called to follow Christ with the possibility of sharing lovingly in the work that Christ came to do (cf. John 17:4)”11. In our work as Christian Engineers, we find a small part of the Cross of Christ and are called to accept it in the same spirit of redemption in which Christ accepted his Cross for us. “In work, thanks to the light that penetrates us from the Resurrection of Christ, we always find a glimmer of new life, of the new good, as if it were an announcement of "the new heavens and the new earth" (cf. 2 Peter 3:13; Revelations 21:1) in which man and the world participate precisely through the toil that goes with work.” In these efforts to co-create, in our exercise of and growth in Wisdom through ‘mechanical arts’, we actively participate in our own salvation and that of the world, with impacts that can be positive and redeeming.17

**Building the Kingdom**

This call to toil while extending creation for others is an extension to the Life, Death and Resurrection of our Savior. Jesus Christ, Our Redeemer came to restore the world to the right relationships that existed before the Fall: our relationship with the earth, with each other, with ourselves, and ultimately with God. This is the call to extend God's Kingdom on earth. This includes our extensions to the physical reality of our world (in its current condition), and even our relationship to ourselves and to our work.11 In our work, directed toward the betterment of man and creation, following the will of the Father, we participate in building the Kingdom that Jesus inaugurated (Mark 1:15).

Our small efforts are parts of the “new heavens and the new earth” when we direct this work to helping to restore the right relationships with the earth, our fellow man, ourselves, or God that Jesus came to restore. These works are not our salvation, but rather a response to the gifts of God—specifically the gifts of creation, of our intellect and will, and of our Redeemer. In our fallen state, this response to create with God does not come without risks.19 We must always remember with the help of Divine Grace who we are, and Whose we are. “Earthly progress must be carefully distinguished from the growth of Christ's kingdom. Nevertheless, to the extent that the former can contribute to the better ordering of human society, it is of vital concern to the Kingdom of God” 13.

In this view of Deus Machinator, we are each called to be imitators of Christ (see 1 Corinthians 11:1 and Ephesians 5:1). Jesus Christ came as an artisan—a Carpenter. He built things, and is the One who put all...
things in Right Order. Rightly ordered, we image God, we obey the very nature that God created in us, and we are imitators of Christ in how we go about as engineers: stewards of creation, subduing and harnessing the power of the earth, in creating things to help humankind, in using our labor and our lives to extend the Kingdom. This is a work that we are each called to perform in our own way, and those who become engineers are called to perform in a more particular way.

Summary

Using God the engineer as a model, the ideal engineer is a problem solver, applying his labor not as an end to itself, but rather for the particular good of others. This ideal engineer is a worker, at work in the world with knowledge of the limits of his human capabilities, developing and perfecting these capabilities. This ideal engineer is a steward, using the resources at hand, and considerate of the costs, long and short term, of their use, fully cognizant of the stability, truth, goodness, proper laws and order of created things. This ideal engineer is an effective worker, accomplishing the tasks in the best way they can be, with a proper understanding of the risks involved in the undertaking, and a wonder for the greatness of creation and our participation in it.

References


[18] Hugh of St. Victor, _Didascalicon_.

Christian Engineers or Engineering Christians?

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Abstract

As humans we tend to seize hold of popular catch phrases and apply them ad nauseam in an effort to increase attention and profit through association. Often, because of the proliferation of the term, its original meaning and significance becomes lost. Inevitably, the term ends up being applied inappropriately, further tainting its effectiveness. Christians are not exempt from this excessive behavior. In fact, the very term “Christian” itself has been, and continues to be, applied liberally to phrases, occupations, and organizations to describe anything remotely, and sometimes not so remotely, associated with Christianity. But what does it mean when we add the “Christian” modifier to an institution (e.g. Christian college) or an individual (e.g. Christian engineer)? Are we using the term properly or have we watered down its essence by overuse and misuse?

The main focus of this paper is to encourage thought and discussion as to the appropriateness and implied meaning behind the application of the term “Christian”. This paper starts by taking a look at what the author considers to be the Biblical meaning of the word. It then evaluates various contemporary usages of the term “Christian” based on this meaning, applied to both institutions and individuals. The paper concludes by challenging us to carefully consider how we use the term “Christian”, with a final encouragement to be more than a Christian engineer; to be an engineering Christian.

Introduction

A recent survey released by the Program on Public Values at Trinity College states that 76 percent of U.S. adults identify themselves as Christian. Articles written about the survey results tend to focus on the decreasing percent of self-identifying Christian individuals. While the decreasing percent may be of concern, a more fundamental concern is the superfluous use of the term “Christian” as an identifier. Consider what the survey results would be if the term “Christian” was applied appropriately – if those identifying themselves as Christians were truly Christian. What would the United States be like if three quarters of the adult population had a real, personal, life changing relationship with Jesus Christ? It would be a vastly different society than the one we see around us. If the survey could have identified the number of “true” Christians, it would have found a significantly lower percent. In truth, the term “Christian” no longer holds the same meaning and power it did when it was first conceived centuries ago.

The reason the poll results can not provide an accurate measure of the number of ‘true’ Christians in the U.S. is because the term “Christian” has been so freely attached to various aspects of our society that it has lost meaning. A quick search on the web reveals everything from Christian automotive repair companies to Christian dating services. But what is a Christian automotive repair company or a Christian dating service? What do we mean when we stick “Christian” in front of everything? The Mayor of Who-ville had the right idea when he stated “Sticking ‘Who’ in front of everything doesn’t make it hurt less. Just wastes time!” Sticking “Christian” in front of everything does not make it truly Christian. Unfortunately, in many cases it just wastes the real essence of the word.

As engineering faculty, what do we mean when we say that we teach at a Christian college, call ourselves Christian engineers, or are members of a Christian Engineering Society? Before answering those questions, a more fundamental question must be answered. What is the meaning...
of “Christian” and how should it be used? Understanding the Biblical meaning of “Christian” will help ensure it is applied properly and restore the power behind the word.

This paper will attempt to refocus our attention on what it means to be Christian and the implications for how we refer to ourselves and our academic institutions. The first part of the paper will look at the historical beginnings and definition of the term “Christian”. An examination will then be made of the term’s use with respect to institutions and individuals. The paper ends with a challenge to carefully consider how we use the term “Christian”.

**Definition of Christian**

The term “Christian” has been referred to several times already but has yet to be defined. Words themselves have no inherent meaning, only those meanings that man gives to them. As such, a word can come to have many different meanings. Hence the ‘true’ meaning of a word is in some sense arbitrary, a subjective selection of the preferred definition. The term “Christian” has been around for centuries, and over that time period has accumulated various explicit and implicit meanings. This has caused confusion as to what exactly is meant when the word “Christian” is used. C. S. Lewis, in his preface to Mere Christianity, pointed out the danger of adding to the meaning of a word. Eventually he says the word becomes useless. Even now Christians differ widely on what it exactly means to be Christian. If the meaning of “Christian” cannot be established, then it is free to be applied however one sees fit, void of any significance. This is an unacceptable scenario.

A full study of the meaning of “Christian” is beyond the scope of this paper. Understanding that there may be some disagreement on this issue, the author has chosen to take a constructionist’s approach as to the definition of the term “Christian”. This is based on the context and implied meaning of the term as found in the Bible when it was originally used. Lewis took a similar approach to his use of the term “Christian” by keeping to the “original, obvious meaning”. The following is a short discussion to support this view.

The English word “Christian” has its origins from the Greek word Χριστιανός (christianos). The Greek root of this word is Χριστός (christos), which means “the anointed one”. In the Septuagint (Greek translation of the Old Testament), the same Greek word Χριστός is used to translate the Hebrew word מւשָה (Messiah), which means “one who is anointed.” In the New Testament the promised anointed one is finally revealed. It is Jesus the Christ (the Messiah, the anointed one). There are only a few times in the Bible where the term “Christian” (Χριστιανός) is found. The first known usage of the term is found in Acts 11:26. “… For a whole year they met with the church and taught a great many people. And in Antioch the disciples were first called Christians.” (Acts 11:26 ESV) From this passage it can be seen that the term “Christian” refers to disciples of Jesus Christ.

The second place in scripture where we find the word “Christian” is in Acts 26 where Paul is proclaiming the gospel of Jesus Christ to King Agrippa. “And Agrippa said to Paul, “In a short time would you persuade me to be a Christian?”” (Acts 26:28 ESV) The king was presented with a compelling case for becoming a disciple of Christ. Yet even with all of the evidence at hand, he refused to accept what he had heard and to be identified with Christ.

The last reference to “Christian” in the Bible is in 1 Peter. “Yet if anyone suffers as a Christian, let him not be ashamed, but let him glorify God in that name.” (1 Peter 4:16 ESV) This passage clearly connects the possibility, and strong probability, of suffering as a result of being a disciple of Christ. However, even in suffering God’s name is to be glorified.

The earliest known usage of the term “Christian” outside of the Bible was by the Roman historian Tacitus in his Annals, written around 116 AD. In his account of the great fire of Rome (64 AD),
Tacitus includes an account of Emperor Nero blaming the Christians in Rome for the disaster. This is followed by an account of the first systematic persecution of Christians by the Roman authorities.

To be called a Christian in the first century was to be unequivocally identified with Jesus Christ in life and in death. There was a significant cost and sacrifice to being a Christian. It was not watered-down in meaning nor overused in application. A Christian was a completely committed disciple of Jesus Christ. It was more than simply a statement of belief; it was a centrality of life. In his essay “Followers not Admirers”, Kierkegaard argues the same point, emphasizing that Christ called people to be followers not simply admirers. “The admirer never makes any true sacrifices. … The follower aspires with all his strength, with all his will to be what he admires.”

A “Christian” could therefore be defined as one who aspires with all his strength, with all his will to be like Christ.

The modern English term “Christian” has both a noun and an adjective definition. According to Merriam-Webster, the Christian-noun is defined as one who professes belief in the teachings of Jesus Christ. While similar in nature to the original definition of “Christian”, the modern noun definition lacks the committed discipleship aspect. Belief is a necessary condition but is not sufficient. Even the demons believe in Christ.

The Christian-adjective is defined as (1) of or relating to Christianity; based on or conforming with Christianity; (2) of, relating to, or being a Christian; professing Christianity; (3) commendably decent or generous. The adjective form of “Christian” falls even further away from the original meaning. There are many ways people can be related to, or conforming with, Christianity but yet be very far from a committed disciple of Christ. Simply professing Christianity has the same problem as the noun form, while the third adjective definition completely removes all connections with Christ.

In examining the original context and usage of the term “Christian”, we find that “Christian” is a person (noun), not an adjective. And that a “Christian” is a committed disciple of Christ, not just an admirer or professor of belief. There is action and sacrifice behind the word. As James states, “… faith by itself, if it does not have works, is dead.” (James 2:17 ESV) Similarly the term “Christian”, without the committed discipleship, is dead in meaning. For this paper then, the meaning of the term “Christian”, based on its Biblical usage, is a committed disciple of Christ, by virtue of the indwelling of the Holy Spirit, as demonstrated by the fruits of the spirit.

One important point should be noted here. The ultimate underlying distinction between a Christian and a non-Christian individual is this: has the person been saved by grace through faith in the death and resurrection of our Lord Jesus Christ. This is not something that we as humans can see directly. However, if a person has been given new life in Christ there should be some outward evidence in their words and actions. The evidence will inevitably increase as the person matures and grows spiritually. In the definition of the term “Christian”, the committed aspect refers to the intentional, ongoing pursuit of maturity that is a result of a changed life. It is not meant to refer to a certain level of maturity or theological understanding. Put another way, a Christian (committed disciple) will out of necessity produce evidence of salvation in their life while a non-Christian (uncommitted disciple) will not.

**Christian Institutions**

Let us first consider the use of the term “Christian” in describing an institution. There are Christian counseling centers and Christian dating services; Christian web sites and Christian social networks; Christian retailers and Christian products. There is Christian music, Christian theater, and Christian movies. Most applicable to this paper are the numerous institutions of
higher education that call themselves Christian\textsuperscript{15}, and more specifically the engineering programs at those institutions. What does it mean when we refer to these entities as “Christian”? An institution cannot be “Christian” in the original noun-sense. People are saved by grace through faith in Jesus Christ, and through the indwelling of the Holy Spirit become committed disciples of Christ. An organization cannot be a committed disciple of Christ. So what then is a “Christian” institution? At best it can only be considered “Christian” in the contemporary adjective-sense. Organizations can be related to Christianity or based on Christianity, but this does not provide a well-defined meaning. There can be various interpretations as to how an organization is related to or based on Christianity. The following is a short examination of some of these interpretations along with an evaluation as to the appropriateness of each with respect to the original meaning.

One way to interpret an organization as being “Christian” is that its members are Christian. Using this interpretation, a Christian college would simply be a college made up of Christians. A Christian engineering society would simply be a group of engineers who happen to be Christian. The use of the term in this case is weak at best. It does nothing more than identify the religious affiliations of its members. There is no real connection between the institution itself and Christianity. There is nothing wrong about every member of an organization being a Christian. In many situations this is a necessity in order for the organization to fulfill its mission. A college made up of Christians is also a comforting option for concerned parents sending their children off to school. However, if that is all the designator “Christian” means, then it is lacking real power and meaning.

A second way to interpret an organization as being “Christian” is that its target customers are Christians. The use of the term “Christian” in this case is relegated to a marketing strategy. “Christian” is the eye catcher to attract a certain group of people. Using this interpretation, a college that refers to itself as “Christian” would simply be trying to attract Christian students, faculty, and staff. Again, having Christians as your customers is not necessarily wrong. However, it is easy for “Christian” to become distorted on the path to financial gain. Take, for example, the Old Testament sacrificial practices. These ceremonies were often corrupted by those seeking to profit financially through the sale of the sacrificial animals. Jesus even expressed his displeasure at this distortion of the sacrifices by driving the sellers and money-changers out of the temple.\textsuperscript{16} In the same way, we must be careful not to devalue the term “Christian” in the pursuit of enrollment. A Christian college does, and should, appeal to students interested in Christianity. However, the attraction of Christians should be the byproduct of the “Christian” designator, not the purpose of the designator.

A third way to interpret an organization as being “Christian” is that its practices are based on Christian principles. But what are these Christian principles? Honesty, respect, good stewardship, and love for one another are a few. These are great principles to live by and to operate an organization. In fact, most good, profitable companies are based on these same principles. Yet many of these companies would not call themselves Christian, nor would they even necessarily consist of Christians. They follow these principles because they are good, effective business practices. Using this interpretation, a Christian college would simply be one that deals with its students, faculty, and staff in an upright Christian manner. This is good and should be the expected behavior of all Christians. What it lacks is the distinction from other institutions that should be associated with the committed discipleship aspect of the original “Christian” meaning.

The interpretations as presented so far are all deficient with respect to the original sense of what it means to be “Christian”. An institution cannot be a disciple of Christ in the personal sense of the word. An institution can, however, be a promoter of Christian discipleship through in its mission,
vision, strategic planning and goals. This is more than just consisting of Christian employees. This is far different than marketing to Christian consumers. This is much deeper than being based on Christian principles. This is integrating the Christian faith into the institution’s framework so that it permeates all aspects of the institution. A Christian institution focused on anything less does a disservice to the term “Christian”.

Does this mean that all organizations and businesses that call themselves Christian have to change their mission and focus to match the interpretation as presented here? Not necessarily, but they should consider carefully the reasons for using the term “Christian”. It may be more honoring to Christ to remove “Christian” from the title than to promote something that is not truly “Christian”.

**Christian Individuals**

Let us now consider the use of the term “Christian” in describing an individual. There are Christian counselors, Christian businessmen, Christian athletes, and Christian artist. We often refer to ourselves as Christian faculty or Christian engineers. What does it mean when we use “Christian” to describe ourselves?

Unlike institutions, an individual can be a “Christian” in the original noun-sense. However, a quick examination of its usage reveals that the term “Christian” when referring to individuals is primarily used as an adjective. The previous section discussed some of the interpretations for Christian-adjective institutions. How should we interpret the Christian-adjective applied to individuals? As before, there can be various interpretations. The following is a short examination of some of these interpretations along with an evaluation as to the appropriateness of it with respect to the original meaning.

One interpretation of the Christian-adjective individual is as a specific subset of a larger group. This is similar to the first interpretation discussed for institutions. A Christian engineer can simply be considered an engineer (main set) whose religious affiliation is Christianity (subset), as opposed to Muslim, atheist, etc. This usage seems reasonable at first, and in fact is true. We are, are we not, engineers who are Christian. The problem is that the essence of the phrase Christian engineer is not “Christian” but engineer. “Christian” is the adjective and engineer is the noun. Remove the adjective (“Christian”) and the noun (engineer) is still left. “Christian” is simply relegated to distinguishing one group of engineers from another.

A second interpretation of the Christian-adjective individual is related to the product of their occupation. A Christian artist, in this case, would be an artist that produces material (music, paintings, etc) related to Christianity. A Christian engineer would be an engineer who produces material related to Christianity. The engineer may work for a “Christian” company, or may work with mission organizations to improve the welfare of people around the world. The engineers working on these projects are demonstrating God’s love by applying their knowledge and skills to assist those that are less fortunate. These efforts are very important, and as Christians we are commanded to love our neighbors. However, there are two dangers associated with the related-to-Christianity interpretation of a Christian engineer. First, the focus can easily end up on the product instead of Christ. Second, there is no assurance that the engineer is even a Christian. As with the first Christian-adjective interpretation, the related-to-Christianity interpretation comes up short.

The two interpretations presented so far refer to the Christian-adjective individual. Based on the original meaning of “Christian” as defined earlier in this paper, the Christian-adjective is inherently deficient in its usage. The more appropriate application of the term is as a Christian-noun individual. Instead of being referred to as a Christian engineer, one would be called an engineer(-ing) Christian. This may seem like nothing more than petty semantics and a nice play
on words. Is there really any difference between the two? I would suggest there is, and while the difference may seem small or subtle at first, it has significant and far reaching implications.

As an illustration, consider the Continental Divide of the United States. The divide separates the watersheds of the Pacific Ocean and Atlantic Ocean. All of the water on the western side of the Continental Divide eventually flows into the Pacific Ocean, while all of the water on the eastern side eventually flows into the Atlantic Ocean. Along the Continental Divide, you can dump two bottles of water a foot apart from each other, one on the east side and the other on the west side. To any observer standing nearby the one foot difference would appear insignificant. However, if you follow the water to its conclusion they end up thousands of miles apart – an unmistakably significant difference.

This is the case between an adjective-Christian and a noun-Christian; between a Christian engineer and an engineering Christian. On the surface the difference may seem trivial – only a few feet apart. After all, it is only a grammatical slight of hand. When taking a closer examination and following the implications to their end, there is a vast separation. In the former case, “Christian” is presented as an add-on descriptor of the individual. Remove the adjective and the noun still exists and has meaning. The fundamental part of Christian engineer in not “Christian”, it is engineer. Grammatically it could be worded as a Christian engineer is an engineer (noun) who is related to Christianity (adjective). Do we want to be just related to Christianity? Or a Christian engineer is an engineer (noun) who professes Christianity (adjective). Do we want to simply be a subset of engineers? Or a Christian engineer is an engineer (noun) who is commendable and generous (adjective). Are we not more than nice, caring engineers?

In the latter case, “Christian” is the essence of the individual. The fundamental part of engineering Christian is not engineering, it is “Christian”. We are Christian, first and foremost. Remove the engineering and we are still Christian. We should not be defined by our vocation. We should be defined by the One to whom we belong. We are Christ’s and we are a new creation.17

This is not to imply that everyone who refers to themselves as a Christian engineer is not a committed disciple of Christ. Rather, this is a challenge to consider carefully what we mean when we use the Christian-adjective as opposed to the Christian-noun. Are we not truly misplacing the focus of our existence by taking the noun away from Christ and putting it on worldly things (engineering)? God must be given His proper place, and that place is the center of our lives. We live to glorify God and His Son, Jesus Christ, who through His life, death, and resurrection has given us new life. Christian, a committed disciple of Christ, is who we are and should manifest itself in all that we do. The specific vocation and means by which Christ is manifested in us is secondary.

Conclusions

This paper was meant to stir up discussion as to the meaning of the term “Christian” and how we apply it. It is the author’s opinion, based on its Biblical meaning and usage, that “Christian” is an individual who is a committed disciple of Christ. Any use of the term should be consistent with this definition. The challenges then before us are this. First, with respect to Christian institutions (colleges, societies, etc.): be more than a group of Christians, be more than an attraction to Christians, be more than an organization based on Christian principles. Be an institution with a Christ-centered worldview where Christianity is at the center of, and part of, every aspect of the institution. Second, with respect to Christian individuals: be more than a religious subset, be more than a producer of religious goods. Be a committed disciple of Christ first and foremost, integrating faith into everything you do. Strive for excellence in education. Engage in the expansion of science and technology. But in all things be Christian.
What then shall we call ourselves, Christian engineers or engineering Christians? The next time someone asks what your occupation is, tell them you are an engineering Christian and delight in the conversation that follows.

References

[12] See James 2:19
[17] See 2 Corinthian 5:17
Guiding Technological Development: An Analysis of Borgmann’s Device Paradigm

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Abstract

It seems clear from observation that contemporary technological developments are not unalloyed blessings for society. Many engineers and others have pointed out the troubles associated with the 21st century lifestyles that we typically take for granted. The discipline of philosophy of technology has devoted much effort to identifying the potential harm caused by technology, both to our health and safety as well as to our personal and cultural flourishing, and proposing ways to direct technology in order to avoid those problems. Albert Borgmann, an influential commentator on society and technology, has made important contributions on this topic. Borgmann’s seminal work, *Technology and the Character of Contemporary Life: A Philosophical Inquiry*, which was published in 1984, describes a particular approach to understanding the situation we currently face. This paper will examine Borgmann’s theories on technology from a Christian perspective.

The key features of Borgmann’s theory include identifying “the device paradigm” as representative of the character of modern technology and advocating the use of “focal things” to better direct technology use and development. This paper will explain and illustrate these concepts while comparing Borgmann’s approach to those of other important philosophers of technology, particularly Jacques Ellul, Neil Postman, and Carl Mitcham. The paper will also analyze the validity of Borgmann’s theories from the multi-aspectual normatively (MAN) perspective on technology described in the book *Responsible Technology*. While Borgmann highlights some important aspects of technology, this paper will argue that design norms are needed in addition to “focal things” to guide technologies which fulfill our responsibilities as Christians to serve God and others.

Once points of agreement and difference with Borgmann’s philosophy have been identified, the paper will conclude with recommendations for integrating these ideas into the engineering curriculum. A perceptive understanding of the relationships between technology and modern society can be emphasized in technical courses as well as in the general education component. The engineering curriculum can be enhanced by micro-insertion of these topics into technical courses, but especially by a focus on these issues in the first year introduction to engineering course and the senior year capstone design course.

1.0 Introduction

It is hard for those of us who live in the developed countries of North America to imagine life without modern technology. Most of us have grown up with and grown accustomed to fast and flexible transportation, abundant communication and entertainment options, and the involvement of electronics in almost every facet of human life, just to name a few examples. It also seems clear from our experiences that, although we can identify many benefits generated by technology, contemporary technological developments are not unalloyed blessings for society. Because of our immersion in and adjustment to a contemporary culture that is closely linked with technology, it takes a special effort to carefully consider
the impact of recent engineering developments on not just our overall health and safety, but on our communal and spiritual growth as well.

As a personal example of the need for technological discernment, I admit to some discomfort with the proliferation of electronics technology and especially the increasing availability of virtual entertainment. Even assuming the quality of the games themselves (e.g., eliminating those that involve violence), I wonder about the intrinsic value of such “high-tech” activities. Some of my disapproval of video games seems to arise because I fear that electronic gaming is less meaningful as an activity compared to, say, reading a book or playing a board game. But is this a reasonable assumption? Is there something about the electronic nature of these games that makes them inherently less worthy of participation? Some of my acquaintances greet electronic gaming with deep suspicion, while others actively search out new games and systems. These different responses are often based on personal intuition, which may reflect unconsciously held biases. Exploring the principles of philosophy of technology should provide a better foundation for personal decision-making related to new electronic gaming possibilities.

On a broader level, many of us have a sense that there are problems with the direction that technology and culture are currently heading. Technology has given us the power to control nature, but seems to have also separated us from nature and contributed to the deterioration of our natural surroundings. Technology has given us new ways to communicate with others, but many of those ways (e.g., email and cell-phone use) seem to diminish and devalue face-to-face human relationships. Contemporary technology seems to impose a life-style governed by time-pressure, stress, and competition. How can technology be directed to minimize or avoid these concerns?

Those involved with the discipline of philosophy of technology have devoted their careers to the analysis of technology. Much effort has been devoted to identifying the harm caused by technology and proposing ways to direct technology in order to maximize its potential for contributing to the flourishing of life on earth. Looking philosophically at engineering and technology can allow us to explore the extent to which the problems described above are due to the nature of the technology itself or to the cultural factors that influence technological development. This paper will be an attempt to summarize some key insights from particular philosophers and then apply these ideas to the processes of engineering design and decision-making.

Albert Borgmann, an influential commentator on society and technology, has made important contributions on this topic. Borgmann’s seminal work, *Technology and the Character of Contemporary Life: A Philosophical Inquiry*, which was published in 1984, describes a particular approach to understanding the situation we currently face. Although Borgmann has more recently produced books written from an explicitly Christian perspective, his earlier work is aimed at a secular audience. This paper will examine Borgmann’s theories on technology from a Christian perspective. In section 2 of this paper, Borgmann’s approach to technology will be described. The key features of his philosophy include identifying “the device paradigm” as representative of the character of modern technology and advocating the use of “focal things” to better direct technology use and development. Several examples will be included to help understand his theory.

In section 3, Borgmann’s approach will be compared with that of several other prominent philosophers of technology, including Jacques Ellul, Neil Postman, and Carl Mitcham. Section 4 will present an analysis of the contribution of Borgmann’s theory from the holistic, normative Christian perspective on technology described in the book *Responsible Technology*. While Borgmann highlights some important
aspects of technology, this paper will argue that broader principles are needed in addition to “focal things” to guide technologies which fulfill our responsibilities as Christians to serve God and others. The paper will conclude in section 5 with recommendations for applying these ideas in engineering education.

2.0 Borgmann’s Theory of Technology

Albert Borgmann currently serves as the Regents Professor of Philosophy at the University of Montana. His focus has been on the philosophy of technology and society. He has published several influential books, including *Crossing the Postmodern Divide* (1992), *Holding on to Reality: the Nature of Information at the Turn of the Millenium* (1999), *Power Failure: Christianity in the Culture of Technology*, and most recently, *Real American Ethics: Taking Responsibility for our Country* (2006). His seminal work addressing technology, *Technology and the Character of Contemporary Life: A Philosophical Inquiry*, was published in 1984 and presents the philosophical foundation for much of his later work. This book is now in its 5th printing. For the sake of brevity and clarity, this paper will focus on his earlier work. The reader is encouraged to read his later books to see how he expands and applies his foundational ideas.

Borgmann begins by noting that modern technology is so integrated into our everyday lives that its effects are difficult to perceive. That is, there is something distinctive about contemporary life compared to life in earlier times or less “technological” cultures. He sees his philosophical task as observing the pattern underlying our experiences with technology in order to “describe and articulate the paradigm of technology.” This paradigmatic view is in contrast to three common types of theories on technology that Borgmann articulates. He summarizes the first category as “substantive”. This includes theories in which technology is considered to be autonomous, something that society responds to and is controlled by. Usually substantive theories are promoted by those who are anti-technology. The second view he describes as “instrumentalist”. Instrumentalist theories treat technology as a value-neutral tool. The third view, “pluralistic”, assumes that neither of the previous views is adequate to describe the interactions of technology with society, rather technology is embedded in a “complex web of numerous countervailing forces.” The pluralists essentially give up on identifying any specific theory that is applicable to technology as a distinctive entity. Borgmann considers each of these approaches to be insufficient in providing a good model of the way in which technology interacts with society.

2.1 Devices

According to Borgmann, the prevailing pattern of contemporary technology can be identified by the device paradigm. The device paradigm follows from the observation that the great promise of technology is freedom from toil and suffering, along with greater life enrichment, enjoyment, and fulfillment. “Availability” is the word that Borgmann uses for the combined effects of the promise. The implementation of technology toward fulfillment of this promise has resulted in making commodities (like heat, food, and communication) readily available by reducing the burdens associated with obtaining those commodities. The primary example Borgmann uses to illustrate the device paradigm is home heating. In the pre-technological past, obtaining heat involved constructing a hearth and burning fuel. This required significant time and physical labor on the part of the homeowner, as well as access to resources. Chopping down trees or collecting peat was a burden that had to be endured in order to create a comfortable temperature inside a home. The hearth required constant attention (keeping the fire stoked) and involved significant risk (burning down the house). A modern technological heating system, on the other hand, isolates heat as a commodity from the burdens associated with maintaining the fireplace.
Borgmann suggests that this is a good thing in so far as it contributes to greater comfort and safety for people, but he is concerned that the isolation of “heat obtainment” from the physical and social engagement associated with the fireplace results in a loss to human flourishing. The fireplace or hearth was a multi-faceted “thing” or tool which engaged humans on a physical, emotional and social level, while the modern heater is a “device” which obtains heat isolated from any other human needs.

According to Borgmann, this tendency toward obtaining commodities with devices implies that the means or machinery by which the commodity is obtained tends to shrink over time and become more and more hidden. From the perspective of the user, it doesn’t matter how the heat is generated behind the scenes (in most cases in our basements) as long as the goal of obtaining heat is achieved with the least possible involvement on our part. Borgmann observes the relative “stability of ends” in modern technological society (we seem to agree on what kinds of functions we want in our technology) along with the possible radical changes in means (experts change these based on creativity and new understandings of science) which are in most cases concealed from the users. This tendency toward separation of means and ends is what makes technology able to fulfill its promises and also what gives technology its potential to interfere with living a good life. According to Borgmann, serving the machinery (work) and enjoying the commodities (leisure/consumerism) have crowded out what is really meaningful in life (focal things and practices).

It is not difficult to observe and describe additional examples of “devices”. Consider the delivery of music as a commodity. Early record players replaced the need for going to a concert hall or practicing personally to develop skill on an instrument with the acquisition of a plastic grooved disk which could be played on a turntable. The quality of the commodity was somewhat reduced, but the disburdenment of being able to effortlessly listen to music in one’s own home was significant. Record players have since been replaced by tape decks, then by CD players, and most recently by MP3 players. Each technological development serves to refine the machinery such that the music is more easy to obtain and of higher quality. The user no longer understands or cares about the system that produces the music as long as the music is more available. The device paradigm acknowledges the tendency of modern technology towards disposability of the machinery. We are willing to radically change our methods of obtaining music when a new technology comes along, because the commodity is all that we are interested in.

In a more personal example, I grew up playing solitaire card games. Limitations on the enjoyment of game play were imposed because of the need to manipulate a deck of cards. A considerable amount of floor or table space was necessary to play, and a great deal of time was wasted in frequently mixing and re-dealing. I now occasionally play electronic versions of solitaire on my computer. The e-version provides disburdenment from the reshuffling effort, which makes it possible to play more games in the same period of time. The e-Solitaire “device” provides the commodity of game play without the burden of physically interacting with the cards.

But, Borgmann also points out the negative side of the device paradigm. In the case of the hearth, family life was centered around engagement with the heat-generating process. Children developed skills and discipline in the process of helping to stoke the hearth. Family members were encouraged to stay close together in order to share the localized heat provided. The hearth served not as a mere commodity-generating device, but as a community gathering place, a regulator of daily activities, and a generator of physical activity. A “thing” like the hearth was closely tied to its context, as opposed to a device, which is intentionally designed to function independently of context. While acknowledging the promise and significant benefits of the “device” character of technology, Borgmann also encourages technology users
to reflect on the extent to which devices may reduce our engagement with things that are really important and break down traditional cultural practices.

Returning to the solitaire example, the greater availability of game play that electronic versions supply is welcome. But, there is also something lost or missing from the electronic experience. The ease with which the electronic game can be restarted means that I rarely try as hard to complete a game. If I want to play double solitaire with a partner, I can do so via the internet with an anonymous partner, but only with real cards can I sit across the table from one of my children and experience face-to-face communication. The tactile feeling of the cards and the interaction of bumping someone’s hand in the competition to lay one’s own cards make the game more interesting and enjoyable. Also, the excessive availability of the computer version can contribute to the temptation to play too often or at inappropriate times.

Clearly, without the availability generated by the device character of technology, our lives would include more drudgery and time spent on tasks that detract from important and enriching activities, like participating in devotions, spending time with our children, or doing service projects. Human existence is bounded by the problem of finite time. There is an opportunity cost to many of the tasks we are required to perform to satisfy basic needs. To the extent that technology eliminates some tasks that we consider non-essential, it can open up time for doing things that are more valuable. But, too much availability may contribute to a number of problems in modern life. For example, the availability of so much mass produced commodity food has contributed to the over-nutrition of many people in the developed world.

2.2 Focal Things

According to Borgmann, in order to reform technology, it needs to be pursued in light of focal things. As mentioned above, Borgmann contrasts modern technology, characterized by the device paradigm, with focal things and practices. A focal thing “…gathers the relations of its context and radiates into its surroundings and informs them.” Focal things are marked by their centrality, by their tendency to clarify, and the way they speak to the human spirit. A key aspect of a focal thing is engagement. Focal things require effort and attention. They are also directed toward a life of competence, excellence, and virtue. The essence of the concept of focal things is derived from the work of Heidegger, who reflected on “simple and eminent” things. Borgmann broadens and fleshes out Heidegger’s original concept.

Examples of focal things/practices for Borgmann, as described in his writing, include the “culture of the table”, as well as exploring wilderness, enjoying music, gardening, and running. This is what Borgmann says about the focal nature of the festive meal:

The great meal of the day, be it at noon or in the evening, is a focal event par excellence. It gathers the scattered family around the table. And on the table it gathers the most delectable things nature has brought forth. But it also recollects and presents a tradition, the immemorial experiences of the race in identifying and cultivating edible plants, in domesticating and butchering animals; it brings into focus closer relations of national or regional customs, and more intimate traditions still of family recipes and dishes.

Clearly, for Borgmann the festive meal is an important part of the good life, and he is concerned that technology (in this case the commodity of fast food) will supplant the richness of the meal experience described above. I believe Borgmann would suggest that the kind of technologies that facilitate the focal experience of the shared festive meal should be favored (perhaps technologies that facilitate the sustainable harvest of local foods, that facilitate living arrangements which allow shared cooking, and technologies that facilitate sharing of heirloom seeds and recipes) over those that make this sort of meal
experience less likely (perhaps the technologies that support large-scale industrial farming or the production of microwavable meals). At a minimum, I think he would suggest that our choices of technological products should facilitate meals at home together rather than fast-food stops.

Yet, how do we decide what qualifies as a focal thing or practice? While it is not hard to appreciate the focal quality of the activities Borgmann describes, especially given his poetic descriptions of them, it is not quite as clear why other activities, like playing a video game or shopping, would not qualify. Surely the definition of what constitutes a focal thing will be personally and culturally influenced. Borgmann’s description of focal things represents a strong preference for nature and tradition. But I am not entirely convinced that this a priori preference for the natural and traditional as being more representative of meaning and “the good life” are entirely warranted. Without a clear connection between focal things and a more comprehensive and concrete set of values, the definition of what constitutes a focal thing appears to be relatively arbitrary.

3.0 Interactions with Additional Theories of Technology

In considering the usefulness of Borgmann’s theories, it is helpful to compare his approach to that of other influential technology commentators. Borgmann suggests that the attitudes towards technology prevalent in our culture are primarily based on an instrumentalist assumption that technology itself is merely a tool, and therefore the problems we experience with technology stem from other cultural constraints, for example the political decision-making system or economic injustice. The authors referred to in the following paragraphs all agree to some extent with Borgmann about the need to counteract the instrumentalist approach.

Initially, Borgmann would seem to have much in common with Jacques Ellul. Ellul also sees something ominous in the pattern of modern technology, which he refers to more broadly as “technique.” Technique includes the methods used to achieve given ends, which in modern society are exclusively scientific and based on considerations of efficiency. According to Ellul, the great danger of technology is not the machinery itself, but that its methods have become the only measurement standard for success, displacing other criteria, especially criteria based on the values of religion or philosophy. Borgmann names Ellul as the principle figure promoting the substantive or autonomous view of technology. Borgmann considers the substantive view contradictory. Regarding technology as if it has its own guiding forces which are out of the direct human control does not seem reasonable when it is clearly humans who make decisions about creating and implementing new technologies. Engineers, who are significant contributors to technological development, also tend to reject the substantive view. Borgmann identifies technology as a key component of contemporary culture, therefore as a part of what humans and societies do. He does not go so far as to say that technology determines culture, but he is alert to the character of technological developments that would tend to constrain our choices. Both Borgmann and Ellul speak to the dangers of doing technology for technology’s sake. They both promote the importance of using values external to technology to promote human flourishing. But, Ellul’s substantive stance toward technology implies that resistance to the dictates of technology may be futile. Borgmann’s approach, in contrast, emphasizes human responsibility in technological development and provides some hope for directing technology more beneficially through the identification of focal things.

Neil Postman is another influential technology critic who emphasizes that technology is not merely a neutral tool whose use determines its worth. He emphasizes that the functions of technology are embedded in their form and that ideas are expressed in our machines. He sees North American society
as having changed from a culture in which tools were invented to serve cultural needs to one in which the invention of tools has been separated from the more general cultural realm and governed by its own technical-scientific rules. He describes this as the development of a “technocracy.” His fear is that this separate technological world will become dominant over other cultural concerns, resulting in a “technopoly.” A technocracy uses the tools of technology for decision-making, but still has cultural forces opposing and constraining its conclusions. A technopoly uses the tools of technology for decision-making because those tools have become the only means by which to judge.9 Borgmann and Postman both agree that something else is needed to counter the influence of technology in our society. Postman appeals more generally to religious and cultural values to help guide technological development, while Borgmann speaks more specifically of focal things, which exemplify many of these values.

Carl Mitcham, another prominent philosopher of technology, proposes a theory that includes four “modes of manifestation” of technology10. These manifestations include technology as object, technology as knowledge, technology as activity, and technology as volition. Borgmann mentions that Mitcham presents a very comprehensive classification of theories of technology and includes useful historical comparisons. According to Mitcham, Borgmann’s analysis falls primarily under the category of technology as object. Borgmann’s device characterization is primarily based on consideration of the products of technology, as opposed to other aspects of technology identified by Mitcham. Mitcham suggests that Borgmann contributes something significant to philosophy of technology by identifying the device paradigm, but he also suggests that other aspects of technology as object could use some exploration, for example, the idea of technological objects as amplifiers and reducers of human abilities. Mitcham applauds Borgmann’s approach and sums it up as follows.

But human beings are not just users of words and signs, they are embodied beings whose lives are realized through what Borgmann calls focal things and practices. While recognizing, with Baudrillard, the presence and influence of devices, he nevertheless, like Illich, calls for “the recognition and restraint of the [device] paradigm. To restrain the paradigm is to restrict it to its proper sphere. Its proper sphere is the background or periphery of focal things and practices. Technology so reformed is no longer the characteristic and dominant way in which we take up with reality; rather it is a way of proceeding that we follow at certain times and up to a point, one that is left behind when we reach the threshold of our focal and final concerns.”11

4.0 Borgmann and Multi-Aspectual Normativity

Albert Borgmann has written later books from a distinctively Christian perspective, but Technology and the Character of Contemporary Life was written for a secular audience. The book Responsible Technology, published in 1986, was written from a Reformed Christian perspective and expresses a theory of technology that I will call Multi-Aspectual Normativity (MAN). This section of the paper will include a comparison of Borgmann’s theory with MAN.

The MAN approach is founded on several Christian pre-suppositions. The first is that humans were created by God in his image, with the ability to create and participate in fellowship with other humans and the rest of creation. The second is that humans are subject to the Cultural Mandate as expressed in Genesis 1:28 “God blessed them and said to them, ‘Be fruitful and increase in number; fill the earth and subdue it. Rule over the fish of the sea and the birds of the air and over every living creature that moves on the ground.’”12 This mandate is interpreted as meaning that we are to cultivate the earth and to use the resources that we have been given to cause God’s kingdom to flourish. The third is that through the fall of
Adam and Eve, all creation is subject to the effects of sin. Not only is our personal relationship with God disrupted, but our culture and institutions have been corrupted, as well as our relationships to non-human creation. The Reformed tradition has expressed this concept as “antithesis”. We live in a time when technical, natural, and social things, as well as human souls, have been impacted by sin. The corruption of the fall also makes it difficult to discern which activities are in accordance with God’s will and his intentions for us. The fourth is that, through the death and resurrection of Jesus Christ, we as Christians can participate in the redemption and renewal of all creation. Since technology is part of our imaging God and cultural mandate activities, we must do what we can to direct it in ways that are pleasing to God.

Additional philosophical pre-suppositions that extend from these beliefs include the idea that God has created a world with many different aspects than can be abstracted from our every day experiences. All of these aspects are subject to the laws and structure of our Creator God. For some aspects, for example, the physical aspect, scientific investigation has uncovered laws that must be accounted for in designing technological objects. For higher level aspects, for example the aspect of justice, it may be more difficult to determine appropriate laws. For the cultural aspects, we as humans also have the free will to disobey those laws. It is therefore incumbent upon us that we work to understand the laws and structure of each aspect in order to refine our understanding of how God means for us to flourish as his children. The principle of “sphere sovereignty” is used to describe these different spheres or aspects of human life and to indicate that each sphere has its own place and rules for living a good life.

The MAN approach to engineering design recognizes that technology is a human cultural activity and interacts with many aspects. Since technology spans the cultural aspects, it is rarely the case that technological products are “value-neutral” or merely tools. The generation of new technologies is a human activity which involves human values. These values are to some extent reflected in the technological objects produced. Good designs, therefore, should not be governed only by technical issues or constraints, but by other cultural values as well. According to Responsible Technology, “sufficient design” requires that norms for all aspects be included in the design specifications for new technologies, along with technical requirements. A list of these norms for design, based on a consideration of the representative cultural aspects, is included in Table 1. These norms express the cultural values that are necessary to consider and balance in the design process to produce the most effective technological products.

Borgmann’s focal things and practices have a holism that matches with the MAN approach. Focal things reflect and honor the multi-aspectual reality of our experiences. Borgmann’s approach especially highlights the importance of the norm of “openness and communication” which has been labeled “transparency.” The device paradigm highlights the potential problems that can occur when the “machinery” behind the commodity is too deeply hidden and not clearly understood by users. The norm of transparency is in fact directed toward reducing the extent to which the objects we design fit the device paradigm.

Both Borgmann and MAN propose that bounds must be placed on technology as on all of culture. For Borgmann, those bounds are determined by placing technology in the context of focal things. MAN recognizes that the bounds on technology, as on all of culture, are a function of the laws and structure that God has built into creation and are identified in the design norms. The necessity for boundaries occurs because of human fallenness and finitude. Borgmann advocates the use of focal things for correcting problems with technology, but he runs the risk of underemphasizing the results of the fall reflected in focal things. The MAN approach is clearer about the need for discernment in the area of cultural values.
Focal things, including nature and tradition, exhibit the fall just as much as technology does. Borgmann’s approach tends to hide this fact. Some Christian anti-technologists also view “nature” as more “pure” than the human designed world. Although there may be more ambiguity built into our human creations, the MAN approach recognizes the potential for good embedded in technological products.

MAN theory supports Borgmann’s rejection of both the instrumentalist and substantive approaches to technology. The definition of technology provided in *Responsible Technology*, “we can define technology as the distinct human cultural activity in which human beings exercise freedom and responsibility in response to God by forming and transforming the natural creation, with the aid of tools and procedures, for practical ends and purposes,” eliminates the possibility of a substantive approach to technology. The MAN approach would qualify as a pluralist approach, according to Borgmann. He might suggest that the danger of being too pluralist could result in overlooking some particular characteristics of technology (like the device paradigm) that we must be more aware of in order to counter them. The MAN approach acknowledges the complex web of forces involved in modern technological development, but doesn’t specifically highlight the device tendencies of current applications of technology. This is an area in which Borgmann’s contribution is valuable.

The *Responsible Technology* definition does not make a distinction between modern technology and historical technology. The implication is that there is no such thing as a “pre-technology” state of culture, since all humans have been and always will be toolmakers and tool users. Borgmann, on the other hand, chooses to make a distinction between the current mode in which we experience technology and the historical development of tools and processes. He then identifies the device paradigm as consistent with technological objects of the last three centuries. In reality it seems difficult to mark a point at which technology becomes characterized by devices rather than things. *Responsible Technology* emphasizes the continuity between current and pre-modern technology, while Borgmann contributes an emphasis on what is particularly distinctive about the way current technology operates.

<table>
<thead>
<tr>
<th>Cultural Appropriateness</th>
<th>Technology should preserve what is good in culture and provide for cultural development</th>
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</thead>
<tbody>
<tr>
<td>Openness and Communication (Transparency)</td>
<td>Technology information should be shared and function should be understandable</td>
</tr>
<tr>
<td>Stewardship</td>
<td>Technology should make frugal use of resources (financial, physical, and human)</td>
</tr>
<tr>
<td>Delightful Harmony</td>
<td>Technology should be pleasing to use and promote quality interaction</td>
</tr>
<tr>
<td>Justice</td>
<td>Technology should promote justice and respect human dignity and environmental integrity</td>
</tr>
<tr>
<td>Caring</td>
<td>Technology should be done out of love and concern</td>
</tr>
<tr>
<td>Trust</td>
<td>Technology should be trustworthy and done in humility in response to our faith in God</td>
</tr>
</tbody>
</table>

Table 1. Design Norms and Descriptions.
5.0 Applications

Many in today’s society are invested in the idea that the potential for technology is boundless, and therefore all limits should be reduced in order to achieve that potential. Stem cell research is one example. The default view is that, because there is potential for cures for debilitating diseases based on stem cells, we should relax all legal restraints on the research process in order to get better results. Borgmann would challenge this assumption. Some restraints are necessary to achieve the promises of technology while avoiding the problem of losing some of our essential humanity.

Borgmann’s theory can direct us toward using design norms appropriately in the realms of consumer choice and public policy. We need to carefully consider the “means” by which our commodities are produced, and use focal values and norms to make better choices and promote process improvements. The resources of the “Industrial Ecology” or “Ecological Intelligence” movement can be helpful in that respect. This discipline focuses on evaluating and providing information to consumers about the processes used in production of goods. An example is the attempt to provide quantifiable carbon footprint scores for various products. The focus of the carbon footprint score is sustainability, but more research could also be devoted to the extent to which some technologies better align more broadly with other focal practices and design norms. Perhaps a score related to the quality of the work involved in producing a given product could be developed. This would take a great deal of effort on the part of researchers to evaluate the means of production and on the part of consumers to use this information when choosing products, but it has potential for providing a way to reduce the effects of the device paradigm.

Engineers have a key role in designing and producing new technologies. A perceptive understanding of the relationships between technology and modern society can help to guide design work and should therefore be part of the curriculum for engineers in training. For these reasons, I think it is important that engineering students be exposed to some of the ideas of philosophy of technology, particularly Borgmann’s device paradigm and MAN. Students need to be pushed to reflect on the place of technology in current culture and the role it plays in daily life. Engineering students may not always be the most receptive of audiences for this subject matter. One of the reasons that they choose to study engineering is that they enjoy math and science. Their interests and talents tend to direct them toward solving technical problems, and they may not be as eager to discuss “fuzzy” cultural issues or may consider them irrelevant. But, the current generation of students is also quite idealistic. We are seeing many engineering students with a strong interest in using technology for bettering mankind, including helping the developing world or disadvantaged in our society.

The most obvious place for engineering students to encounter Borgmann would be in a “Technology and Society” or “History of Technology” course. Unfortunately, most engineering programs are unable to fit a course of this type into their curriculum. The next most obvious possibility might be in a required Philosophy or History course that many students are required to take as part of their general education requirements. Unfortunately, there is usually very little engineering educators can do to affect the content of courses offered by departments in the humanities. In the case of my institution, agreement on the appropriate content for the introductory philosophy course is rare even among philosophy professors, and I have not heard much interest expressed in adding technology or engineering considerations to the course.

Given these constraints, the best approach may be injections or “micro-insertions” of philosophy of technology concepts into other engineering courses when they have some connection to the course.
Design projects offer the best possibilities for doing this successfully, since open-ended problems often include a broader context. The introductory engineering course taken by most first year engineering students (which often includes a design project) and the senior design capstone course would be appropriate venues for addressing Borgman and MAN. It may be difficult to take time out for this material, since these courses have others goals as well, but I believe the effort to do this would bear fruit.

In the introductory course that I teach, we currently include the introduction the MAN as one of our course goals. The material presented to students includes an article by Charles Adams reflecting on the implications of non-neutrality. Students follow up reading the article with a class discussion of the validity of non-neutrality. This topic generates lively discussion as students face some of their instrumentalist assumptions and start to consider different perspectives. Later the idea of normativity is presented and students are provided with the list of norms from Table 1. As a class discussion exercise, students are challenged to identify examples of particular technological products that exemplify or contradict each of the norms. Students are also required to use the norms as part of the decision matrix for selecting a power generation option for a developing country in a later course project.

I propose adding consideration of Borgmann’s device paradigm and focal things to this package. An introductory reading would be necessary. Perhaps some sections from Technology and the Character of Contemporary Life could be chosen for this purpose. But this book (like Responsible Technology) is relatively dense and not appropriate for most first year students. There may be sections from Borgmann’s later books that cover the same topics but are written at a more digestible level. As a follow up exercise students could be encouraged to list examples from their personal experience that exemplify the device paradigm. It might be interesting to have students identify their own lists of focal things and activities. This would relate well to activities in the course that help students reflect on their conception of the meanings of “vocation” and “Christian calling” and how they relate to the profession of engineering.

Similar activities to those described in the previous paragraph could be added to the senior design capstone course. Since design norms are heavily deployed in this course at our institution, a counter-emphasis on Borgmann and the device paradigm might help defuse some of the student sense of indoctrination associated with the norms. The device paradigm can also be used as an introduction to the need for the norm of transparency in design.

6.0 Conclusions

A Christian perspective on technology emphasizes the need to serve others with our engineering work, to practice our profession in order “to act justly and to love mercy, and to walk humbly with your God.” Borgmann’s theory, even though it arises from a secular focus on empirical observation of modern technological developments, can help us to develop a better understanding of the world in which we live and serve. His identification of the importance of focal things challenges us to carefully examine our beliefs about the place of technology in our lives and to clarify the values that arise from our Christian faith which should guide our engineering work.

Borgmann’s contribution to philosophy of technology is important enough to be included in the engineering curriculum along with MAN. Both perspectives provide guidance for personal choices with respect to technological activities, as well as insights that can improve engineering design. In a culture that is disposed toward worship of technology itself, we can all benefit from being reminded of its appropriate purpose in serving the kingdom of God. Unless we all have a foundation that derives from
values located outside of technology itself, particularly from our Christian faith, we may succumb to the allure of trusting too much in technology and unquestionably accepting its conclusions.

So, how can a computer game be guided by focal things? Perhaps players can be encouraged to become more engaged by consulting additional resources to learn more about the game and its creators. Perhaps game designers can be encouraged to allow more participation of players in construction of the virtual world. Perhaps game system engineers can be encouraged to develop hardware that allows more communication and cooperation between game players. The challenge posed by Borgmann is for all of us to rise above mindless participation in technological activities, to actively discern to what extent an activity is worthy of our limited time and attention. While taking advantage of the benefits provided by our creative innovations of technology, we may also sometimes be called to sacrifice some availability in order to better serve our God and our fellow humans.\(^{20}\) Borgmann’s device paradigm provides us with one more reminder about the need as Christians and as humans to more carefully decide what God would have us do while we are here on this earth.

References

[1] University of Montana, Department of Philosophy, Faculty Information webpage (http://www.cas.umt.edu/phil/Faculty/Info%20Pages/borgmann.htm), accessed 3/30/09.


[3] Ibid., Ch. 2, p. 11.


[5] Ibid., Ch. 23, p. 197.

[6] Ibid., Ch. 23, p. 205.


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[19] Micah 6:8, NIV.

Can Design for the “Poor” Result in Better Designs for Everyone?

Matthew G. Green
LeTourneau University

Abstract

Although the global market allocates relatively fewer resources to some of the neediest on our planet, Christians are called on to take special concern for the disadvantaged. Scripture speaks of the blessing of serving the “poor,” which might be understood as including a lack of influence, position, or power such as may be experienced by persons with disabilities. Recent design research suggests insights gleaned from design for persons with disabilities may lead to breakthrough innovations benefiting the larger community. A new “Extreme Experience Design” method at the forefront of this exciting theme places interviewees in simulations which often parallel physical disabilities (such as wearing dark glasses to simulate low vision), in order to elicit non-obvious design needs and ideas. This paper describes implementation of “Extreme Experience Design” in a first-year design course at a teaching university, along with results and survey data. The overwhelming majority of student-designers agreed the technique led to design ideas significantly benefiting average users. This case study suggests that the scripturally promised blessing of heeding the needs of the “poor” may give an immediate and tangible manifestation in engineering design – better designs for everyone. Future work includes extending the disability simulation into other realms such as economic scarcity simulation.

1 Introduction

Although the global market allocates relatively fewer resources to some of the neediest on our planet, Christians are called on to take special concern for the disadvantaged. Scripture exhorts “Love your neighbor as yourself” (Lev. 19:18 quoted by Jesus in Matt. 19:19, Matt. 22:39, Mark 12:31, Luke 10:27 and later referenced in Ro. 13:9-10, Gal. 5:14, and James 2:8.) Jesus’ parable of the Good Samaritan (Luke 10:25-37) indicates “neighbor” here could include the poor, disabled, and otherwise disenfranchised. Scripture speaks often of God’s concern for the “poor” (such as Isaiah 61:1-2 quoted by Jesus in Luke 4:18-19) and indicates blessing for those who share this concern (e.g. Prov. 19:17, Prov. 22:9, Prov. 28:27, Jer. 22:16, and Matt. 19:21.) Although the word “poor” in the English translation is often understood to mean lacking financial or material means, the Greek word Ptochos might be understood as including a lack of influence, position, or power to accomplish an end. Rural villagers in developing countries and persons with physical disabilities in any country may fit this definition due to the additional obstacles they face in daily living and occupational pursuits.

The engineering design community has recently shown tremendous interest in design for such “frontier contexts” as persons with disabilities and rural villagers. Recent design research not only acknowledges the importance of accounting for persons with disabilities in the design process, but further suggests the insights gleaned may benefit the larger community and lead to breakthrough innovations. A new “Extreme Experience Design” method at the forefront of this exciting theme places interviewees in simulations which often parallel physical disabilities (such as wearing dark glasses to simulate low vision), in order to elicit ideas and needs which are normally hidden known as “latent needs.” Innovative design for special populations may lead to niche innovations that are valuable to a larger segment of the user population. Table 1 lists examples gleaned from everyday experience of other technologies which have broader impacts than the target audience. The table is divided into “trickle-down” effects in which high-dollar development efforts resulted in more affordable products versus the less common “trickle-up” effect in which less lucrative niche markets resulted in broader impacts.
Table 1: Examination of Broader Impacts: Trickle-Up and Trickle-Down

<table>
<thead>
<tr>
<th>“TRICKLE-DOWN”</th>
<th>Target Beneficiaries</th>
<th>Wider Beneficiaries</th>
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<tr>
<td>Technology</td>
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<tr>
<td>Tang</td>
<td>Astronauts</td>
<td>Kids</td>
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<td>Photovoltaic cells</td>
<td>Space program</td>
<td>Remote individuals</td>
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<td>Anti-glare coatings</td>
<td>Astronauts</td>
<td>Glasses wearers</td>
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<td>Anti-lock brakes</td>
<td>Luxury car or Volvo drivers</td>
<td>Normal car drivers</td>
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<tr>
<td>Crumple zones</td>
<td>Luxury car or Volvo drivers</td>
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<td>Brita car seats</td>
<td>Affluent families</td>
<td>Middle-class families</td>
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<td>RV refrigerators</td>
<td>RV vacationers</td>
<td>Individuals “off grid”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>“TRICKLE-UP”</th>
<th>Target Beneficiaries</th>
<th>Wider Beneficiaries</th>
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<tbody>
<tr>
<td>Technology</td>
<td></td>
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<tr>
<td>Curb cutouts</td>
<td>Wheelchair users</td>
<td>Bicyclists, skaters, cane users, cart pushers</td>
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<td>Easy doorknobs</td>
<td>Motion-impaired</td>
<td>All users, especially load carrying</td>
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<td>Closed captioning</td>
<td>Deaf or hard of hearing</td>
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<td>Freeplay Wind-up Radio</td>
<td>Rural African villagers</td>
<td>Survivalists, Gadget lovers</td>
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<td>Screen readers</td>
<td>Visually impaired</td>
<td>Users preferring audio</td>
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</tbody>
</table>

The greatest engineering challenges of the 21st century, such as clean water and energy for all, call for a generation of engineers inspired and equipped to tackle *frontier-design* \(^2,3\) needs *outside their experience and expertise*. Prototypical frontier-design needs include persons with disabilities, rural areas of developing countries, and space exploration. Circumstances often call on engineers to design for such *frontier-design contexts* outside their experience and expertise. This occurs by default because engineers are a subset of society, and design products to be used by children, remote villagers, illiterate individuals, and other groups typically not represented among design engineers. Additionally, the importance multinational companies place on positioning products in a global marketplace requires design for customers in other countries, cultures, and economies. Although most design engineering is performed in *developed* countries, 86% of the world lives in a developing country\(^4\).

In view of these needs, LeTourneau University seeks to foster a global-service mindset, an experiential learning curriculum, and state-of-the-art design methods throughout the interdisciplinary curriculum. LeTourneau offers a B.S. in general engineering with concentrations in biomedical, computer, electrical, mechanical, civil, and materials joining engineering. The “Extreme Experience” design method is being piloted in freshman cornerstones design (the focus of this paper) as well as a junior design methods course.
The “Extreme Experience” Design Method for Customer Needs Elicitation

Effective design hinges upon obtaining high-quality customer requirements; however, many current engineering design texts give little guidance on how to acquire this important data. Some progressive texts suggest either a verbal interview or an articulated-use interview, in which a volunteer actively uses the product to be re-designed during the interview. Lead-user interviews and empathic design techniques have also generated recent interest in the design community. It has been shown that persons with disabilities qualify as lead-users who often identify novel and important needs which many customers value, but few articulate. For example, many pedestrians and bicyclists appreciate curb cutouts, yet only wheelchair users articulated this need.

Building on these findings, empathic lead-user analysis simulates a disability (such as dark glasses simulating visual impairment) while a test subject experiences the product of interest during an interview. This disability-simulation approach greatly broadens the availability of “lead-users,” and enables every engineer on the team to experience the product as a lead-user. Not surprisingly, research on the empathic lead-user technique indicates vastly improved customer needs elicitation over currently taught methods, showing a 500% increase in latent needs collection over articulated-use techniques and a 25-fold increase over verbal-only approaches. Seepersad and Holtta-Otto continue to build on their empathic lead-user research with the development of the “extreme experience” design method for needs elicitation.

These recent findings hold exciting implications for teaching and learning design methods. Implementation in first-year design at LeTourneau University provides anecdotal evidence that students learn problem-definition techniques most effectively when nudged outside of their comfort zone into a frontier-design need. The extreme experience approach allows every student to experience a product from the point of view of a person with disabilities, as well as to conduct a number of disability-simulation interviews on classmates.

Piloting “Extreme Experience” Design in a 1st Year Design Course

3.1 Course Background: 1st Year Cornerstones Design

The first-year cornerstones design course (ENGR 1812 “Fundamentals of Engineering Design”) introduces the engineering design process to ~130 students each year from all engineering disciplines. Project work includes interdisciplinary teams adapting everyday products to accommodate persons with disabilities, such as a digital camera interface accommodating fine motor disabilities. Experiential, project-based teaching stimulates learning of teaming skills, design process, written and oral communication, and basic robotics and programming skills. Interdisciplinary teams use a machine language trainer and the LEGO™ NXT robotics kits programmed with LabVIEW™ as electro-mechanical “breadboards.”

In the final project, teams re-design and prototype everyday products adapted to accommodate persons with disabilities. Examples include an automated pill dispenser accommodating visual, dexterity, and cognitive disabilities (Figure 1); an alarm clock accommodating dexterity disabilities, a digital camera interface accommodating fine motor disabilities, and a mixer-blender accommodating one-handed use with fine motor disabilities. This frontier-design project is one of the most popular among students, and the only project to-date with unsolicited comments from students after class such as “thank you for doing this [assistive] project.”
3.2 Classroom Implementation of the “Extreme Experience” Design Method
Appendix A shows the most recent “Extreme Experience” design project assignment from first-year Cornerstones Design (ENGR 1812 “Fundamentals of Engineering Design.”) The design scenario includes individuals who need an accessible mixer-blender due to one-handed use or severe fine motor impairment. Table 2 outlines the design process involving: (1) need definition (including simulation interviews), (2) concept development and selection, and (3) prototyping and demonstration.

Table 2: Design Process Steps for the “Extreme Experience” Design Project
(*Underlined Steps are Project Deliverables.)

<table>
<thead>
<tr>
<th>Phase I: Clarify the Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>► Background Research – review handout, ask questions, web, experiments</td>
</tr>
<tr>
<td>► *Planning Project (AIM) – “Team To-do List” or “Action Item Matrix (AIM)”</td>
</tr>
<tr>
<td>► *Customer Needs Interviews – ask people what they need</td>
</tr>
<tr>
<td>► Requirements List – list what the final design must do &amp; be</td>
</tr>
<tr>
<td>Phase II: Develop Concepts (&amp; Select)</td>
</tr>
<tr>
<td>► *Functional Outline – divide problem into functions to solve</td>
</tr>
<tr>
<td>► Brainstorming – verbal &amp;/or graphical</td>
</tr>
<tr>
<td>► *Solutions Grid – list as many ideas as possible (per function)</td>
</tr>
<tr>
<td>► *Concept Choices – define concepts to choose among</td>
</tr>
<tr>
<td>► Concept Selection - pick the best solution to move forward with</td>
</tr>
<tr>
<td>Phase III: Embody (Implement) Concept</td>
</tr>
<tr>
<td>► Flowcharting &amp; Programming</td>
</tr>
<tr>
<td>► *Prototyping (Building) – NXT kits, online reference guides</td>
</tr>
<tr>
<td>► Test Requirements List – refine design as needed, trouble-shooting</td>
</tr>
<tr>
<td>► *Communicate Results - class demonstration, memo, video, web</td>
</tr>
</tbody>
</table>

Table 3 shows the interview procedure demonstrated live in class. The instructor interviews a student volunteer and types notes into the template (Figure 2) projected overhead. The interview method

---

a Design, functional prototype, and photo by “Team #18”: Brent Ludwig, Nolan Bryant, and Christopher Schults
combines three needs elicitation techniques: an articulated use interview finishes with like/dislike questions, and then is repeated under an “extreme experience” simulation of disability. Throughout the interview customer comments are recorded in the template and actions or interviewee questions are shown in brackets as shown in Table 4. In step #2 the “voice of the customer” interview notes are translated into positive, solution-independent need statements such as “easy to use with limited motor control” and given an importance rating such as “must” or “nice.” In step #3 each team distills their interview data into a needs summary list similar to that shown in Table 5. The list shown in Table 5 is actually a “uniform customer needs list” compiled by the instructor from the entire class’s data and distributed to form a common basis for grading across all teams.

Table 3: Interview Procedure

1. Interview 3+ people
   a. Record normal usage interview transcript (two hands used normally)
   b. Repeat Q's#2-5 with Extreme Experience usage (one-handed with an oven mitt or equivalent)
   Important: clearly separate parts a & b in transcript
2. Add translated needs & weights to transcripts
3. Compile a separate needs summary list (~5-15)
   (Add any additional needs the team has discovered)

Figure 2: Customer Needs Interview Template Provided to Students
Table 4: Sample Interview Transcript with Interpretation and Importance

<table>
<thead>
<tr>
<th>Voice of the Customer</th>
<th>Interpreted Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1: When &amp; where would you use this product?</td>
<td>Suitable for countertop</td>
<td>4</td>
</tr>
<tr>
<td>I would use it in a kitchen</td>
<td>Can mix or blend food/liquid</td>
<td>4</td>
</tr>
<tr>
<td>to make something to drink or quickly chop food</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2: Please show me how you would use it ...</td>
<td>Place to insert ingredients</td>
<td>4</td>
</tr>
<tr>
<td>[first takes off lid]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[insert ingredients]</td>
<td>Easy to operate</td>
<td>2</td>
</tr>
<tr>
<td>[pushes button]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>likes this</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3: What else do you like about the product?</td>
<td>Stylish/Attractive</td>
<td>1</td>
</tr>
<tr>
<td>it looks really cool</td>
<td>Portable</td>
<td>1</td>
</tr>
<tr>
<td>It’s very lightweight</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

***EXTREME EXPERIENCE (One hand & oven mitt)***

| Q1: When & where would you use this product? | Easy to remove lid | 3 |
| Q2: Please show me how you would use it ... | Container stays attached to unit | 3 |
| [shakes violently] | Easy to pickup | 3 |
| [container falls to the table] | | |
| [uses “thumb” holder] | | |

Table 5: Uniform Customer Needs List (Adapted from Class Needs Lists, FA’08)

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Weight (5=Must)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Functionality</td>
<td></td>
</tr>
<tr>
<td>1.1. Mixes contents well</td>
<td>5</td>
</tr>
<tr>
<td>1.2. Cup held stationary</td>
<td>5</td>
</tr>
<tr>
<td>1.3. Variable speed</td>
<td>1</td>
</tr>
<tr>
<td>1.4. Works with different cups</td>
<td>1</td>
</tr>
<tr>
<td>2. User Interface</td>
<td></td>
</tr>
<tr>
<td>2.1. Easy to operate w/ limited hand usage</td>
<td>5</td>
</tr>
<tr>
<td>2.2. Simple/easy to understand controls</td>
<td>4</td>
</tr>
<tr>
<td>2.3. Little strength and grip required to move</td>
<td>3</td>
</tr>
<tr>
<td>2.4. Auto-reset</td>
<td>1</td>
</tr>
<tr>
<td>3. Cleanable</td>
<td></td>
</tr>
<tr>
<td>3.1. Easily cleanable parts</td>
<td>4</td>
</tr>
<tr>
<td>3.2. Dirty parts detach</td>
<td>3</td>
</tr>
<tr>
<td>3.3. Non-stick surface</td>
<td>1</td>
</tr>
<tr>
<td>4. Stability</td>
<td></td>
</tr>
<tr>
<td>4.1. Stays upright and in place when used</td>
<td>5</td>
</tr>
<tr>
<td>5. Aesthetics and Size</td>
<td></td>
</tr>
<tr>
<td>5.1. Compact for easy storage</td>
<td>3</td>
</tr>
<tr>
<td>5.2. Aesthetically pleasing</td>
<td>2</td>
</tr>
</tbody>
</table>

Adapted from Team #34 (SP’09): Paul Power, Alex Schaeffer, Michael Stockholm

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3.3  Student Survey Results

After finishing the mixer-blender “extreme experience” design project, students completed the survey found in Appendix B, rating agreement with 18 different statements on a 1-5 scale (1=strongly disagree, 3=neutral, 5=strongly agree). Table 6 summarizes the results from 22 students.

Section (A) of the survey seeks to understand the student’s background such as attitudes towards designing for persons with disabilities. The response average of A3=3.0 is a concern indicating clearer teaching is needed on the distinctions among the interview types. (This has already been implemented in the semesters following.) The response A4=3.7 indicates that students enjoyed the design-for-disability theme of the project. Section (B) responses deal with the normal customer interviews (using both hands normally), and indicate students understand and like the technique and would like to re-use it on future projects. Responses also indicate the interviews enhance understanding of customer needs and in some cases gave good design ideas. Section (C) responses deal with the extreme experience interview (one-handed with oven mitts), and indicate students understand and like the technique and would like to re-use it on future projects. The most significant response item for the primary question of this paper is C8=4.0 indicating students believe the extreme interviews “inspired ideas that are better for average users as well.”

<table>
<thead>
<tr>
<th>#</th>
<th>Prompt</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) General</td>
<td>I have done very little design before this class.</td>
<td>2.7</td>
</tr>
<tr>
<td>1</td>
<td>I have experience with people with special needs such as physical disabilities.</td>
<td>3.1</td>
</tr>
<tr>
<td>2</td>
<td>The three interviews (normal, one-hand, over mitts) all blurred together into one.</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>I enjoyed designing for people with special-needs such as arthritis or a newborn.</td>
<td>3.7</td>
</tr>
<tr>
<td>(B) Normal Customer Interview (both hands, normal)</td>
<td>I understand customer interviews well enough to use them in a future project.</td>
<td>3.9</td>
</tr>
<tr>
<td>1</td>
<td>I like the customer interview technique for finding design needs.</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>I would like to do customer interviews next time I am designing for a customer.</td>
<td>3.9</td>
</tr>
<tr>
<td>3</td>
<td>Customer interviews helped me better understand customer needs.</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>Customer interviews gave me good design ideas.</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>Customer interviews made me more interested in an engineering career.</td>
<td>3.1</td>
</tr>
<tr>
<td>(C) Extreme Experience Interview (one-hand, oven mitts)</td>
<td>I understand extreme interviews well enough to use them in a future project.</td>
<td>3.9</td>
</tr>
<tr>
<td>1</td>
<td>I like the extreme interview technique for finding design needs.</td>
<td>3.7</td>
</tr>
<tr>
<td>2</td>
<td>I would like to do extreme interviews next time I am designing for a customer.</td>
<td>3.7</td>
</tr>
<tr>
<td>3</td>
<td>Extreme interviews helped me better understand customer needs.</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>Extreme interviews gave me good design ideas.</td>
<td>3.6</td>
</tr>
<tr>
<td>5</td>
<td>Extreme interviews made me more interested in an engineering career.</td>
<td>3.1</td>
</tr>
<tr>
<td>6</td>
<td>Extreme interviews inspired ideas that are better for average users as well.</td>
<td>4.0</td>
</tr>
</tbody>
</table>

4  Conclusions and Future Plans

Exposing students to frontier design scenarios beyond their experience and expertise, such as persons with disabilities, can serve as rigorous design training comparable to strengthening grammar through foreign language learning. Including design for disability projects in the curriculum potentially has multiple long-term benefits: increasing awareness of the needs of disabled persons, better trained
engineering designers able to deal with frontier environments, and intangible spiritual blessings promised in scripture (i.e. the “treasure in heaven referenced in Matt. 19:21.) In addition to possible long-term benefits, the case study in this paper suggests that the scripturally promised blessing of heedng the needs of the “poor” in engineering design may give an immediate and tangible manifestation – better designs for everyone.

The case study here ends at the proof-of-concept prototyping stage. Carrying the work further into courses which result in a more refined product that may be delivered to a customer for long-term testing is a next step. Future work may also include extending the disability simulation into other realms such as economic scarcity simulation.

References


Appendix A: Extreme Experience Design Project Assignment (ENGR 1812, LeTourneau U.)*

Design Project #4: Accessible Mixer-Blender

Project Statement: Apply the three-phase design process to design and prototype a mixer-blender for one-handed users and users with dexterity disabilities. Prototype the device using your class-issued LEGO® Mindstorms kit along with up to $10 in pre-approved† non-LEGO passive hardware (such as bolts, custom wood or metal parts, string, springs, etc).

Customer Profile: Mr. Jones is an independent-minded senior-citizen who loves to prepare health shakes. Unfortunately his severe arthritis makes thorough mixing difficult, and conventional blenders are large, awkward, and difficult to keep clean. Mr. Jones lives with his daughter who is a new mother. His daughter Emily often finds herself with the two-month-old baby in one arm, and needing to puree fresh vegetables into baby food with the other. For such small amounts of food, Emily also considers a counter-top blender large, awkward, and difficult to keep clean. Mr. Jones and Emily are convinced there is a market for their needs, and have asked a group of engineering students to design and prototype a device to help them safely and conveniently mix and puree small quantities of drink or food.

Customer Interviews: Your team will conduct customer interviews and develop a detailed needs list for the mixer-blender. Each team will either quickly construct a simple NXT prototype, or (optionally) obtain a blender to use in your interviews. The people you interview will simulate Emily’s child-care needs and Mr. Jones’ arthritis by using only one hand with an oven mitt on. The interviews must include both mixing and cleaning. After all teams have collected customer needs, results from the entire class will be combined into a standardized needs list to guide final design work.

Final Demonstration: Each team will demonstrate a final prototype for the class. A functional test will involve thoroughly mixing 50 mL (10 tsp) of powdered oatmeal with 50 mL of water in a standard size Styrofoam cup. After 5 seconds the mixing must be complete (defined as a mixture such that no water may be poured off and no dry mix remains.) Cleaning should be demonstrated or explained by the team. The class instructor will also test the prototype against the standardized customer needs list, including one-handed use with simulated arthritis (wearing an oven mitt.)

Graded Components: The project includes the following graded components:
1. Design Process Checkpoints (150pts) – These checkpoint items will be due as indicated on the schedule: (1) Action Item Matrix, (2) Customer interview data (transcripts, compiled needs list), and (3) a Solutions Grid.

2. Design Memo (200pts) - Describe your design approach and results according to the guidance given below. Attachments will include a device photo, customer interviews with a needs summary, function outline, solutions grid, and the first and last AIM’s.

3. Final Demonstration (200pts) – Demonstrate the full capability of your prototype. Grading will be based on the fulfillment of minimum design requirements in addition to customer design requirements in the instructor’s judgment.

* This assignment and related documents are freely available from the author in electronic form.
† A proposed parts list must be pre-approved by the course instructor with normal retail prices.
Design Memo: Describe your design approach following the three phases of design: (1) Task Clarification, (2) Concept Generation and Selection, and (3) Embodiment. Explain how the team determined what should be designed (e.g. customer interviews). Identify how concepts were generated functionally, and any unusually insights or experiences. When discussing embodiment, highlight key hardware and software capabilities integrated into your device in response to the customer needs. In the text be sure to reference all of the attachment items listed below, and describe if appropriate.

- Include the following attachments, numbered as indicated:
  1. A clear, high-quality photo of your final device
  2. Customer interview transcripts (3 “normal usage” combined with 3 “EE” transcripts)
  3. Customer needs summary list
  4. Function outline
  5. Solutions grid (with chosen solutions indicated)
  6. Printout of any LabVIEW program(s) used (print using File>Print>VI Documentation)
  7. AIM’s - initial and final

- Use a memo format consistent with those recommended in the course textbook. Memo fields should include a minimum of the: instructor’s name, author’s names (with signed initials), due date, assignment name, and “ENGR 1812, Team #__”.

- The text should be a maximum of 2 pages in length (printed on one side only), 1.5 spaced, with an 11-point font or greater and one inch margins all around. This does not include attachments. Use paragraph and section headings as appropriate.

SCHEDULE (Tentative):

<table>
<thead>
<tr>
<th>L#</th>
<th>MW</th>
<th>TTh</th>
<th>Assignments Due</th>
<th>Class Topics/Activities/Assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>3/23</td>
<td>3/24</td>
<td></td>
<td>P4: Final Design Project (Customer-Driven)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lec: AIM &amp; Customer interviews</td>
</tr>
<tr>
<td>21</td>
<td>3/25</td>
<td>3/26</td>
<td>AIM P4 #1</td>
<td>P4 Q&amp;A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Example FO, SG, &amp; Concepts</td>
</tr>
<tr>
<td>22</td>
<td>3/30</td>
<td>3/31</td>
<td>P4 HW: 3*2 interview transcripts w/ translations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P4 HW: Needs summary list</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(submit both assignments by printout + email)</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>4/1</td>
<td>4/2</td>
<td>P4 HW: function outline, solutions grid</td>
<td>[LV Quiz Prep.]</td>
</tr>
<tr>
<td>24</td>
<td>4/6</td>
<td>4/7</td>
<td>[Quiz5: LabVIEW]</td>
<td>TBA</td>
</tr>
<tr>
<td>25</td>
<td>4/8</td>
<td>4/9</td>
<td></td>
<td>TBA</td>
</tr>
<tr>
<td>26</td>
<td>4/13</td>
<td>4/14</td>
<td>Demo: P4 Final Prototype</td>
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<td></td>
<td></td>
<td></td>
<td>Memo: P4 Design Memo w/ final AIM</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>4/15</td>
<td>4/16</td>
<td>Check in MLT + Kit w/ Inventory (signature req.)</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Extreme Experience Design Project - Student Post-Survey

This survey is anonymous and voluntary. Only the average results of all surveys will be shared. No individual results will be reported. Do not sign your name. The results of this survey will help improve design courses. Thank you for taking a moment to complete this – your response is appreciated!

0. How many total LETU semester hours did you have when this semester began?
(a) 0 hours  (b) 1-30  (c) 31-60  (d) 61-90  (e) 90+ hours

1. Please circle your gender (optional): Male / Female.

2. What is your current first choice of a degree concentration (circle one)?
(a) ME  (b) MET  (c) BME  (d) EE  
(e) EET  (f) CE  (g) MJE  (h) MJET  
(i) Other: LeTourneau_  (j) Undecided

Please indicate whether you agree or disagree with each statement by placing a √ in the appropriate column to the right.

<table>
<thead>
<tr>
<th></th>
<th>1) Strongly disagree.</th>
<th>2) Disagree.</th>
<th>3) Neutral.</th>
<th>4) Agree.</th>
<th>5) Strongly agree.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I have done very little design before this class.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I have experience with people with special needs such as physical disabilities.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>The three interviews (normal, one-hand, over mitts) all blurred together into one.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>I enjoyed designing for people with special-needs such as arthritis or a newborn.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These question are for the normal customer interview (both hands used normally)

<table>
<thead>
<tr>
<th></th>
<th>1) Strongly disagree.</th>
<th>2) Disagree.</th>
<th>3) Neutral.</th>
<th>4) Agree.</th>
<th>5) Strongly agree.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I understand customer interviews well enough to use them in a future project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I like the customer interview technique for finding design needs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I would like to do customer interviews next time I am designing for a customer.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Customer interviews helped me better understand customer needs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Customer interviews gave me good design ideas.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Customer interviews made me more interested in an engineering career.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These question are for the extreme experience interview (one-hand, oven mitts)

<table>
<thead>
<tr>
<th></th>
<th>1) Strongly disagree.</th>
<th>2) Disagree.</th>
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<td>I understand extreme interviews well enough to use them in a future project.</td>
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<td>I would like to do extreme interviews next time I am designing for a customer.</td>
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<td>Extreme interviews gave me good design ideas.</td>
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<td>Extreme interviews made me more interested in an engineering career.</td>
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<td>Extreme interviews inspired ideas that are better for average users as well.</td>
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Enhancing Student Learning through Interaction on Service-Based Projects

Michael R. Foster
George Fox University

Introduction

How can I enhance my students’ learning experience? As I complete my second year of teaching, this question is often present as I prepare a lecture or a student asks a question in class. Many times I try to remember my own experience learning a topic for the first time. How did I grasp the concept? Would these students see the material in the same way I did? Thankfully, a required new faculty class at my institution provided partial insight into this question by having us read *The Courage to Teach* and providing a venue for discussion and reflection on effective teaching. During these discussions, as well as those with other colleagues, I was encouraged to discover my own teaching style and not get caught up with a cookie-cutter idea of teaching. If I am honest with myself, I will be comfortable with how I teach and challenge my students to learn. However, students have their own learning styles, which may not mesh well with my teaching style. So I am cognizant of the need to add variety in the classroom and laboratory environments. Yet, does a better way exist to enhance my students’ learning?

I propose that our education of engineers can be enhanced by the purposeful use of teamwork between students in different years of study working on service-based projects. I am passionate about teamwork and what students can learn through teaching each other and how they can be leaders wherever they are in a group hierarchy. My argument is that by working together on a service-based project in a field that interests them, students begin to practice the skills they have developed in ways that extend beyond just engineering.

My Experience

When I entered Messiah College (MC) in 1998, the engineering program had just graduated its seventh class a few months earlier. During my freshman year, I sought out a leadership experience in the department and was directed toward the West Africa Pump Project, a subgroup (and the only group at the time) of Dokimoi Ergatai (DE), the forerunner to The Collaboratory for Strategic Partnerships and Applied Research (a kind of service-learning organization). I participated in the construction and design of a PVC water pump and its actuation system for a handicap clinic in Mahadaga, Burkina Faso, even before I took the Fluids course. Through my interactions with upper-level students in DE, I learned what to expect from different professors and to have a healthy fear of certain courses (Thermodynamics and Fluids). At the time, DE was extra-curricular, and I only received course credit when I traveled to Africa to implement the pump (3 credits for a cross-cultural component). Yet, I enjoyed my experience working with my fellow engineering students both in and outside of my own year of study. Though I rarely, if ever, received any homework help during my time in the group, I did experience a variety of interactions with students throughout the department and was encouraged as we learned and matured together.

I took advantage of my wiser peers’ knowledge the most while I was in the Engineering House during my junior year. The “House” was one floor in an on-campus apartment building that has four suites. A couple times during my sophomore year, I had gone to the Engineering House to work on the pump project and get homework help, and I saw the “interesting” community they had. For the year that I was in the House, all the students on the floor were engineering students except for two or three students from other majors to help fill out two of the rooms. My suite had three juniors (including myself) and two seniors. I believe one of the key draws of the House was that, at MC, juniors were not guaranteed apartment housing. The Engineering House was a way for junior engineering students to “get in early.” As special interest housing, we held homework help sessions (poorly, if ever, attended), had dinner with

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different engineering professors/staff once a month (where we had fun fitting 17 people around tables in a single suite), and completed service projects.

My roommates and I enjoyed fun “non-engineering” times and also several “nerdy” engineering endeavors. The juniors in the apartment received homework help during the difficult third-year studies and had access to the seniors’ old exams (if they saved them) to prepare for classes. We also followed our senior roommates’ Senior Design project and job searches.

Fast forward six years and shift 3000 miles across the country to my current position as Assistant Professor of Mechanical Engineering at George Fox University (GFU). The GFU engineering program graduated its sixth class (completing a four-year curriculum) in May. During my limited time of teaching and interacting with students, I have noticed a clear distinction to what I experienced at MC. Students in different years of study communicate very little, if at all (graduates have even mentioned this observation to me). I have given several exams that are almost, if not completely, the same as the previous year, and I have not suspected that any of my students poured over an exam from a student that has already taken the course. While it makes it easier for me to not worry about making up a second exam, a stronger community exists when I have to prepare/create more variety because students are learning from different sources and growing together.

Before the start of the past academic year, an engineering student initiated and, during the year, coordinated the first Engineering House at GFU. Unfortunately, there was only one other engineering student in the house! The Student Life Office was willing to try a major-specific Learning and Living Community to see if it enhanced student learning. (Note: GFU owns many houses adjacent to campus in addition to a couple of “traditional” apartment houses. The coordinating student was responsible for recruiting students to be in the house.) The only requirement of House participants was to perform a service project during the year. I was the advisor to the Engineering House, and we were able to connect with Matt and Julie Walsh, engineering alums of MC, who are missionaries serving in Mahadaga, Burkina Faso. They are trying to find a solution to the continual complete discharge of the batteries storing charge from solar panels on the missionary compound where they work. The task was to create a kilowatt-hour meter so that electrical usage in a particular structure could be monitored. They requested that the meter provide an alarm when a set point was reached, as well as store various metrics regarding usage throughout the year.

Of the two students in the house, one is on the Mechanical track (ME) and the other is on the Electrical track (EE). We announced the project to all the students in the department via a pizza party at the beginning of the semester and received a handful of interested students, which quickly dwindled to only one other ME student; all were juniors. Due to the electrical nature of the project, the EE student completed a general circuit design but did not have a course in microprocessors until the Spring Term. The ME students just came to meetings to check on the progress of design and complete research of components when necessary. The design and prototype construction of the electrical portion was handed off to another EE student to complete as a project in the spring Microprocessor course. The MEs are waiting to see what aspect of the meter housing they can design during the summer when the microprocessor and circuit manufacturing are completed.

I believe the difference between my experiences at MC and GFU is due to a couple factors, but they both point to an effective means of education. First, the MC curriculum at the time of my studies was more focused on traditional, systematic coverage of material than it is currently. This approach has since changed to the Integrated Projects Curriculum, a more organizational and team-based approach that builds on work that was done by previous groups. When I was a student, groups such as the Genesis solar car, Flying Club, and Dokimoi Ergatai were attended well by students because we wanted to do engineering. GFU’s program has had a design/build mentality from the beginning. Many of the courses give students opportunities to experience hands-on engineering. This keeps them quite busy. As a result, they have very limited time for any extra-curricular engineering activities, such as ASME-sponsored...
projects, where they could develop relationships with students from other years of study. As a colleague at Seattle Pacific University observed, “The biggest obstacle to these types of interactions is time. All of our students are extremely busy, generally doing great things! But it leaves them little time and energy to invest in inter-class interactions.”

As for the Engineering House, reasons for the lack of interest may be due to the inertia of a new endeavor, busy students, and/or the ease at which students can find “non-dormitory” housing at GFU prior to their senior year.

Discussion
As I reflect on my experiences at MC and GFU, I suggest that students can learn more and feel a greater mastery of the material they are studying when they interact with students from different years of study. In addition, these students can potentially experience key learning advantages when they collaborate on service-based projects. A group of students can experience an enhanced learning environment and true fellowship through three aspects—common passion, common purpose, and uncommon experience.

Common Passion
As highlighted in the title (and in the book) Dog Training, Fly Fishing, and Sharing Christ in the 21st Century and practiced by small groups in many churches, people are drawn to fellowship with those with whom they share a common passion. Out of that initial connection, God develops a relationship with and through members in the group. The environment is not contrived; it is relaxed and familiar to those who both know Christ personally and have never heard of Christianity.

Can this model be valuable for us in the education of our students? What if we allow students with a passion for an area of engineering (or just engineering in general) to come together to solve a problem? Better yet, let us make sure that students from different years of study can and do participate. Many (if not all) engineering programs have this component already in place. ASME, IEEE, EWB, or other professional or service organizations allow students from different years of study to participate. As educators, we should be concerned about maintaining a passionate pursuit of engineering and providing a clear and meaningful purpose for students.

Common Purpose
I want to contend that service-based projects are a great path to achieving fellowship and enhancing learning. Generally, any common experience can bring a group closer together. My students complained recently about a homework assignment I gave them near the beginning of a previous semester’s class. They were recalling their dread of the quantity of work (13 problems), not the difficulty of the concepts. I mentioned that they now had a common experience together that would help to strengthen them as a class. They rolled their eyes at me, but when I asked if I should reduce the assignment for next year’s class, they said, “No. It would be good for them to go through it, too.”

I suggest that when students serve people cross-culturally or co-culturally by looking beyond themselves, they can further enhance the bond that common experience brings. Students can begin to internalize their work and serve their colleagues by collaborating with them in a similar way. When churches put together a ministry of landscape maintenance for the community or a small group gets together to help a family displaced by Hurricane Katrina move into temporary housing, a common experience occurs and the group members’ connection to each other can grow stronger. Does this connection happen every time? Perhaps not, but many students will make a connection (maybe only subconsciously at first) between what they do as temporary servants and how they can continually live as servants, especially as it is consistent with the mission of their engineering program.

So students have a common passion of engineering. They have a common purpose in solving a problem to help and serve other people. As they work together, they experience fellowship.
“I think that there is also a self-reinforcing community effect, where the younger students see what the juniors and seniors are accomplishing and become self-motivated to tackle similarly difficult projects. Similarly, students hear each other's stories and these begin to build a community understanding of calling, vocation, and purpose. Faculty can do a lot to foster this type of development, but it certainly takes time and thus I expect that more established programs might see fruit in these areas more readily than younger programs.”

In addition to the above observation, the fellowship borne from common experience is affirmed both by the Bible and academia. I recently heard an analogy of fellowship that helped me see the deeper implications of students coming together. Coast Redwoods are the tallest trees on earth. However, their root systems grow laterally, only penetrating 4-6 feet underground. For every three feet of vertical growth above ground, they have approximately 1 foot of radial growth in their root system. How can these trees grow so tall and not uproot due to their exposure to wind? Coast Redwoods are usually found in groves, because as their root systems extend outward, they intertwine with all the trees in the area. By linking together, the grove of trees stands strong together. How can we create this level of fellowship with the coming and going of students every year? I contend that one strong answer is through students from different years of study completing service-based projects together.

Uncommon Experience
In addition to strengthened fellowship, learning is a key advantage of inter-class teams completing service-based projects. As part of the ABET Program Outcomes (“an ability to function on multidisciplinary teams”) and our desire to develop quality engineers, we have a responsibility to teach teamwork skills. I think students can achieve a higher level of teamwork skills if they work, not only with students in their classes and labs, but in teams of non-homogeneous knowledge. As previously mentioned, I was able to learn aspects of fluid dynamics from other students through my group service project experience even before I entered the formal class.

Here are two approaches that engineering departments have implemented to take advantage of the interaction between students throughout their departments:

“The Engineers Without Borders group, as well as our student branch of the IEEE allow for inter-class interaction. We have also arranged for returning students and upperclassmen to mentor incoming students and lowerclassmen. We are not yet satisfied, though, with our mentoring efforts.”

“I think that interactions between years is beneficial for students. Informal mentoring, role-modeling, etc. are the benefits. We see those benefits in the clubs and interest groups. Schools that have dedicated projects (like solar car, solar decathlon, etc.) get these benefits from having students of multiple years work on the same project.”

Students who have been in the program the longest have at least two avenues of potential growth, humility and further learning. They can learn and experience humility when asking for help from an underclassman who has unique knowledge and/or abilities due to personal experience or an internship. For the students who taught me about fluids before I took the class, they reinforced and maybe even clarified their knowledge of the material as they taught me. As previously mentioned, a student may come to better understand a topic that was just taught in the classroom when a different teaching style is used by a colleague on the team. As a result, the knowledge level of the student increases. The student who now understands parts of a topic from working on a project will be more engaged in the class and can even raise the knowledge of class to a higher level.

This approach may sound like tutoring, but it happens “naturally.” It is not contrived through a specific group or forced by departmental requirements. Students seem to avoid tutoring or asking for help from their peers except for their core group of friends. My suggestion as the best option for encouraging students to get the help they need is to provide the opportunity for them to expand their network of friends...
via a mutual project setting. This type of interaction can be much more natural than a help session or even peer tutoring such as what several university math departments\textsuperscript{7,10} have implemented via the MATH EXCEL program.

The MATH EXCEL program is an optional one credit offering commonly associated with the first few semesters of calculus. The grading is pass/fail based on attendance and participation only. Students work together on problems, mentored by TAs and/or MATH EXCEL graduates, that are based on the material currently being covered in their courses\textsuperscript{7,10}. In answering the question, “What makes MATH EXCEL work?” one program echoes the above mentioned advantages of students teaching students with “Students helping students to learn mathematics’ is our focus. We learn best when we teach. MATH EXCEL students learn as they teach and help one another; asking questions, explaining concepts, discussing strategies, sharing frustrations and celebrating successes.”\textsuperscript{7}

I think MATH EXCEL is a great beginning to a positive learning opportunity for students. Students with different teaching styles can match up with students of different learning styles. The groups that students form can help to augment the classroom experience where the professor can only employ a finite number of teaching methods during a given class period. However, the focus of the MATH EXCEL is on learning, not service.

George Fox’s engineering program is just beginning to see the consistent fruition of what John Natzke wrote about in his 1999 paper introducing the program to the Christian Engineering Educators Conference. “The basic features of the proposed BSE at GFU are as follows: …Potential for mission/serve engineering projects”\textsuperscript{8}. A course, titled “Servant Engineering,” will begin in 2010. This will be a required one credit course beginning in the spring of the sophomore year. It continues each semester through the fall of the senior year. This schedule provides overlapping interaction between sophomores and juniors in the spring and the same students again in the fall of the next academic year. In the subsequent spring, the “now” juniors will then join the new sophomores, perpetuating a cycle of knowledge transfer and providing community between the classes both a year ahead and a year behind each student.

The approach that GFU is taking is similar to what MC has implemented with their Integrated Projects Curriculum (IPC). Speaking with Randy Fish, MC engineering department chair, I learned that the graduates this May are the first students to complete the entire IPC. He mentioned that the preliminary results are very encouraging and they will begin tweaking the program in the coming years\textsuperscript{17}.

Conclusion

Throughout this paper, I have argued that students can experience a strong learning environment through service-focused engineering. Together, students pursue their passion by doing engineering and work toward a purpose of helping people in need. Because of the environment created by their common passion and purpose, students can teach and learn their uncommon knowledge about engineering topics, life in general, and what it means to serve without expectation of acknowledgement. As Christian engineering educators, we have a distinct advantage in the kind of learning atmosphere we can provide for our students. Though other institutions can pursue service for the sake of serving, we do engineering as service to share God’s love with our neighbors. As a result, students, whether Christian or not, can experience the fruits of their own labor as they learn to reach out and strengthen each other.
References


Technological Justice by Intentional Design

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Calvin College

Abstract

Christians are called to act justly. Creatively developing and designing products can result in technology that improves the cause of justice in the world, but the results of our engineering can also create situations of injustice. In this paper, I will begin with a brief sampling of the literature of justice, touching on theological perspectives such as Niebuhr; philosophical perspectives such as Rawls, Norzick, and Wolterstorff; and political perspectives such as King and Tutu. I will then examine the intentionality of the technology designer and evaluate the cause of justice in the devices we build. Justice is not always easy to obtain. Consider that injustice can result from unintentional consequences even when good design practices are followed. Poor design practices that lead to injustice can be labeled negligence. Worse, injustice can be intentionally created when we know the unfair consequences of a design alternative but choose it anyway. Whereas injustice can result without our active intent, justice must be an intentional, willful choice (because of our fallen and fallible nature). Technological justice might be the elimination of injustice created by a previous technology, or the design of technology to eliminate an injustice that could not be solved any other way, or perhaps technology provides the communication mediums that fortify the political will to solve a social justice issue. In order to achieve technological justice, one must make astute choices based on Biblical principles when designing, fielding, using, and disposing of technology.

Introduction

No justice, no peace. Know justice, know peace. This nice turn of phrase is reminiscent of Martin Luther King Jr. connecting the experience of peace with the need for justice. Those that have experienced injustice know what it is to cry for recompense, to plead with the Almighty for relief. The community cannot be at peace if some of its members have not been treated justly. Justice is one of the technology design norms proposed in Monsma along with a number of others, such as open communication, stewardship, and trust. The subject of this paper is justice and injustice related to the product of engineering: technology. While the ethical behavior of engineers is certainly important, my particular interest here is only in their behavior as it affects the decisions they make in designing technology. Those decisions become embedded in their technology. Thus, the justice or injustice of a device or product can be traced back through the design to the engineer. Our unjust treatment of another may affect one or two; our design of an unjust technology may affect millions. Although more subtle, the design of just technology has potentially far greater consequences than our interpersonal dealings.

The literature on justice is vast, so the next section provides only a few notable examples as an overview. This survey is not specifically about engineering, but rather is meant to set the context. The following two sections look at the product of engineering (technology) by examining technological injustice and then technological justice. The paper concludes with a few challenges.

Literature Survey on Justice

Although a comprehensive review of the literature of justice is beyond the scope of a single paper, it may be helpful to briefly review a few of the important works on the subject before looking at the specific connection of technology and engineering with the concept of justice. This section starts with scriptural references to justice, then turns to some samples from theological, philosophical, and then political writing regarding justice.
Biblical Views of Justice

Justice is important to God. So important that the word “justice” appears 134 times in scripture, and “just” appears 46 times (when used as an adjective describing justice). The Christian philosopher Nicholas Wolterstorff argues that the related word “righteousness” can sometimes be translated legitimately as justice. So some of the 232 occurrences of this word may also refer to the concept.

Scripture provides ample evidence that our Lord loves justice. There are many passages that identify justice as a central and even defining characteristic of God. The following two examples show God cares deeply about justice.

For I, the LORD, love justice.  
Isaiah 61:8

For the LORD is righteous, he loves justice; upright men will see his face.  
Psalm 11:7

Further examples demonstrate that justice is a defining characteristic of our Lord.

The LORD is known by his justice  
Psalm 9:16

Yet the LORD longs to be gracious to you; he rises to show you compassion. For the LORD is a God of justice. Blessed are all who wait for him!  
Isaiah 30:18

But the LORD Almighty will be exalted by his justice, and the holy God will show himself holy by his righteousness.  
Isaiah 5:16

Lest we think that Jesus did away with justice (perhaps supplanted rather than augmented by love), here are a couple New Testament examples.

God is just  
2 Thessalonians 1:6

This was to fulfill what was spoken through the prophet Isaiah: "Here is my servant whom I have chosen, the one I love, in whom I delight; I will put my Spirit on him, and he will proclaim justice to the nations. “  
Matthew 12:17-18

As God's people, following a just God, we are called to pursue justice ourselves. Note that this is not justice for ourselves – justice in the Bible is not couched in terms of our own rights but rather in terms of an obligation to treat others fairly and with respect.

He has showed you, O man, what is good. And what does the LORD require of you? To act justly and to love mercy and to walk humbly with your God.  
Micah 6:8

Hear the word of the LORD; O house of David, this is what the LORD says: “Administer justice every morning...”  
Jeremiah 21:11

Follow justice and justice alone, so that you may live and possess the land the LORD your God is giving you.  
Deuteronomy 16:20

1 Scripture taken from the HOLY BIBLE, NEW INTERNATIONAL VERSION®. Copyright © 1973, 1978, 1984 International Bible Society. Used by permission of Zondervan. All rights reserved.
“But you have neglected the more important matters of the law—justice, mercy and faithfulness.”

[Jesus speaking to the pharisees.]

Matthew 23:23

Although scripture contains numerous references to the requirement of justice, many assume the hearer has an inherent understanding of justice. Proverbs indicates that this inherent understanding of justice can be damaged by sin, yet God's people can still comprehend its demands.

Evil men do not understand justice, but those who seek the LORD understand it fully.

Proverbs 28:5

A handful of passages give us some further insight into the definition and application of justice. Justice is equitable and fair treatment. Our treatment of someone should be fair; favoritism should be avoided.

Do not follow the crowd in doing wrong. When you give testimony in a lawsuit, do not pervert justice by siding with the crowd, and do not show favoritism to a poor man in his lawsuit.

Exodus 23:2-3

Do not pervert justice; do not show partiality to the poor or favoritism to the great, but judge your neighbor fairly.

Leviticus 15:19

Administration of justice does not depend on the wealth (great or small) of the person. It does not consider the opinion of the crowd. It focuses only on the right or wrong of the actions under consideration. But while someone that is poor should not receive undue favor, God's special concern for the disadvantaged make it clear that one must be especially careful not to unfairly treat someone on the basis of their poverty.

Woe to those who make unjust laws, to those who issue oppressive decrees, to deprive the poor of their rights and withhold justice from the oppressed of my people, making widows their prey and robbing the fatherless.

Isaiah 10:1-2

Avoiding favoritism, that is, remaining impartial means not only that justice is blind to the irrelevant circumstances of the victim, but also that the administrator of justice must not allow the litigants to unduly influence their decision directly.

Do not pervert justice or show partiality. Do not accept a bribe, for a bribe blinds the eyes of the wise and twists the words of the righteous.

Deuteronomy 16:19

Finally, administration of justice requires careful, critical thought. One must carefully work towards true, sound judgments regarding right and wrong.

No one calls for justice; no one pleads his case with integrity. They rely on empty arguments and speak lies; they conceive trouble and give birth to evil.

Isaiah 59:4

Theological Views of Justice

When considering theological thought on the subject of justice, one heroine that comes to mind is Mother Theresa, who dedicated her life to helping the disadvantaged. Consider this prayer of justice that has been attributed to her³.

O God, we pray for all those in our world who are suffering from injustice:
For those who are discriminated against because of their race, color or religion;
For those imprisoned for working for the relief of oppression;
For those who are hounded for speaking the inconvenient truth;

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For those tempted to violence as a cry against overwhelming hardship;
For those deprived of reasonable health and education;
For those suffering from hunger and famine;
For those too weak to help themselves and who have no one else to help them;
For the unemployed who cry out for work but do not find it.

We pray for anyone of our acquaintance who is personally affected by injustice.
Forgive us, Lord, if we unwittingly share in the conditions or in a system that perpetuates injustice.
Show us how we can serve your children and make your love practical by washing their feet.

In a pastoral letter, the 1985 National Conference of Catholic Bishops defined justice in terms of
distributive and social justice. Lebacqz summarizes the three key beliefs that underlie a Catholic understanding of justice: all people deserve dignity (based on being created in the image of God), people have an essentially social nature, the resources of nature are given to all people. She further identifies three types of justice advocated in the bishop's 1985 letter: (a) commutative justice demands equity in contractual exchanges, (b) social justice demands participation by all in the common good, and (c) distributive justice demands allocation of resources without discrimination and with a minimum distribution to all. Specific outcomes of these positions include a call for full employment for all and rectification of extreme disparities of wealth.

In her book on various approaches to justice, after exploring a Catholic approach, Lebacqz also explores a Protestant viewpoint, focusing on the theologian Reinhold Niebuhr. In his theology, justice would not be needed in a society founded in love, but the impact of sin necessitates a focus on justice. Niebuhr sees injustice, at root, as exploitation—taking advantage of others because one values them less than one's self. For Niebuhr, the two key principles underlying justice are freedom and equality. Because of sin, he concludes that distribution of resources is not sufficient to achieve justice—a system is also needed to balance power (which unchecked can easily leads to injustice).

Philosophical Views of Justice
In his seminal work on the subject, John Rawls does not attempt to trace the ancestry and source of our ideas on justice. Instead, he constructs a mental experiment in an attempt to derive a pure, unadulterated concept of justice based solely on logic and common sense. In his cognitive investigation, he proposes a group of humans that are given the task of developing justice principles for all. In order to provide the fairest principles (which perhaps implies a preconceived definition of justice), Rawls makes the conjecture that they are in an “original position”, a sort of a pre-birth consciousness or a strange kind of amnesia, in which they are behind a “veil of ignorance”. No one in the group is aware of what their own position in society might be—not their gender, race, birthplace, ancestry, income, education, nor any other details about their life or lifestyle. Rawls then asks the reader to consider the nature of the justice they would deliver. He claims that in this situation, when the group was asked to develop rules for justice, their own self-interest would drive them to construct principles that will not put them at a disadvantage in case their place in society is a lowly one. He calls this a “maximin” approach. Rawls believes that each person in the group would be motivated to maximize the minimum position of anyone in society (because they might find themselves in that minimum position). Thus the rules of justice would provide equal resources to all. The only allowable instances of unequal distribution would be those that resulted in better overall circumstances for even the worst-off in society. Ursula K. Le Guin explores this theme from the opposite viewpoint in one of her science fiction short stories. In her imagined city of Omelas, the citizens enjoy health and happiness in a paradise-like society. However, whenever a young citizen comes of age, they are told the secret of this idyllic existence: a single young child must be kept in darkness and filth in a dank dungeon beneath the city—and everyone of age must know that their joy depends on that child's sorrow. Upon learning this, some cannot bear the thought and depart. These citizens who recognize the injustice are using a Rawlsian approach, considering the worst-off in society as the basis for evaluating justice.
Rawls recognizes that his maximin rule could result in some wildly imbalanced decisions, at least theoretically: “Yet it seems extraordinary that the justice of increasing the expectations of the better placed by a billion dollars, say, should turn on whether the prospects of the least favored increase or decrease by a penny.”10 He subsequently disposes of this hurdle by concluding that it is not practically possible: “The possibilities which the objection envisages cannot arise in real cases; the feasible set is so restricted that they are excluded.”11 However, in a global economy, it might actually be the case that a particular decision which results in a billion-dollar difference for a wealthy Western corporation might make a difference of mere pennies for a third-world subsistence farmer – and thus Rawls's theoretical situation may indeed occur.

A Christian might object to Rawls's approach due to the fact that he attempts a purely human conception of justice, rather than recognizing God as the source of justice. Rawls presupposes that self-interest will drive those in the “original position” to develop fair and just laws. But a faith-based approach should reject self-interest as the fundamental principle of justice (though it must certainly take self-interest into account in the light of the fallen nature of humankind).

Robert Nozick offers a counterpoint to the Rawls theory of justice. Rather than focusing on equity for the worst-off (which presumes that the resources around us are equally owned by all), Nozick proposes that a just society would be based on transactions that are just12. If principles of fairness guide each contractual exchange, then if society starts with a fair distribution, the resulting distribution after any number of just exchanges will remain just. If the starting distribution were not just, then Nozick proposed approaches to rectify the situation by crediting those suffering the injustice. Nozick focuses on the autonomy of the individual and the property rights to which each is entitled. For Christians, the fact that humans are created in the image of God might provide some basis for such an approach, but Nozick, like Rawls, does not recognize God as the owner of resources in which we humans act only as stewards.

Wolterstorff says Rawls's theory of justice is fundamentally an argument for natural rights. Wolterstorff does not have much further to say about Rawls because while Rawls makes the case for rights, he does not examine much further what those rights entail, while by contrast, this is Wolterstorff's particular interest13. He is emphatic that the New Testament call for love is not a replacement of the Old Testament call for justice. “And God loves the presence of justice in society not because it makes for a society whose excellence God admires, but because God loves the members of society... God desires that each and every human being shall flourish, that each and every shall experience what the Old Testament writers call shalom. Injustice is perforce the impairment of shalom. That is why God loves justice. God desires the flourishing of each and every one of God's human creatures; justice is indispensable to that. Love and justice are not pitted against each other but intertwined”14.

**Political Views of Justice**

The opening line of Kafka's *The Trial*, is mesmerizing because one immediately recognizes the unfairness – the injustice – implied: “Someone must have slandered Josef K., for one morning, without having done anything wrong, he was arrested.”15 As Kafka demonstrates, the political landscape is fertile ground for analysis of justice and injustice.

Martin Luther King, Jr. spoke frequently and passionately about political justice, often in racial and economic terms. Like Niebuhr, he recognized that unchecked power rarely results in justice. He called for love to temper power so that it is directed to the needs of justice: “Power at its best is love implementing the demands of justice, and justice at its best is power correcting everything that stands against love.”16

Archbishop Desmond Tutu reminds us that “There are different kinds of justice. Retributive justice is largely Western. The African understanding is far more restorative - not so much to punish as to redress or restore a balance that has been knocked askew.”17 This restorative form of justice may be a useful model for justice related to technology, as we shall see in subsequent sections.
Technological Injustice

As there are many definitions of justice, so too injustice can appear in many forms. If we define justice as equitable and fair treatment (which implies, for example, the avoidance of favoritism), then injustice would be inequitable or unfair treatment (for example, showing favoritism). While we can find examples of injustice related to social and cultural traditions even in our own field (e.g., inequities for women pursuing a calling in engineering\textsuperscript{18}), rather than discussing ethical and just behavior in interpersonal relationships, in this paper we will focus our attention on the product of our labors: the technology itself. As we consider injustice as it relates to engineering design, we can find several ways inequity and unfair bias can creep in\textsuperscript{19}. First, our designs might quietly incorporate an injustice, implicitly including a prejudice that we fail to notice. Such failure of observation bears different corresponding levels of blameworthiness. Second, we may explicitly and intentionally incorporate features and functions in our engineering designs which tune the design in ways that result in injustice. Here, culpability is clear.

Injustice Due to Unintentional Design

The unintended consequences of engineering design can create injustice. When engineers do not anticipate an important consequence, in a sense they have designed something into the technology without realizing it (else they would have designed it differently to avoid a negative impact). In these cases, an unintentional design feature is included. It is an accidental attribute that wasn't recognized until after the product was shipped, a parasitic property that didn't make it self known until something went wrong.

Fatigue is a good example. The concept of fatigue as a failure mechanism in metals was not well understood when the steam locomotive began to criss-cross the nation. The train axles were designed using standard practices to chose the size, shape, and material of the product. The strength of the steel was considered entirely adequate for the job. But certain repetitive stresses in the axle caused unanticipated failures. The engineers went back to the drawing board to better characterize this type of failure and design new axles that took fatigue into account. This example illustrates how even well intentioned, careful design can result in unforeseen consequences. We could perhaps excuse the first design for fatigue failures; once this consequence was experienced, engineers could be held accountable to design with fatigue in mind.

Unforeseen consequences can cause loss of property, pain and suffering, or even loss of life. If these effects are disproportionately experienced by an identifiable group, then the consequences have produced injustice. How could fatigue failure in train axles cause injustice? If the fatigue failure was particular acute in certain terrain, then the population in those areas might experience train breakdowns more often. As the train became the primary link to goods and services, those living in the affected areas then would experience inequity.

Just as the engineer who ignored fatigue could be held accountable (but only after it had been discovered), so too, the engineer who ignores injustice caused by one's own technology can be held accountable (but only after it has been discovered). Professionally and morally, engineers are expected to maintain their competence and expertise so that they foresee the consequences of their designs. Where those consequences might cause injustice, engineers who believe in Christ have a particular calling to tune their designs to avoid such consequences. They are then redemptive agents in the act of creating technology for justice. Otherwise they are guilty of negligence.

Sometimes the engineer is aware of a defect, i.e., the consequences can be foreseen by use of reasonable, predictive engineering methods and analysis. For example, there were engineers who warned of issues with the space shuttle booster o-rings during particularly cold launch temperatures. Those warnings were registered but overridden by managers who were perhaps under too much pressure to keep up an aggressive launch schedule. The result was the catastrophic loss of the Challenger and her crew. How far the engineer should have gone in blowing the whistle versus accepting management's decision is a matter of judgment and discernment.
In Deuteronomy 22:8, God admonishes the Israelites to take care in designing the architecture of their homes: “When you build a new house, make a parapet around your roof so that you may not bring the guilt of bloodshed on your house if someone falls from the roof.” This is a seminal guideline for engineers -- anticipation of consequences in a technology design in order to avoid harm is the ethical and legal responsibility of the designer, confirming that theories of negligence in civil and criminal law have a sound basis in scripture.

Our responsibility with regard to the potential consequences is clear – we must foresee as many consequences as possible and actively prevent future harm by modifying the design appropriately or even abandoning a certain line of technological development which cannot be readily constrained. Egbert Schuurman considers whether society should pursue certain scientific or technological endeavors: “New scientific developments are warranted only if they enable us to bend reality to our will and to solve old as well as new problems.”

He develops this thinking into a cautionary principle for technology: “There is room for responsible technologies only when the ethical principles of ‘no, unless’ is accepted. That ‘unless’ then unambiguously serves and protects human life.”

In the light of the almost irresistible “progress” of technology described by Ellul, Mumford, and others, this cautionary principle begs the question – will not someone else develop the technology if I do not? Perhaps a stronger version of the cautionary principle is necessary. Christians are called not only to passively avoid developing a technology that too easily causes harm, but also are called to actively work to prevent such development, provide prophetic witness against it, and to develop protective technology that eliminates or at least reduces the threat of harm. For example, rather than lament the fact that others might design thermonuclear weapons even if we do not, engineers could develop technology to help society limit nuclear proliferation (such as satellite surveillance, seismographic detection, and other instruments).

Better modeling may lead to better understanding of the possible failing in new technology. Engineers must carefully consider the limits of the materials and structures in their machines. In some cases it may be possible to build warning systems right into the technology so that the user is alerted when some design assumption is broken or an environmental condition is beyond the design parameters. This is the idea behind the design of the lining in automobile brakes that squeal when they are near the end of their useful life as a warning that replacement is necessary.

We can improve the ability of engineering students to foresee consequences by providing them with not only a solid technical education but also a broad, contextual understanding. Consider a few examples. History may not directly help us determine the consequences of a newly envisioned technology, but it can do so indirectly, by teaching us the types and categories of unforeseen technological consequences based on past experiences. Psychology can provide insight into human behavior so that we understand why the product user might use the product in ways that seem normal and obvious to them but completely foreign to the designer. Political science can lead to understanding of regulations that are legislated to provide protection from known harms.

**Injustice Due to Intentional Design**

Engineering design is always about trade-offs. The old saw “faster, better, cheaper – pick any two” is one summary of the engineer's dilemma. You cannot have it all. An automobile can be designed for better gas mileage by decreasing the weight, but often with a penalty of reduced safety. A table can be designed to carry a heavier load, but with higher overall cost. Software can be optimized to run faster, but the resulting memory “footprint” for the program is often much larger. There is usually no easy, technical, objective formula for deciding on the proper balance between these competing goals. So the engineer must make a judgment. The decision is likely driven by others too (managers, customers, regulators, competition, and more). In the end, some consequences of the design are accepted as a necessary evil that is the result of these trade-offs. However, some of these consequences may result in injustice. Such a choice might be excusable if the negative impacts are the lesser of two evils. But then one must also consider whether the product should be introduced if not all injustice can be avoided. On the other hand,
perhaps the new product also rectifies some other injustice, so that doing nothing is also an ethical choice with impacts to consider.

During the civil rights era, one of the city architects in the New York City area purposely designed tunnels and overpasses for highways to the local beaches so that the arches were too short for city buses to pass underneath. By doing so, he prevented a large portion of the black population (which more heavily used the bus for transportation) from getting to the beach and thus implemented an implicit segregation policy via his technological design. This is a classic example of a design that creates an injustice not simply because a consequence was unforeseen but precisely because the designer exploited a particular design consequence.

**Technological Justice**

In the previous section, we explored a number of ways that technology can produce injustice, i.e., inequity that can be directly tied to the technology. In this section, we will consider the more difficult problem of designing for justice. At its most basic level, the engineer must at least avoid the problems discussed earlier. But we may go further, designing technology with a redemptive purpose.

Justice is fair and equitable treatment of others. It is respect for their rights. Justice can also be defined in the negative, e.g., avoidance of favoritism. Justice requires a careful attention to all stakeholders. Children are often keenly aware of situations that are not fair to themselves, but we must be keenly aware of situations that are unfair for others – especially when they cannot speak up for themselves. Because justice must in many cases be intentionally pursued, it is rare that a technological design will unintentionally produce justice. Intentional design is usually required for justice to be achieved. At least two reasons drive this requirement of intentionality. First, all humans (including engineers) are fallen and naturally inclined to choose evil. Only by the grace of God can we counter this inclination. Secondly, all humans (including engineers) are fallible. We are creatures, in the sense that we are part of God's creation, and thus finite. We do not have the infinite wisdom of our Creator and are thus limited in our ability to anticipate all possible outcomes of the technology we create. Furthermore, we are prone to make mistakes and introduce errors during the design process.

Nevertheless, engineers, as designers of technology, are called to seek justice regarding our product – in its conception, design, production, distribution, use, and disposal. We are not excused from responsibility because of our sinful nature or because of our finite character. Likewise, ignorance is not a viable defense. Engineers are professionals who must be held accountable to maintain sufficient competence in our chosen domain. Transfer of responsibility is not a workable justification either. Engineers cannot claim they are not accountable simply because a manager told them to do it. As Dr. King noted, power must be called to account in the service of justice. Technology represents power because it amplifies our human abilities: the hammer amplifies the force of the swinging arm; the telescope amplifies the ability to see, and so forth. The engineer has a special responsibility, as the creator of technology, to channel this power in just and fair ways.

Every user is an amateur engineer who must anticipate the consequences of using the product, who cannot help but reflect the creativeness of their creator and thus sometimes modify the product with intent to produce better or even new results. But the two characteristics that hound the designer also bear upon the users of our technological products. They too are fallen and thus inclined to use products in sinful ways. They too are finite and thus unable to anticipate all the possible consequences of their actions. Nevertheless, they too must be held accountable. Our society has gone too far in letting the consumer off the hook and demanding that the seller be held responsible for even egregiously irresponsible behavior of the buyer.

Seeking justice is more than simply passive avoidance of injustice – it is active pursuit of righting wrongs. Distributive justice approaches typically assume that there are a fixed number of resources: a zero-sum game. If there is inequity, it is solved by taking resources from the rich and giving them to the
poor. The resource might be money, but it could also be land, clean water, access to jobs, or any other resource we consider a basic necessity to which all humans have a right by virtue of their humanity. Technology can contribute to distributive justice by providing tools to analyze needs, means to transport resources to those in want, communication channels to raise awareness, and so forth. Thus, though justice might be pursued primarily by political or social means, technology can lend support to its achievement.

Other approaches to justice take a different tack, such as the restorative justice that Archbishop Tutu describes. Here the focus is not so much on equalizing the distribution of resources (though this may play an important role), but rather on the ways that the community may be healed by identifying the evils of the past, by confessing those wrongs, by seeking the truth about what happened. Technology can contribute to this kind of justice by providing instrumentation to analyze past crimes, communication channels to publish results, and documentation tools to record or recreate historical events. We can even interpret the term “restoration” more literally and consider technology that cleans up toxic waste dumps as a means of restorative justice, redeeming a previously unusable plot of land to productive use.

Finally, engineers may have the distinct opportunity to seek another kind of justice that alters the situation not by redistribution but by creating new possibilities. That is, technology can not only aid in distributing resources in a fair manner, but it can also change the rules of the game. Whereas political will may not be sufficient to wrest resources from the “haves” who may feel entitled to them (perhaps with cause), technology can give to the “have nots” from a newly created surplus rather than by reallocation. Engineers can design solutions that produce a sum greater than zero – more clean water, more jobs, more food, more arable land. Consider the new kind of fairness and equity an engineer can create by developing hearing aids for those disadvantaged with hearing loss or developing technology that picks up cues directly from brain waves to give quadriplegics some ability to control their own movements. When “life just isn't fair” for some person, this should be a clarion call to examine their situation and seek solutions that provide a little justice. If there is a people group that suffers because they do not have enough clean water, engineers can rectify this injustice by designing technology to purify water and obtain potable sources where they did not exist before. Even more broadly, technology can create opportunities for new jobs. This was suggested in the 1968 letter of Latin American Bishops in their recognition that industrialization (properly overseen) could raise the standard of living for many living in poverty. While one might argue over whether hearing loss, mobility loss, polluted water, or poverty are reflections of the fallen creation or not, I suggest technology that corrects or ameliorates these deleterious effects is redemptive in nature.

Conclusion

In this paper I provided a survey of views of justice in several contexts. I then explored how injustice results from unintentional (and worse, sometimes intentional) design of technology. Further, justice is rarely obtained without intentional action, such as explicit consideration during the design and use of technological products. I call engineers that hold to a Christian faith to seek that justice. I call Christian engineering educators to teach students to recognize injustice and work for justice in their technological designs. This discernment starts with an ability to predict the consequences of a design (a basic part of a typical engineering curriculum), but requires a “systems” approach to recognize the impact on stakeholders who may not otherwise be considered. Finally, I call each of us to prophesy (in the sense of calling society to account) about injustices that we recognize in the world around us, including those missed opportunities for new technological justice. Our faith ought to drive us to make choices about new technology in favor of the cause of justice.

References

Curriculum Development for Training in Basic Energy Concepts for Developing Countries

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Abstract

As part of an undergraduate course, engineering students positively responded to an opportunity to develop a curriculum on basic energy concepts for developing countries. The curriculum will be used to equip volunteers for maximum impact in assisting people in third-world countries with sustainable energy-related development. The students found motivation in the stewardship of their newfound understandings of science and engineering applied to the service of the world’s poor. They also gained valuable experience in several non-technical areas. Student feedback on the project is presented, as well as a summary of the curriculum modules.

Introduction

In a recent popular book1, Thomas Friedman argues persuasively that the United States is well-positioned to lead in a worldwide effort to replace our wasteful energy practices with a strategy for conservation and clean and efficient energy production. It is important that developing countries learn from the energy mistakes made by already developed countries. This effort also reflects thoughtful stewardship of natural resources, which is an important aspect of the Christian worldview. Many Christian organizations send missionaries to assist with meeting physical needs in developing countries. Such assistance is maximized if missionaries receive training in basic energy concepts prior to deployment. The School of Science and Engineering at Oral Roberts University (ORU) is assisting in the development of such a curriculum for AgPrep International, an agricultural development training center at Oklahoma State University (OSU), where volunteers are equipped to assist developing countries in the efficient utilization of local resources for economic sustainability. The development of the curriculum and the center is a collaboration between ORU and OSU, with support from Dominion Farms, Inc., in an effort to assist economically depressed areas of the world with sustainable development.

The energy portion of the curriculum is primarily being developed by undergraduate engineering students as a course-project at ORU. These are junior and senior-level students enrolled in the Energy Systems Engineering course taught in the spring semester of 2009. Some of the students had previous experience with short term missions work in developing countries through the ORU summer missions programs. In addition, one of the students was president of the new chapter of Engineers Without Borders at ORU. The curriculum will include a survey of state-of-the-art energy conversion and generation systems for developing countries. Examples of such systems are the zero-head hydroelectric generator2 developed at LeTourneau University, and the solar rechargeable light3 developed at Cedarville University. Both of these promising systems were recently described at the 2008 Christian Engineering Education Conference. The curriculum will also include basic instruction in energy concepts for non-engineers. This will facilitate the development and maintenance of efficient energy systems with a minimum amount of input from those formally trained in engineering and associated technologies. The real-world nature of the institute will also require the development of hands-on experiences that will mimic conditions in developing countries. Hence, missionaries will become more adept at sizing up available natural resources and assessing the impact of utilizing such resources to meet local energy needs. A systems approach to sustainable development will be stressed throughout the curriculum. This paper will include a summary of the resulting curriculum, and a description of the course in which it was developed, including feedback from students on what worked well, and how the course might be improved.

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A Project to Enliven a Course on Energy and Help Change the World

In this world there is no lack of opportunity to engage in good works. In Christian higher education, such projects seem to present themselves at just the right times, and in a way that complements the intellectual development of the students. In the fall of 2008, a few upper division engineering students at ORU requested that a course on alternative energy systems be provided. Such a course had never been offered at ORU, but the need was obvious. At about the same time, ORU’s involvement was requested in the development of AgPrep at OSU. Assistance was requested in the development of various curriculums for training volunteers prior to deployment in third-world countries to assist locals in sustainable development. One of the areas needing a curriculum was in energy and fuel systems. This seemed like a good project for students in an energy course, and helped sway the decision to offer a new course called Energy Systems Engineering at ORU in the spring of 2009.

The leadership of AgPrep at OSU was grateful for the help, and the seven engineering students (5 seniors and 2 juniors) who enrolled in the new energy course at ORU seemed genuinely excited about the challenge of developing an energy curriculum. They were also enthusiastic about making a positive impact in the world by equipping volunteers to better assist locals with sustainable energy-related development. The project was introduced by the AgPrep leadership in the first week of classes in January, and classroom discussion commenced on the most effective way to achieve the aforementioned goals. It was decided that each student would take a lead role in developing the curriculum for one of seven energy modules (wind, solar, water, geothermal, biofuels, chemical, and human/animal power). Each student would also play an assisting role in an area where they were not the lead engineer. This structure provided each student with opportunities to relate to both superiors and subordinates, simulating on-the-job relationships. The course instructor played the role of an intermediate customer, while the AgPrep leadership served as the final customer.

In addition to reading the textbook for the course (Energy Systems Engineering by Vanek and Albright), the students were required to conduct literature searches for pertinent information. They were also required to choose a book on which to report in both written and oral forms. They delivered in-class progress reports throughout the semester, and traveled three times to OSU to present progress and receive customer feedback. Each of the energy modules was comprised of five parts. Each of the following parts was related to the form of energy discussed in the module: 1) an inspirational true story of how someone had a positive impact on the poor, 2) a survey of what is currently being applied in developing countries, 3) basic scientific principles and engineering concepts that volunteers should understand to have a positive impact, 4) hands-on projects, demonstrations, and experiments to facilitate understanding, and 5) a list of books and articles that people can refer to for more information. The seven energy modules, as well as an introductory module on energy in general, are described in the next section. This is followed by responses to the project and the course from the students.

Summary of Energy Curriculum

Module #1: Introduction to Energy Concepts

This module of the energy curriculum is designed to cover basic concepts that are universally helpful when considering nearly any form of energy or application. It begins with a simple definition of energy and a discussion of its various guises. The concepts of potential energy and kinetic energy are discussed and illustrated. Energy transition and conversion from one form to another are also discussed. Simple machines are introduced in this context. A systems view of the universe, and earth and its available resources is presented as the most intelligent approach to sustainable development. A discussion of stewardship concepts enhances this dialogue. Each of the following energy modules is briefly introduced in this section.

Module #2: Human/Animal Energy

Human beings are always using energy just to stay alive. With proper nutrition, vigorous physical activity has been shown to assist in maintaining good health. Thus it is good for humans to regularly use their own muscles to perform various tasks. But humans aren’t always strong enough or fast enough to perform a task with the desired efficiency. Knowledge of mechanical advantage and use of simple
machines can often make this possible. Another thing that must be considered is the correlation between power output and the amount of time that an energy level may be sustained. A graph is provided of the power output of humans and the amount of time that this power may be achieved while pedaling. Human arms aren’t able to generate as much power as legs for as long, but are capable of doing more precise jobs in this way could be more productive if using the proper machine. For example, legs may be of better use for pedaling, but arms would be much more efficient for pulling rope from a pulley or using a lever. Women generally aren’t as strong or have as much endurance as men. Complexity of a job affects the efficiency of a job and complex jobs should be done in times of least fatigue.

Animals, like humans must be fed in order to work and the workload is a variable in the amount of feed required to maintain that animal’s strength. Certain animals are easier to train and control and even safer than others and this should be a consideration in the selection process. The strength and feeding requirements is another factor that should be considered. Most animals require at least one human to operate and some animals need more human interaction than others. Training of the animal can reduce this and make the use of that animal more efficient. For example, a stubborn donkey will wear out the human operator and take longer to do tasks. Some animals are cheaper than others and more can be purchased for a smaller price than a stronger animal. Buying multiple animals for the same price as one animal has less liability since if one dies, the loss in functionality is less. Carts can greatly reduce the strain on an animal when hauling cargo since the force of gravity of the load is applied to the ground. This means the animal must apply more force horizontally to overcome the friction force created by the cart but will not have to hold up the load. This is an advantage when frequent stops are required on flat surfaces, since when the cart is not moving the animal doesn’t have to support the load.

Newton’s laws of conservation tell us that you can never get more energy from a process than you put in but by using tools with a mechanical advantage, you can make jobs require less force or distance of movement. By using a wedge, the distance traveled increases but the force required per unit of distance is decreased. In the case of a lever, dividing the bar at the fulcrum, if the force is applied at the longer section’s end then less force is required to pry something with the opposite end. Likewise the opposite is true if the force is applied at the shorter end. Pulleys can be used for changing the directions of a force or to provide a mechanical advantage depending on the number of pulleys and the way the rope or cable is set up. Pulleys and gears also can create a mechanical advantage if different sizes are used to turn separate shafts or if they are attached together. The same principle is applied here as with the lever. If the force is applied on the bigger pulley then less force is required but more distance of movement is required. Brief experiments are suggested to demonstrate the utility of simple machines for various applications. A treadle pump is a good example of using human power for pumping water. The construction of a simple treadle pump out of readily available materials is suggested as a project.

Module #3: Wind Energy

Wind is a valuable resource in the world. In areas where wind is plentiful and reliable, it can be used to provide various services to people. As an example, a boy of 14 in a poor African village was able to transform his village by installing a windmill, using only a picture from a book and spare materials from a junkyard. He created a better life for his family with electricity and drew attention to the town, which brought in funds and even a program to provide computers for children.

In the wind module of the energy curriculum, the AgPrep student will learn the basic engineering and aerodynamic concepts of harnessing the wind, specifically by using a windmill. First, in order to choose a proper location (and height) for a windmill, the student will learn about the available wind resource: wind speed, variability, reliability, speed versus altitude, and the venturi effect. Another important factor is the blade design, which should be aerodynamically appropriate to exploit as much wind power as possible. In dealing with forces from the wind and rotation, it is vital to create a strong structure that does not fall over, come apart, or fatigue. This requires an understanding of torque, moment arms, balancing, and vibrations. To allow rotation of a shaft, bearings must be used; thus, an understanding of bearings and their maintenance must be understood.

By knowing the components needed for a windmill to function, the student will be able to build a windmill out of a variety of materials. There are two basic types of windmills, the vertical axis wind
turbine (VAWT) and the horizontal axis wind turbine (HAWT). These two configurations permit diverse
turbine designs from a variety of materials, including, but not limited to, tractor rotors and oil barrels.

Various experiments have been designed for the student to be able to understand the concepts more concretely. For example, a simple anemometer will be built to measure wind speeds at various locations and times of day. Additionally, to see the effectiveness of different turbine blades, an experiment can be conducted. The projects that are integrated into the curriculum are flexible, allowing the student (or teacher) to determine which ones would be more beneficial for the student. There are projects for using a windmill to move water, pump water, grind grain, saw wood, or generate electricity. To save time and resources, a new windmill does not need to be created each time; the original windmill can be modified for each project if needed.

As the windmill essentially transforms the wind’s kinetic energy into rotational energy, this module is highly related to the water unit. The adaptation of the rotating horizontal shaft of the waterwheel for different jobs is very similar to the adaptation of a HAWT for those jobs. Therefore, if time or resources need to be saved, one can choose not to do certain projects and still get the basic concept for both energy modules. The wind energy module will also be able to help the AgPrep student complete objectives in other courses, such as grinding grain for food processing, or assist in making the living area more comfortable and more capable of meeting needs.

Module #4: Water Energy
There is much potential in the way that water can be manipulated to produce energy. People have been tapping into water not only for drinking, but also as a source of energy for at least a millennium. This has mostly been through the use of the water wheel. Recently in our history, the technology has developed to focus water energy into turning turbines as well. These are the two main applications on which the water module focuses. Both water wheels and water turbines have such sophisticated and widespread uses that it becomes quite difficult to decide where exactly to focus the information. The structure we decided to use for every module made this task much easier.

When considering technologies such as water wheels and water turbines, it is important to have a basic understanding of scientific concepts such as fluid flow, flow measurement, pressure change with depth, and energy in water. The “basic scientific and engineering concepts” portion of the module covers the basics of these subjects, assuming that the audience is a high school graduate with basic physical understanding, but has not placed very much previous thought into the subject. The underlying concept of water energy is that the energy is a direct result of water in motion, exerting forces on other objects (i.e. wheels and turbines) to cause them to move as well. Since the resulting motion of these objects is usually rotational, there will also be a description of rotational motion; what it is, how it is measured, and what it can be translated into.

The sections following the “basic scientific and engineering concepts” will be a list of applications and possible experiments to better illustrate the previous concepts. The list of applications contains the two most common types of water wheels: overshot and undershot, and describes where they are best used, their pros and cons, and some of their most common mechanical applications. To better illustrate the uses of water wheels, the section includes many pictures, both basic and realistic diagrams, to not only give the students a general idea of each machine, but also give them replicable plans for water wheels. Also in the application section is a basic description of the different types of water turbines available. Water turbines are a little more difficult to build, so it is assumed that if one was to use it, they would purchase it or use some sophisticated machinery, so basic uses of each turbine and their pros and cons are all that are provided. There is also a portion on building dams, including the basic types of dams, their purpose, and the positive and negative consequences of building them. Again, dam building is such a large subject, including such a vast array of considerations that it cannot be contained in a simple module on water energy.

The experiments listed in this chapter vary in scale and time commitment. Some experiments can be completed in minutes, such as an illustration of water flow through pipes using a cup attached to a rubber or plastic tube. This can illustrate the effects of pressure with varying depths of water and how the height
of the cup affects the exit velocity of the water out the tube. The experiment can also be modified into a
demonstration of siphoning. Some of the more large scale experiments are to create a water wheel out of
wood and bamboo shoots, to create a ram pump which uses the hydraulic pressure created from falling
water to pump smaller amounts of water up to fifty times higher than its original falling height, or to
experiment with different ways of using rotational energy to perform basic mechanical tasks.

Both the water and wind chapters of the energy curriculum will involve the use of rotational energy
created from spinning wheels propelled by moving fluids. This is good, because there are so many uses
for this type of energy that it needs to be stressed more than once. Many of the processes of transferring
rotational to mechanical energy will be very similar in both sections, as will information on generating
electricity. In the interest of not repeating too much information needlessly, the water section will simply
refer to the wind portion with most things considering electricity generation. The human/animal energy
module will also cover subjects quite close to this one, such as water pumps and other methods of
creating and using rotational energy. However, this module will be different enough for there to be no
real overlap between subjects and experiments.

Module #5: Geothermal Energy
This module of the AgPrep energy course consists of the scientific and engineering principles,
experimental projects, and applications of geothermal energy. Geothermal energy is defined as heat from
within the earth. The steam and hot water produced inside the earth can be used to heat buildings or
generate electricity. Geothermal energy is a renewable energy source because the water is a part of the
earth’s natural water cycle and the heat is continually produced from inside the earth. The module
discusses the interior of the earth and why natural geothermal phenomenon, such as volcanoes, fumaroles
or hot springs, occurs. Also, locations of this phenomenon, like our planet’s “ring of fire”, and the
countries that are leading geothermal energy producers are divulged. These countries utilize geothermal
resources through different types of power plants, heat pumps and natural heating systems, each
application being discussed in the module.

However, poor people may not have access to geothermal phenomenon or the technology to make
efficient use of the resources that are available. Also found in the module are fundamentals such as the
conservation of energy and basic heat transfer methods such as conduction and convection. It is explained
that energy can neither be created nor destroyed, but that it can only change forms, from kinetic to
thermal for instance. Also for example, it is demonstrated how the insulation in a thermos blocks heat
transfer, thus keeping coffee hot even when the outside temperature is very cold. These scientific
principles and many others have been included so that students can grasp the science behind the forces at
work within the earth with the hopes that they can use this knowledge for the benefit of the others on the
mission field.

Very relevant projects are provided within the geothermal module to hammer home the concepts
discussed. One example of a project is to do an experiment testing the thermal resistance of various
natural materials found on the test site, like grass or leaves or soil. This knowledge can then be applied to
the construction of an effective earthen habitat to provide shelter for the relevant season. Another
application is to build a natural refrigerator. A smaller pot is placed inside a larger pot and in between the
two surfaces wet sand is poured. Any perishable food can be placed within the smaller pot and as the
water evaporates from the sand between the large and small pots, the heat is sucked out with the
evaporation. This type of natural evaporative cooling is in fact already in use in third-world countries.
These projects and others will demonstrate basic heat transfer principles that will help volunteers teach
others how to survive and thrive in unfavorable conditions.

It is the goal of the geothermal module to equip students to go out into the field with knowledge of the
energy within the earth, how to harness it, and how to conserve it and transfer it. This knowledge will be
relevant to the volunteer or foreign missionary in an urban setting, but even more useful to someone
living in a rural location. Many people can benefit from understanding and employing the energy
resources from inside the earth.

Module #6: Energy from Biofuels
Jes Sprouse decided to quit his job and pursue algae farming. In Burrowsville, VA, Sprouse has started an algae pond that successfully produces diesel daily. He and local chemist Patrick G. Hatcher believe algae could pump out 3,000 to 5,000 gallons per acre per year! This is quite a lot of fuel, compared to an acre of soybeans—around 48 gallons—which is currently the main biodiesel source in the U.S. Sprouse harvests the algae by using centrifuges to draw the water out of the algae, which is then a green paste which is converted into fuel. Sprouse realized there are advantages to harvesting energy from algae, which is a biological resource.

Biofuels are a result of the harnessing of energy from biological sources, specifically biomass, which is a renewable energy source (unlike fossil fuels) and, in 2005, biomass was responsible for 46% of total renewable energy in the world. There are three ways to use biomass. It can be burned to produce heat and electricity, changed to gas-like fuels such as methane, hydrogen and carbon monoxide or converted to a liquid fuel. The biofuel module within the energy systems curriculum introduces and explains common methods of producing liquid and gas biofuels from biomass. Although methane digestion is the main biofuel extraction method discussed, one advantage of biomass is that if needed, it can be burned directly rather than converted into a more useful fuel (gas or liquid). With this in mind, volunteers in the field will be able to utilize the raw biomass as a fuel while they perfect the digestion method as ideal to their unique environment.

Pyrolysis, gasification and digestion are three methods for harnessing useful energy from biomass resources such as wood, solid waste, sawdust, grasses, animal wastes (manure), algae, etc. Pyrolysis is not as popular as gasification, and is not as effective as anaerobic digestion, and is thus beyond the applicable scope of this module. Gasifiers convert biomass into biogas, but are more complicated and less popular than methane digesters. Digesters are used widely to convert biomass into methane, which can then be burned. As a plus, digester “waste” can serve as a wonderful fertilizer and has no less nutritional value than the original raw material (and it’s odorless). Other biofuels, such as ethanol and methanol are also possible replacements for conventional fuels, but these liquid fuels require controlled chemical reactions which may not be feasible in a third world country, and are thus only explained briefly within the module.

Hands-on experiments and interactions are also provided, including detailed instructions on how to create and efficiently operate a methane digester using a variety of popular biomass sources. Pictures, diagrams and sketches are used as much as possible to help the students visualize mechanical and chemical interactions that take place within a digester unit.

Module #7: Chemical Energy

The chemical energy module will focus on the combustion of various types of fuels, and which fuels are more efficient than others. In general, the chemical energy is what holds the particles together before they will be broken apart to create kinetic energy by combustion. To accomplish this action, three components are needed: fuel (methane, wood, etc.), air (oxygen) to react with the fuel, and an ignition source (spark, pilot light, etc.) to get the reaction started in the chemical. A match would be a great example of this transformation because the heat from the ignition is generated by friction when the match is rubbed across the striker. In this action, the heat will ignite the chemicals in the match head and combine with oxygen, which will light the body of the match. Once the combustion starts, it will continue until the fuel (wood) or the oxygen is consumed.

In teaching the concept of combustion, many different applications can be used such as the internal combustion engine or a simple cooking stove. In order to understand the inner workings of these systems, a person has to know the first law of thermodynamics, which is that energy cannot be created or destroyed (conservation of energy). It is the whole premise of chemical energy. When a fuel in an engine gets consumed, it is not being destroyed, but it is being converted to thermal energy. For example, an internal combustion engine will take a certain fuel and inject it into a piston chamber to be ignited by a spark plug. Here, the combustion of the fuel causes a chemical reaction and a spike in the pressure of the piston chamber. This event will cause the piston to move downwards in the chamber while turning a crank shaft to which the piston is connected. When the gas from the combustion disperses, the pressure drops in the chamber, and the piston moves upwards for the cycle to repeat.
Using combustion, the main project that would be the most beneficial to the students is the creation of their own adobe stove. It is quite a simple design that uses easy to find materials for its structure, yet it is a significant improvement over the use of an open fire or three stone fires used in most 3rd world countries. There are three major benefits in the use of this adobe stove which are the increased efficiency of heat transfer (conduction, convection, radiation) to a concentrated area, the ability to control the amount of fuel (wood) used per unit time by increasing or decreasing the amount of air allowed to the fire, and the proper venting of smoke to decrease the amount of smoke inhalation causing health problems. Even with these advantages, the one benefit that open fires or three stone fires have over a adobe stove is the ability to keep insects and small animals away at night, but this is only a small advantage compared to the many advantages of an adobe stove.

Throughout this module, it is important to understand that chemical energy addresses the use of certain fuels, while the module on biofuels addresses the making of these different fuels. Although these two modules have had much interaction between them, there had been some problems in distinguishing them apart because biofuels can involve chemical energy. The line was eventually drawn with biofuels being the making of the fuels, while chemical energy was the combustion of the fuels. With this line, these modules still have a distinct relation with each other and should probably be taught one after another to the students.

Module #8: Solar Energy

Solar energy is the electromagnetic radiation (rays) from the sun that reaches the earth. Solar energy can be transformed to various forms such as heat and electricity. The total solar energy absorbed by Earth’s atmosphere, oceans, and land masses is approximately 3.850,000 exajoules (10^{18} joules) per year. We can convert the energy from the sun to use for heating things such as water or food. The energy from the sun can also be converted to electricity using photovoltaics (solar panels) or by using the sun’s rays to heat fluid to produce steam which is used to turn a generator.

Solar energy has many advantages. After the initial investment of equipment, the energy is basically free. If you have a photovoltaic system and more energy is produced then needed, the extra energy can be sold back to the utility company. Solar energy does not require any fuel. Solar energy is clean, sustainable, and doesn’t let off carbon dioxide, sulfur dioxide or other harmful gases which usual electric generation does. A solar energy system can operate entirely independent, not requiring a connection to a power or gas grid at all. Systems can therefore be installed in remote locations, making it more practical and cost-effective than the supply of utility electricity to a new site. Solar energy also has some disadvantages. The initial cost is the main disadvantage of installing a solar energy system, largely because of the high cost of the semi-conducting materials used in building one. The efficiency of the system also relies on the location of the sun. Solar electricity and heat are not available at night and also may not be accessible in case of bad weather conditions.

In order to teach the volunteers about solar energy, it is imperative to have experiments to show how solar energy works in reality. The solar energy module will contain two to three experiments. The first will be an experiment that shows how a passive solar heater system operates by constructing a simple passive solar heater model and measuring temperatures that result. The experiment can be constructed and performed using simple materials that are readily available. The second experiment will show how photovoltaic cells can be used to generate electricity and power an LED solar light. The experiment requires a photovoltaic cell in order to be performed, which can be purchased from a supplier. Small electronic components will also be required for the experiment.

Applications for solar energy have a wide range. Solar cookers use solar energy to heat and cook food by convection. The sun is used to heat an enclosure which contains food. A solar hot water heater heats water by passing it through a collector which uses solar energy to heat the water and is then pumped to a reservoir. A solar still is a simple device for distilling water by using the sun. In the still, impure water is pumped in and evaporated using solar energy. The pure water vapor condenses on the roof of the device and drips down to the side where it is collected. Solar water disinfection is a method for disinfecting water using sunlight and plastic bottles. The water is exposed to sunlight through the bottles. The sunlight is used to remove pollution and bacteria. A solar pond is simply a pool of saltwater which is used to store...
solar energy. Heat is trapped in the salty bottom layer of the pond which can be used for many things including heating buildings, drive an organic Rankine cycle, or operate a Stirling engine. A solar chimney consists of a black chimney which is placed in direct sunlight during the day. The air within the chimney is heated and rises which creates a suction at the base of the chimney. The suction at the base is used to ventilate and cool the building connected to it. Solar electricity generally refers to the use of photovoltaics in order to generate electricity for use in many applications. The photoelectric effect is what generates the electricity in the panels.

**Feedback from the Students in Energy Systems Engineering**

Feedback from the students was largely positive with regard to taking on this kind of project as a major component of a course in energy systems engineering. However they had a few suggestions for making improvements, as well as lots of encouraging comments on what they learned. Several of their comments are listed below, followed by a short section of analysis and discussion.

1. “I always knew that cultures were different in different parts of the world but never thought that they were as diverse as I found out in this class. The more I researched, the harder it seemed to be to create a universal curriculum that could be used anywhere. I knew that circumstances were different in different parts of the world and that some things just weren’t available or wouldn’t work. I never realized that the populations in some parts of the world don’t care about some very fundamental desires that we in the United States seem to have.”

2. “I already knew a lot about working by hand and using animals because I grew up on a farm. I never used animals to do work but my grandpa always told me about how he used to do tasks. One thing he told me was ‘if I had to go back to using horses to plow, I’d just quit.’ I have been keeping this in mind as I researched uses of animals as power sources.”

3. “I like the idea of [submitting regular] progress reports, since they remind us to keep working and coming up with something new to put down on the progress report. The presentations took time to create and should have helped us gain feedback for what we had done so far but since time was limited and everyone had a presentation, not much feedback was attained from them. The presentations did help me see missing elements that I left out and allowed me to improve my project. In the beginning of the project, teamwork really helped us to get started, and was a great way to find sources. The teamwork aspect has slowed down for me since then.”

4. “From creating this curriculum for AgPrep, I have been exposed to some of the history of energy development. By teaching the volunteers how people throughout history have lived well without electricity and having the volunteer do it himself, it is our hope that he can actually go into a third-world country and create better living situations for the people. Encouragingly though, I have also become aware of some of the cutting edge technology that places like the US will be able to implement into our society and they seem rather innovative and helpful.”

5. “In designing the curriculum, we had to create flexible modules that: could stand alone or with the whole curriculum, could be done in one typical semester or in one week, and were understood by high school graduates and yet be technical enough for an engineer to go more in depth. Although we have to teach engineering and scientific concepts, there will be no traditional classrooms in which to do so. Additionally, we had to keep in mind that the student that we are teaching needs to be able to go into the field and be able to teach the natives. It was definitely slightly difficult for engineers to keep this all in mind and figure out how to fulfill all these requirements. Our solution was a type of manual or handbook that students could reference in class or out in the mission field.”

6. “The course, ME 450, that assigned this curriculum development as a class project has been modified quite a bit to incorporate this project. As a project for the class, it has been more or less appropriate. However, it is also a very time-consuming project that has been very difficult for me as a senior (taking 18 hours and in the 2nd semester of senior project) to incorporate into my schedule. It is a worthwhile cause, and something that will be good to talk about with possible
future employers; it is just hard for me to do it during this semester. Also, I struggled with determining how much was needed for our first exam, which was what we had so far for our individual energy module. It felt rather subjective; a more defined scoring rubric would be helpful. The other difficult part is taking 6 hours to go to OSU to present what we had gotten done already on the curriculum. There wasn’t much learned from that meeting of which I wasn’t already aware. It was helpful, but hard to justify, especially for only two 50-minute periods of class canceled.”

7. “This class has been a very useful class for me and I am glad I decided to join it. I had my reservations, knowing that it was a new class that had not been attempted in our school before. The reason why I like the class is not because of the text book which occupies the “academic” half of our class with regular reading assignments, but the curriculum project we have been assigned. I am greatly interested in applying my engineering expertise internationally in development projects and specifically the mission field. This project has been my first chance to pursue this ambition within the boundaries of “academic obligation”, in a sense forcing me to learn what I want to learn. This is a great chance for me, and I know I have not capitalized on it to the extent I would have liked due to the demands of other classes. Still, I understand that the project does not cater to everyone’s interests as much as it does to mine, so I desire to embrace the opportunity while it is here and learn all I can.”

8. “There are many things I have learned through writing the water module for the curriculum. One of these things is how difficult it is to explain things to the ‘layman’. I am now realizing that it is a truly important life skill to be able to communicate effectively not only with the people of your common background, but all people of high and low education, and all backgrounds. Through this I have also learned the effectiveness of pictures in communicating basic plans, physical concepts, and specific ideas. Pictures are much more replicable and, in many ways less ambiguous than words.”

9. “I am a junior engineering major in a group of primarily senior engineers, so I know that I have a different situation from the others in that I do not have a senior project to work on this semester. This means a few things: I have more time and energy to dedicate to other projects, I can use this project as an opportunity to learn how to better work with a customer, and I can also use my current customer as a potential customer for later projects. We have had times in which we would present the progress of the curriculum to the directors of Dominion Farms (parent company) and leader of the AgPrep development team. During this time, I learned how to better communicate with a customer and received helpful feedback from some people with real experience in working with technology in third world environments.”

10. “This brings up a challenge and frustration of mine encountered in researching and writing this project. I do not have much experience in living in third world conditions and nor do the rest of my colleagues. We can read about things in books all we want, but none of the wisdom we are attempting to impart on the students is our own. Because of this, we may be missing out on something extremely important that they should know, but since it is not in a book or any other resource we could track down within the realm of American academia, we do not know about it and will not include it in our report. We will need to stress how our source should be treated as a suggestion and as a fluid model of what we think should be taught, and if situations and experts arise which suggest something else, then they should not be ignored.”

11. “This project is a little different than the average research paper, because we are writing to better equip a group of people for the mission field. This adds an element of pressure that I do not usually feel when writing a paper, to the effect that I really do not want to miss anything that could remotely be important to someone, and I will not easily be satisfied with what I have. This is a good thing to a point, but eventually I will have to be content with my own efforts and turn something in. This is something with which I am presently learning to be at peace. Overall, I have enjoyed this course greatly because the project and all the opportunities it presents to learn, make connections, and make a difference with my work.”
12. “Taking the Energy Systems Engineering course has been very rewarding at ORU. Since it is the first time this course has been offered at ORU, obviously it is going to be experimental in some aspects. The structure of the course has been based around studying a textbook and producing a curriculum for a missions training center. Other smaller assignments have also been given by the professor, such as a book report on supplemental reading. The textbook presents a systems approach to future energy needs, covering carbon-based, nuclear, and renewable sources. The readings from this book have been very informative and interesting and I would recommend continuing the use of the textbook for this course. Student written questions correlating to reading assignments have been effective for a deeper understanding of the textbook material.”

13. “Much of the time of this course has been taken up by the class working on the energy curriculum for AgPrep. While this is very worthwhile in the scope of things, it is not what I expected to be doing in the course. I came into this class hoping to study relevant solutions to America’s energy crisis. We have done this to some extent, but have not really progressed beyond the textbook material. I have enjoyed researching for the curriculum and believe the work we are doing really will help to train people to be more effective missionaries. I wish the technology researched would be more applicable to the current situation in America, but the technology in poorer countries is sometimes nearly a century behind.”

14. “Working as a team has been effective in making the different modules better. Having more than one worker on each energy type has been beneficial in producing more diverse modules. Teamwork is a good idea in my opinion. The question still remains, should a project for missions work where you spend most of your time learning about engineering methods only beneficial in a third-world setting be a large portion of junior/senior level engineering course? My selfish side tells me that I should focus my efforts on things, which benefit myself, a resident of the USA where we have air conditioners and nuclear power. But my sympathetic side says it is extremely valuable to help others, however they need help. Engineers are called to help others, and to pass up an opportunity that really is only available this year to help out AgPrep wouldn’t be right. So I am thankful for the opportunity I have had working on this project.”

15. “As a student at ORU, I have received (and continue to receive) a well-rounded education that incorporates a Christian worldview. This can sometimes be difficult within science and math courses, but the course responsible for this missions training curriculum project (Energy Systems Engineering) is an upper-division class and has effectively explored energy systems concepts while also incorporating Christian worldview. While the missions training project is very important and we have dedicated the majority of our in-class discussion time to it, the project is still only one part of the overall course. Interestingly, the class is brand new and students in the course are also creating tri-weekly reading assignments for future coursework. This provides an opportunity for us to learn through teaching important concepts and vocabulary from the text. Aside from the learning opportunity, it will be enjoyable to look back years from now and be able to claim that we had a part in the creation of the [Energy Systems Engineering] class.”

16. “The concept of incorporating engineering into missions is not new to me, but until this year it was vague to say the least. There was always the question ‘How can I, as an engineer, help in the missions field?’ From the past three years I have spent at ORU, I have learned that ministry is not restricted to particular interests or skills or some unseen “Holy” factor that only certain people possess; ministry is universal. Unique abilities, skills and talents provide individuals with ministry tools that could prove more effective in some areas than others, but knowledge is also universal and now, after Energy Systems Engineering, I have learned that I can use my research experience and engineering background to promote the efficient integration of energy systems in areas of the world where modern energy commodities like electricity and gasoline are less-common or even nonexistent.”

17. “Overall, with the regular progress reports, presentations, discussions and debates, the course has been a success. I am particularly grateful for the teamwork assignment layout, which involves a senior engineer and assistant/support engineer for each module. This gives us an opportunity as
students to build our resumes with another good example of leadership experience, and in this case it combines leadership with community service, which we all know HR reps like. I would have liked to have been held more accountable concerning communication with my assistant engineer, as it could only improve my resume-building strategy.

18. The logistics of the course were slightly lacking, but what dragging was present did not seem abnormal for a group of senior engineering students, especially in light of it being a new course. I was finding myself too often annoyed by useless tangents we would sometimes shift our discussions towards. Tangents are unavoidable, and I feel the overall experience I have from this course has been very enlightening, because the medium-sized group of classmates provided a wonderful model of a real world engineering/research team along with real problems. The conflicts and problems that were addressed seemed to be elementary issues, but I may not have had any idea as to what course of action to take if I were to be in a similar situation during my career. Finally, I have gained dozens of very useful resources from this course. Here are the three most significant books I have referred to many times over the past few months, and have come to appreciate very much.”

19. “I believe that the Energy Systems Engineering course has been one of the more beneficial courses that I have taken in my four years at ORU. This class has taught me a great amount of information about alternative energies as well as how to communicate to a layperson through vocal and written interaction. In the class itself, I have enjoyed reading our textbook, working on our project, reading our own chosen book, and doing weekly progress reports. It has been greatly beneficial to me as an engineer.”

20. “The project that was presented for this class was greatly beneficial to this course. It was a great growing experience for the whole class in working with a customer as well as learning how to communicate with the layperson from the student’s expertise. The class also got a little taste of being a leader and delegating tasks to their assistant. In conclusion, the project gave our class more understanding in teaching a subject to a layperson, which will be extremely valuable to us in the engineering profession.”

21. “I believe that our book reports were a great idea for a deeper understanding of the energy systems in this course because the textbook may only touch the surface of each energy system. With each of us doing a book report, the student will increase their knowledge on the subject and also present their knowledge to the rest of the class; in turn, he or she will increase the knowledge of the class on a certain subject. It is just a great idea for us to be able to learn more about an area where we are interested.”

22. “The progress reports have been greatly beneficial to the class as a whole for keeping us on track for finishing our project and book reports on time. I have enjoyed taking part in the progress reports because it has made me accomplish my tasks at hand in a timely matter during my loaded senior year. If it was not for these progress reports, I would have procrastinated until the last minute to finish my project or book report because of all the workload from my senior project. These reports have been a great addition to the course and should be a part of the upcoming classes to keep the students on track to finish their work.”

23. “I do though have some concerns within the course and its setup. During the course of the semester, the students seemed to have times where the teacher did not give them a clear cut definition for the grading of their work. I believe that the teacher needs to have hand outs on what he is expecting for the task at hand, for it not to seem like subjective grading.”

24. “Lastly, the problem that I saw in the course overall was the workload presented for the semester. It seemed as though the class had a little too much on its plate. We had to write a curriculum for OSU, read a textbook while doing a few problems, and read a book and present on it as well. The curriculum itself is a semester project and does not need a book on top of it because the curriculum is like reading ten books instead of just one. For this class, I believe the workload to be a little too much because it starts to sacrifice the quality of work.”
25. “This course and project made me learn about many of the different forms of energy that are used in the world today. I learned how precious our natural resources are, how we should be good stewards of our environment, and how we should use the knowledge we gain as engineers to better the lives of the less fortunate individuals in the world. I learned how the economic aspect of a technology is one of the main concerns if an energy production method is being considered. The many different forms of energy production learned in this class and the general overview of how the technologies work is something that I hope will be very useful to me in the future in my career. I highly enjoyed all the chapters that referred to alternative fuels and alternative energy in this class, which is a passion of mine, and I hope to work in the field in the future.”

26. “The progress reports were very useful for me because I know that in my future job I will be required to present project progress reports to my leader as I do for my senior project as well. Writing project progress reports is a vital part of any engineering profession. The presentations both in class and at OSU just further my experience of speaking in front of groups. The presentations were basically like vocalizing our progress reports to a group which will be useful for when I have to present to a project group at a job. The presentation in class was experience for presenting to experts. The presentation at OSU was experience for presenting to lay people. The textbook reading really forced me to learn the material from the book. This is a good thing since the book contained a lot of useful material which I will be using as a reference in the future.”

27. “The project was very good for this class. It allowed me to apply the knowledge being learned in the class as a lab or experiment would. It gave me an opportunity to learn how to present a topic in engineering as I would to a layman or someone with no engineering knowledge. Learning how to present complex engineering information to an audience that has no engineering background is a valuable tool. I learned a lot about the many applications of solar energy with my unit as well as the concepts involved. I learned how third world countries are in desperate need of energy technology but how careful selection must be made in choosing a technology for an area.”

28. “Overall I am very happy with this course and how it taught me about energy. I would suggest that this course be geared towards juniors or seniors with light loads. I had a full load and also had senior project so this class added a lot to my load for this semester. I appreciate that the instructor took the time to teach this course and pursue this project. I hope that he will continue to teach it.”

Analysis and Discussion
It has been said that the best way to learn something well is to attempt to teach it to others. The students of the Energy Systems Engineering course seemed to appreciate and learn much by playing the role of teacher (curriculum developer) throughout the semester. However, they realized early on that this project would be a difficult challenge, especially at their level of limited experience. One student had a significant agricultural background, and a few others had short-term missions experience in developing countries. But the lack of long term experience with conditions in developing countries was a definite drawback. Reading about it can only go so far. Perhaps some “laboratory” experience out in the wild, practicing some of the experiments and projects we were recommending in our curriculum, would have been appropriate. However, multiple students already suggested that the course was overloaded, so this would require the deletion of other material and activities. Looking back, I think it may have been worth it to introduce some of these more practical, hands-on experiences. Perhaps the additional book report could be deleted. In any event, the course could have been more structured, with more detailed scoring rubrics provided to the students. In the future this will allow the students to see a little more clearly how their grade was determined.

The students seemed to genuinely appreciate the teamwork and leadership/subordinate interactions associated with the project. Only twice were they required to work with their assistant engineer on some aspect of module development. With the success of this interaction, it should be more fully incorporated into projects in the future. This is just one example of nontechnical skills that the students developed. They also gained experience in considering multicultural and global perspectives, especially seeing things
through the eyes of the poor. They also gained practice in both oral and written communications of their ideas to various groups, including customers and those with little technical background. They recognized that they had to make sacrifices in order to complete this project. But at the same time, they learned that they can use their science and engineering know-how as a ministry to benefit the world’s poor. Hopefully, this realization will continue to influence their engineering work throughout their careers.

Conclusions

Although it required a lot of additional work, the development and implementation of a new project-oriented energy systems course for undergraduate engineering majors at ORU was successful and rewarding for both students and instructor. The reduction in technical content to make room for non-technical content related to the curriculum development project seemed to be justified. However, future courses may devote slightly less time to project-related activities and more time to technical content. Based on written feedback, the students gained valuable experience in research, stewardship, customer relations, teamwork, leadership, writing, speaking, and relating the usefulness of scientific and engineering concepts to the layperson. The realization of how their knowledge of science and engineering could be leveraged in service to the poor motivated them to produce an excellent product. This was found to be especially true in light of Jesus’ teachings regarding personal stewardship and helping those in need. The full curriculum manual is compiled under the name of Basic Energy Concepts for Developing Countries, and may be obtained by contacting the first author of this paper.

References

Lifecycle Design and Christian Viewpoint in Technology Development for Developing Agrarian and Rural Economies

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Abstract

The teaching on compassion, love and care for the less privileged can be found throughout the Bible. It was also demonstrated by the Lord (Acts 10:38). How can we apply this doctrine in helping many people in the less developed countries that are suffering due to inadequate or even unavailable basic infrastructure and suitable tools that could make their work easier and thereby improve their quality of life?

The goal of this research, therefore, was to contribute to innovations in rural technological development as it applies to developing countries. It intends to achieve this by identifying and developing strategies, approaches, tools, and/or resources that promote effective development of appropriate technologies, and in the process help in solving a number of challenges faced by governmental and non-governmental agencies that are responsible for rural development. The project also considered how the application of biblical teachings on love and the teachings of 1Corinthian 10:31 and Colossians 3:17, 23 can influence the attainment of these goals. An intensive study and past experiences in working with- and developing technologies for rural communities in developing countries revealed that a sustainable solution to rural technology development and utilization lies in the application of lifecycle design concepts to every aspect of the rural technology development process. This led to the subsequent development of the conceptual lifecycle-based technology development process design framework that is presented in this paper. The analysis of the methodology revealed that when rural communities and other stakeholders in rural development are engaged in unique, participatory forms of relationship throughout the lifecycle of a developmental project, an appropriate technological development will more likely result. It will also bring about positive changes in a community’s attitudes/behaviours towards the utilization and maintenance of public infrastructure.

Keywords

Christian viewpoint, Agrarian economy, Lifecycle design, Lifecycle management, Appropriate technology, Rural communities

1. Introduction

An Agrarian Economy can be defined as an economy that relies on farming, while a rural economy can be defined as an economy that is dominated by rural communities and derives its earnings from both farming and non-farming activities of the rural dwellers. While a rural economy is essentially farming based, it

Acts 10:38 You know about Jesus of Nazareth and how God poured out on him the Holy Spirit and power. He went everywhere, doing good and healing all who were under the power of the Devil, for God was with him (GNB).

1Corinthians 10:31 Well, whatever you do, whether you eat or drink, do it all for God’s glory (GNB).

Colossians 3:17 Everything you do or say, then, should be done in the name of the Lord Jesus, as you give thanks through him to God the Father (GNB).

Colossians 3:23-24 Whatever you do, work at it with all your heart, as though you were working for the Lord and not for people. Remember that the Lord will give you as a reward what he has kept for his people. For Christ is the real Master you serve. (GNB).
also has significant contributions from non-farming rural manufacturing activities like handloom weaving, oil presses, soap making, various types of food processing, and blacksmithing.

Determining, developing and transferring appropriate technologies for/to developing countries have always been the main concern of many engineers and policy makers in those countries. Studies revealed that this aspiration can be achieved by identifying the characteristics of agrarian and rural economies, the types and characteristics of technologies used in rural areas of developing countries and how they were developed, and the problems associated with the use of those technologies in the rural areas of developing countries.

Consequently, this paper presents a methodology on how to determine and develop appropriate technology for rural communities, and how to ensure that the developed technologies for the rural areas are technically sound, economically sustainable, socio-culturally compatible and environmentally friendly. It also examines the role that biblical teachings on mercy and love could play in designing and developing appropriate technology for agro-industrial and rural communities. The paper is concluded with how the infusion of lifecycle management concepts can foster the development of indigenous technology in a developing economy.

1.1 Characteristics of Developing Agrarian and Rural Economies

Developing agrarian and rural economies are characterized by a large percentage of the labour force depending on agriculture, forestry, crafts and other related activities. They are also characterized by low productivity in those vocations. Although many of the developing countries have made appreciable progress in diversifying their economic base, the majority are still agrarian economies with a large percentage of their population residing in the rural areas. According to Tomich et al, 3.1 billion people from the developing countries, which account for about 60% of the world population live in the rural areas and over 50% of their labour force is engaged in agriculture, small scale rural manufacturing and service activities. In addition, rural areas in developing countries have high rates of natural (population) increase, inequitable land distribution, and inadequate employment opportunities and incomes. Moreover, due to large differences in income and socio-economic infrastructure levels between urban and rural areas, rural areas have lower economic opportunities and poorer services in the area of transportation and communications systems, education and healthcare, etc. Furthermore, in recent years, many of these rural areas have witnessed a lot of decline in the agro-export, oil export, manufacturing, construction and service sectors as a result of deregulations, globalization and other policy changes.

Tomich et al suggested that developing agrarian and rural economies will need to i) use new biological-chemical-mechanical inputs in their production process, ii) acquire new technical and organizational knowledge, and iii) have access to expanded markets for agricultural produce in order to be able to raise their productivity level to that of their developed peers. Making economic progress in the rural areas would therefore require the development and use of machinery/technology whose power, speed and precision multiplies the yield of human effort and current practices.

1.2 Types and Characteristics of technologies used in rural areas of developing countries

Realizing the importance of technology use in ameliorating rural problems, many governmental and non-governmental organizations at the local, national and international levels have invested heavily in the development and deployment of technology in the rural areas. However, many of these investments failed to yield the expected dividends. The answer may lie in the understanding of the differences between the rural technology needs and the characteristics of the technologies on which heavy investments were made.

Rural technologies are essentially those used in agricultural mechanization, forestry, rural transportation, and rural industrial/craft activities. Agricultural technologies of significant impact in rural areas include
tractors and farming implements like seed planters, agrochemical (like pesticide and fertilizer) applicators, power tillers, bullock/tractor drawn implements, reapers, threshers, transplanters, cleaners/ graders, irrigation equipment, and various hand tools. Other rural technologies include agro-industrial technologies used for edible oil production, soap production, leather tanning, staple food processing, and food storage. There are also rural manufacturing technologies that are used for spinning and local textile manufacturing, black-smithing/local foundry, lumbering and woodworking, pottery and ceremonial objects, amusement and other related services. Many of these technologies were developed for large scale production for which locally available resources are inadequate. A number of them are too complex for local technicians to maintain.

1.3 Problems associated with technologies used in rural areas of developing countries

Although many of these imported technologies are widely used and a number of successes have been achieved in the acquisition and utilization of improved technologies in the rural areas, substantial problems still remain and some new ones have emerged as a result of the new technology deployment and use. The majority of witnessed problems can be attributed to inconvenience in the availability of spare parts and repair facilities. Others include inappropriateness of a number of the technologies in relation to the rural terrains, rural culture and other unique conditions of the region where they were deployed. For instance, the deployment of high speed small sized automobiles in the rural areas is incompatible with the heavy load carriage capacity, high shock absorbing and low speed transportation devices that are needed by the rural dwellers for transferring agricultural produce and other bulky goods to the markets. Such disparity between the rural technology needs and supplied technologies is one of the main problems that have to be addressed if the problems of low productivity and consequent poverty would be solved. The question then is: how can this be achieved where many people are only interested in amassing wealth without any thought of what happens or is happening to the less privileged or anybody else? What are we Christian Engineering Professionals expected to do and what can we do?

2. Christian Viewpoints on the Poor and Solutions to Rural Technology Problems

There are several passages in the Bible that enjoin us as Christians to show love, care, mercy and compassion to the poor and the needy. For instance, in Mark 12:29-31, Our Lord Jesus Christ in response to the question of a scribe on the greatest commandment said, "The most important one is this: 'Listen, Israel! The Lord our God is the only Lord. Love the Lord your God with all your heart, with all your soul, with all your mind, and with all your strength.' The second most important commandment is this: 'Love your neighbor as you love yourself.' There is no other commandment more important than these two." This was also re-echoed by Paul in Galatians 5:14 "For everything we know about God's Word is summed up in a single sentence: Love others as you love yourself. That's an act of true freedom." In addition, Our Lord Jesus Christ, in Luke 10:27-37, illustrated how we as Christians need to demonstrate our faith by showing mercy and care for the needy. This command to love is echoed by P.M.

Mark 12:29-31 Jesus replied, "The most important one is this: 'Listen, Israel! The Lord our God is the only Lord. Love the Lord your God with all your heart, with all your soul, with all your mind, and with all your strength.' The second most important commandment is this: 'Love your neighbor as you love yourself.' There is no other commandment more important than these two." (GNB)

Luke 10:27-37 The man answered, "'Love the Lord your God with all your heart, with all your soul, with all your strength, and with all your mind'; and 'Love your neighbor as you love yourself.' " 'You are right,' Jesus replied; 'do this and you will live.' But the teacher of the Law wanted to justify himself, so he asked Jesus, "Who is my neighbor?" Jesus answered, "There was once a man who was going down from Jerusalem to Jericho when robbers attacked him, stripped him, and beat him up, leaving him half dead. It so happened that a priest was going down that road; but when he saw the man, he walked on by on the other side. In the same way a Levite also came there, went over and looked at the man, and then walked on by on the other side. But a Samaritan who was traveling that way came upon the man, and when he saw him, his heart was filled with pity. He went over to him, poured oil and wine on his wounds and bandaged them; then he put the man on his own animal and took him to an inn, where he took care of him. The next day he took out two silver coins and gave them to the innkeeper. 'Take care of him,' he told the innkeeper, 'and when I come back this way, I will pay you whatever else you spend on him.' " And Jesus concluded, "In your opinion, which one of these three acted like a neighbor toward the man attacked by the robbers?" The teacher of the Law answered, "The one who was kind to him." Jesus replied, "You go, then, and do the same."
Burban\textsuperscript{10}. He reiterated that “as Christians, we have a special opportunity to obey the biblical injunction in Deuteronomy 15:11 as we embark on the Great Commission to the third-world by meeting both spiritual and material needs of people. Burban further stated that as an act of love and obedience to Jesus Christ to love others, we should implement the best technologies at our fingertips to help solve important drinking water problems”.

In the same vein, W. Jordan\textsuperscript{11} said that “we engineers as practical people can use our engineering skills as a mission tool in helping poor people better their lives. By using our engineering skills in solving rural technology problems we will be providing direct blessing to the rural populace. The rural dwellers will consequently see what Christ can do in us/through us and thereby making faith reasonable and practicable to them”.

However, in order to adequately address agrarian and rural technology problems, Christian engineers need to research, design and develop technologies that are not just appropriate in solving the problems, but also user- and environmentally friendly. One of the ways (if not the only way) that these goals can be attained is through the use of lifecycle design concepts which takes into consideration not only what S.H. Vanderleest\textsuperscript{12} called the eight technology design norms but also integrates a number of sustainable design paradigms in ensuring the adaptation of the technology developed to the unique condition of the rural area and empowering the rural populace in perpetuating and improving the technology. Achieving these goals is particularly important in keeping with our view of engineering as a Christian vocation and in fulfilling the biblical injunctions in 1Corinthians 10:31; Colossians 3:17, 23-24; Ecclesiastics 9:10 and Proverbs 3:27.

3. Lifecycle Design for Rural Technological Development

Developing suitable technologies for rural economies requires a pragmatic effort and consortium approach. It necessitates the involvement of all rural technological development stakeholders like governmental agencies responsible for rural development, technology marketing companies, funding agencies, NGOs and rural dwellers. It makes sense to involve those who have lived all their lives in the rural communities, who know the terrain, who know what works and what doesn’t, and who will use the developed technology in the process to ensure that their needs are met adequately.\textsuperscript{13,14} After all, sustainable development requires the involvement and contributions of all people.\textsuperscript{15} A.K. Rajvanshi in recounting the Indian experience on rural technology development also buttressed this point. He hinted that such technologies will need to have the convenience of easy availability of spare parts and a large number of repair facilities.\textsuperscript{2} He further reiterated that the success of such technologies in upgrading the life style of the rural population require creating consumer demand through high volume production, good quality products, media advertising, sales outlets and after sales service. In addition, he advocated that the variety of the technologies available should be very large and be in great demand. Since the rural conditions are unique, they also require unique solutions. It is therefore necessary to tailor the design and development of technologies to be used in rural areas specifically for the rural areas. The spread of rural technologies will be facilitated if they are also employment generators. Thus high-tech (not necessarily complex or automated) agro-based industries can provide a possible solution. These industries could be in the areas of food processing, energy production (electricity producing plants running on biomass and ethanol production) and/or production of raw materials for chemical industries. A critical analysis of how to develop and propagate such technology that will benefit the rural population as well as satisfying

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\textsuperscript{10}Deuteronomy 15:11 For there will never cease to be poor people in the land; that is why I am commanding you, ‘You must willingly open your hand to your afflicted and poor brother in your land.’ (HCSB)

\textsuperscript{11}Ecclesiastes 9:10 Whatever your hands find to do, do with all your strength, because there is no work, planning, knowledge, or wisdom in Sheol where you are going (HCSB).

\textsuperscript{12}Proverbs 3:27 Whenever you possibly can, do good to those who need it (GNB).
most of the requirements of funding agencies and other stakeholders (like NGOs) led to the development of the following “lifecycle design framework for sustainable rural technology development process” described in this paper.

3.1. Lifecycle design

There are many definitions given to lifecycle design. The author would however define lifecycle design as a process of creating a sustainable product system by considering how the proposed product system will affect each and all animate and inanimate objects that interact with it at each stage of its life, and analyzing how individual and several changes made will affect the outcome of its interactions with the aim of reducing the total environmental loads and increasing the overall utility of the system created (Figure 1).

By sustainable product system the author implies a product that is technically sound, environmentally friendly, economically viable and socio-culturally compatible with the “consumer’s world”. A product’s lifecycle design consideration starts with the identification of the sources of its material constituents and how they are produced. It also considers how each of the material production process and the material’s utilization affects the well-being of people within the manufacturing facility (i.e. in the workplace environment) and outside the factory as well as the welfare of the surrounding ecosystems. This approach is used for each stage of the product lifecycle with the aim of determining the overall impact of each product design alternative and to evaluate the significance of each and all changes that is/are made to such design on the overall impact of the product.

Having evaluated resource consumption, emissions and the potential impacts, what should I do to the product or process to:

- reduces land use/impacts
- reduces raw material use
- reduces energy & transportation
- reduces environmental releases
- increases life span
- increases reusability and recyclability

Figure 1: Lifecycle Thinking

3.2. Lifecycle Design Methodology for Rural Technology Development

The process of developing this methodology started with a study of the problems facing rural technology development and its utilization. It also considered the conventional design process and areas of its lapses in meeting rural technology development needs. This was followed by a re-examination of past experiences in mechanical products’ development and thorough examination of various lifecycle design concepts, consideration of which of the concepts to incorporate, where to incorporate them and how to adapt them to meet the goals of achieving sustainability in rural technology development. Thereafter several attempts were made to come up with a design process model that factored in the results of these governmental and non governmental project reports. Figure 2 shows the resulting conceptual lifecycle.
design model for sustainable rural technology development process. It is a multi-stakeholders’ cooperative approach.

The proposed lifecycle design-based rural technology development process starts with the identification of needs or the recognition of market gaps or essential areas of improvement that can create a substantial demand for the end product/technology. This may originate from the product developer, policy makers or any other stakeholder. It may also come from consultation with the stakeholders. Wherever it comes from, the technology developer then arranges how the needs will be addressed through the consideration and assemblage or incorporation of various design components and features. This step is followed by generating conceptual designs and applying various environmental friendly design concepts (DFXs) on the conceptual designs. DFX refers to design for X where X could be material, modularity, assembly, manufacturability, disassembly, testability, maintainability, use, reuse, upgradability, remanufacturability, recyclability, energy efficiency, packaging, multi-lifecycle, multi-purpose, or minimum residue, etc.

Figure 2: Conceptual Lifecycle Design based Rural Technology Development Process Model
Each of the conceptual designs to which these paradigms are applied is then subjected to a series of lifecycle evaluations. The lifecycle evaluations that determine the appropriateness and sustainability of the technology to the specific rural area are: Enabling Supply and Infrastructures’ Availability Assessment (ESIAA), Design for X Assessment (DFXA), Cleaner Production Assessment (CPA); Environmental Lifecycle Assessment (ELCA); Lifecycle Costing (LCC); Social Lifecycle Assessment (SLCA); Risk Assessment (RA), and Cost Benefit Analysis (CBA).

Enabling Supply and Infrastructures’ Availability Assessment (ESIAA) helps us to determine if the resources required for the effective utilization/running of the technology is locally available or they have to be imported. This is particularly important to determine the possible capacity utilization and to plan ahead in case of emergencies.

Design for X Assessment (DFXA) is necessary to determine how environmental friendly the technology would be and to spot where the bottlenecks may arise. It is applied to both the development of the hardware part of the technology and to the design of the process that is used to produce the hardware.

Cleaner Production Assessment (CPA): This is applied in two ways. Firstly, it is used to evaluate how the utilization of the technology will affect resource consumption, emissions and resource use efficiency. Secondly it is used to assess how the process for producing the hardware part of the technology will affect resource consumption and emissions.

Environmental Lifecycle Assessment (ELCA) is used to evaluate the environmental burden associated with the materials consumption, energy consumption, and emissions to the environment at each stage of the lifecycle of the technology. It is also used to determine the impacts of these consumptions and emissions to the environment and to determine the improvement opportunities that could be applied to eliminate or reduce the impacts.

Lifecycle Costing (LCC) is similar to the environmental lifecycle assessment except that it is used to analyze the technology cost at each stage of its lifecycle. This helps us to account for the true and total cost of the technology.

Social lifecycle assessment is also a lifecycle analysis approach. It is used to determine the socio-cultural impacts of the technology at each stage of its lifecycle. Here, we account for how it will affect the way of life of people that develop, use and live/work in the neighbourhood where the technology is deployed.

Risk Assessment (RA): This is the determination of the potential impact of an individual risk associated with each stage of the lifecycle (especially the development and utilization) of the technology by measuring or otherwise assessing both the likelihood that it will occur and the impact if it occurs.

Cost Benefit Analysis (CBA): This is an analysis that compares present values of all benefits derivable from the technology less all costs related to the technology when benefits can be valued in dollars the same way as costs. This is performed in order to select the (technology) alternative that maximizes the benefits of a technology or program.

Furthermore, prior to the evaluation of each option of the technology being considered for development, a minimum acceptable performance level should be set for each of the evaluations described above such that any or all technology options that fails to reach such performance threshold is discarded while those that performs better are ranked according to their overall performance at each stage and throughout their entire lifecycle.

For instance, assuming the conceptual design option A (out of options A, B, ..., K) is the highest ranking option, a decision will then be made as to whether the results of that conceptual design option/alternative of the technology are acceptable or not. If they are acceptable, a prototype of the conceptual design option A is developed. The prototype is then evaluated using the lifecycle evaluation tools earlier discussed. If the results obtained from the prototype evaluation are acceptable a pilot plant of the technology will be
developed to showcase it to the consumer before it is either marketed or transferred to the consumer (i.e. the rural development agency or the rural community).

Although the technology thus developed is suitable for rural utilization, it may not be sustainable unless the technology is completely transferred. The transfer of the technology will include the transfer of the hardware (i.e. the capital goods); skills and know-how for operation and maintenance; managerial skills, and knowledge for generating and managing technical change (i.e. adaptation/redesign) to the rural populace. These can be achieved by training the local hands in each of these areas, thereby improving their production capacity and technological capacity. Furthermore, the transfer will require/should involve continuous monitoring and collection of feedbacks from the utilization of the technology in the rural area to facilitate future improvements on the technology’s performance. The monitoring process would start from the point of agreement on the technology option/choice to the point of deployment of the technology through the various steps of installation, utilization, adaptation, maintenance and decommissioning/end-of-life management.

If the evaluation results are not satisfactory at any point during the developmental stage, the previous step(s) taken would have to be re-examined to determine what needs to be done to improve the performance and thereby make the technology appropriate for the rural area in question.

4. Illustrative Example of Lifecycle Design Application to a Rural Technology Development

This illustrative example of the application of the lifecycle design concepts to a rural technology development involved the design and development of a multi-purpose shelling machine for rural use by the author while working with a federal government owned industrial research institute (FIIRO). The following highlights the background of the project and the development steps taken:

4.1. Background

Many of the farmers in Nigeria are peasants characterized by small capital investment and mostly manual operations because they could not afford to purchase the machinery required for large scale operations. Consequently they have large harvest losses annually due to non-availability of adequate post-harvest treatment and storage facilities. In addition, those that could afford it have to import them from Thailand and India. Many of these imported machines can only process single produce and many of them become unserviceable when they break down because of non-availability of spare parts and repair facilities. Furthermore, the processing capacity of many of these machines is far beyond the needs of these farmers, therefore many of these machines lie idle for most part of the year. These inadequacies served as a research gap on which new product and process design and development could be built.

4.2. Approach to lifecycle design of the machine

FIIRO management mandated the author to develop a locally produced portable peanut-shelling machine that is appropriate in processing capacity and locally serviceable. The first step taken was to look at operating conditions under which the machinery will be utilized and the level of technical know-how in the area. This was determined through literature search, site visits, and consultation with colleagues and other stakeholders. The appropriate throughput capacity, (local) availability of materials and spare parts, resource consumption, emissions and multi-functionality potential are other factors considered in the design of the machine.
In addition to aforementioned considerations, the machine was designed for simplicity to facilitate easy and cheaper maintenance cost. Furthermore, it was designed for multi-purpose use and multi-lifecycle in view of the economic and environmental needs of the intended rural users.

Two conceptual designs were produced and each of them was assessed qualitatively and quantitatively, wherever appropriate, as follow:

ESIAA- Availability of enabling supply and infrastructures for the design were assessed by answering questions like: Will spare parts be available locally or regionally or they will have to be imported? Are there local technicians that could service the machinery whenever the need arise or foreign expert will have to be hired? Does the quantity and quality of locally produced raw materials match the requirements of the machine? Are the energy, lubricants and other resources required for efficient operations of the machinery locally available in the required quantity and quality? How will the efficiency of supply of these items affect productivity and lifespan of the machinery?

DFX/CPA- the environmental friendliness of each design and the manufacturing processes that would be used to produce it locally were assessed. Assemblability, disassemblability, manufacturability, remanufacturability, reusability and upgradability are the parameters used for this evaluation.

ELCA – Each of the designs were evaluated in terms of the type, quantity and sources of raw materials and energy that is required for its manufacture. The potential impacts of the resources consumption were then assessed in terms of global warming, ozone depletion, acidification, eco-toxicological, eutrophication, abiotic resources and biotic resource impacts. These parameters were evaluated at each stages of the lifecycle and the over the entire lifecycle.

Similar approach was used for the lifecycle cost analysis, social lifecycle impact assessment and risk analysis. The results from these analyses were then tabulated and comparison made to determine the best design option.

A prototype of the best conceptual design was then produced. The subjection of the prototype to lifecycle evaluation necessitated some modifications in the separation and grading units. Thereafter we fabricated the machine and subjected the machine to lifecycle- and other performance evaluations. Modifications were made on the fabricated machine until the upgrade version met the desired performance level. The upgraded machine was then transferred to the technology marketing arm of the organization which took the machine to trade fairs/trade shows and demonstrated its use. The consumers are then given intensive on-site training on the nitty-gritty of the technology operation and hardware maintenance.

5. Conclusion

The results so far obtained reveals that the technology performance has been found satisfactory. The author has learned that involving the potential users (i.e. rural dwellers) throughout the development process will facilitate better product development and ensure the adequacy/suitability of the technology for the people that it is meant for. Complete and cyclic transferring of the technology and its upgrade versions through training, continuous monitoring and upgrading of the technology will consequently facilitate the application of the lifecycle design principle by the local technicians to improve indigenous technologies and to the hybridization of the imported technology with the indigenous ones.

Overall, experience has shown that lifecycle design cooperative approach to rural technology development methodology is a win-win approach that ensures that the technology is appropriate for the users. It is technically adequate for the rural setting, socially compatible, environmental friendly, and economically reasonable. It will in the long run result in continuous improvement of the technology used in the rural areas, improve their productive capacity and thereby improve their standard of living.
References


Calling and Motivation for International Engineering Pursuits

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Abstract

The practice of engineering is increasingly becoming a global enterprise. This involvement can range from working with large multinational corporations to small scale appropriate technology startups, such as creating a village-based energy business in a developing country. As we engineering educators seek to prepare students for future global participation, we may personally seek to become internationally active as well.

We will use as a starting point the analysis done by Stephen Evans in his essay, The Calling of the Christian Scholar-Teacher. Evans describes three types of Christian scholarship. The first one is purely vocational Christian scholarship. The professor is showing that Christians can work hard and do excellent work, but the result is not intrinsically different from that of others. The second type is implicit Christian scholarship. In this situation, the person’s Christian faith has shaped the choice of the problem to be analyzed and the hypothesis to be used. The third type is explicit Christian scholarship, where the Christian faith of the professor shapes the work in a direct and obvious way.

All three of Evans’ categories can be regarded as Christian scholarship. We will use his categorization to examine the different ways Christian engineering professors can become directly involved with international activities. We will use personal examples from our own international activities to illustrate our points.

The second author’s involvement in educational projects in Southeast Asia is an example of vocational Christian scholarship. His motive is based on his Christian faith, to serve his brothers and sisters, though the contributions and outcomes are relatively secular. His work is government sponsored and in-country colleagues do not share a strong faith.

The first author’s involvement in Central America this past year is an example of implicit Christian scholarship. The project involved creating village-level energy systems in the rural part of a country. The work was sponsored by a secular foundation. Our contacts in the country were pastors from churches in the area. We wanted to do something that would help them and their parishioners. Our motives were Christian, our choice of local contacts was based on our shared faith, but our actual engineering implementation was not noticeably different from what others might do.

Our university’s work in Kenya and Rwanda is an example of explicit Christian scholarship. Our motives are Christian and we are working with local Christian organizations. Our funding comes from donors who support our missionary goals. The result of our work is intended to help local poor Christians. As part of our work in the country we are also directly involved with Christian ministry activities.

Background—Essay by Stephen Evans

This paper has its origins in the essay by Stephen Evans and prior work done by the first author in the area of Engineering as Mission. Evans’ essay brings out several important points. This section of this paper is adapted by the authors from Evans’ work. As Christians who work in a Christian university, we are concerned with how we can relate our faith and our scholarship. We want to expand on what Evans has done and apply it to Christian engineers working on service projects in developing countries.

We need to engage our culture and participate in its common life. Evans makes the point that a Christian in academia is a “kind of double missionary. On one hand the educated Christian is a representative of
Christ’s church in the spheres of life where intellectual issues are important…the Christian scholar is also a missionary for the life of the mind within the church… The calling of the Christian teacher-scholar forms the heart and soul of Christian higher education.”

Evans groups Christian scholarship into three basic types:

- **Purely vocational Christian scholarship.** This is scholarship that is motivated by the Christian faith of the scholar, but whose outward appearance is not any different from what would be done by a non-Christian scholar.

- **Implicit Christian scholarship.** In this situation the Christian faith of the scholar has shaped the choice of research topics as well as the hypothesis he/she is testing.

- **Explicit Christian scholarship.** This is where the Christian faith of the scholar is an integral and direct part of the entire scholarly activity.

Evans offers some cautionary thoughts. One key issue is which type of scholarship should a Christian scholar pursue. Evans’ response is “all of them.” Any one of them is not inherently better than another one. Depending on the context, all of the above approaches can and should be done by Christian scholars. All of them can be legitimate with some qualification as to the perspective of the viewer, be it the promotion and tenure committee or the editor/reviewers for a journal or conference. As will be shown later in this paper, the authors have done scholarship of all three types depending upon the specific situation.

We agree with Evans when he says that Christian scholarship should not be done in an intellectual Christian ghetto. While this paper is presented at a Christian conference, the authors have presented papers at other locations that deal with many of these same topics.

When the types of Christian scholarship are analyzed in the context of different academic fields, it becomes clear that explicit Christian scholarship will be easier in some disciplines than others. For example, there are many areas within engineering where it is not obvious to say there is a Christian perspective on that topic. For example, the first author would never claim that there is a truly Christian perspective on fracture mechanics. However, it is much easier to say that there are Christian perspectives on engineering ethics. This does not make work on fracture mechanics any less Christian. It just means that scholarship in that area will be more likely to be *vocational Christian scholarship*. If we do an excellent job on *vocational Christian scholarship*, then others in our academic community will be more willing to listen to us when Christian topics do come up for discussion.

When we conduct Christian-related scholarship, we need to recognize another caution from Evans. Evans writes:¹ “In a pluralistic community Christians must model respect and tolerance, even while they show that intellectual humility can coexist with committed conviction and action.”

**Background—Engineering as Mission**

We wish to relate Evans’ concepts about Christian scholarship to some earlier work the first author has done concerning engineering as mission. The first author has written previously on engineering as mission²−³. The approach that was used in those papers overlaps the approach being used in this paper. The next few paragraphs are adapted from reference [2]. Engineering as Mission is much more than just taking engineering students to another country to conduct a service project. For it to be truly mission there has to be much more thinking done before the trip is made to make sure the trip accomplishes what it really is intended to do.

The concept of engineering as mission has been influenced by a similar movement concerning how business can play a major role in missions. This emerging movement is known as Business as Mission. One example of this is the Business as Mission network⁴ website: [www.businessasmissionnetwork.com/](http://www.businessasmissionnetwork.com/) which attempts to link various efforts in this area.
The concept of business as mission rests on businesses that have a social purpose as well as an economic one. Sometimes it is presented as businesses with a triple bottom line. They sustain themselves by making a profit, they provide jobs for poor people while making products that help poor in developing countries, and have a social impact, such as spiritual transformation in the local culture. An example of this is the Treadle pump. This was developed by International Development Enterprises. About two million of these human powered water pumps have been built and sold throughout the developing world. Several million people have escaped extreme poverty because the water provided by these pumps helped increase the yield of their farms. These pumps are not only built for poor farmers, but they are built by thousands of small shops whose owners also benefit by making a profit on the sale of the pump itself.

With respect to objectives or the purpose of engineering as a mission in developing countries, we have identified four purposes or objectives.

1. **Helping poor people in developing countries better their lives.** This provides a direct blessing to others. This is often done by engineers working with secular organizations in other countries. While the engineering work may not be any different than what would be done by a secular organization, the motive of the individual engineers may be very different.

   The use of engineering as a missions tool has been previously reported at CEEC conferences. Most of these are direct attempts to help poor people. This is a legitimate approach as we are called to help the poor, whatever their worldview perspective. Treese has reported on work in Nepal. In 2004 Kelley and others reported on work in the Kurdistan portion of Iraq. At the 2006 conference there were three papers dealing with projects in Uganda, Thailand, and other locations. These papers all give useful insight into how Christians can practice engineering in a developing country. Many of them give an explicit Christian justification for what they have done.

2. **Using engineering projects as a way to build credibility with the people we are helping.** They see what Christ can do in those of us who are volunteering our time and talents and it makes the faith seem more reasonable.

   Most of the papers shown under approach #1 above describe projects that also had this as a goal. As the local people are shown Christian faith in action, it will appear to be more desirable. This is frequently followed up with direct presentations of the gospel by either the engineers or their hosts. The author has presented a paper about a project in western Kenya at an ASEE conference. This project worked with a Christian school for deaf children. In addition to helping to provide them with clean water and electricity this project was also undertaken to show the children (many of whom are not Christian) some of the reality of the Christian faith. While most of this paper describes work that has been done by engineers related to universities, there are also groups that work with professional engineers. An example of this is Engineering Ministries International (EMI). This group has professional engineers visit the site of a potential project in the developing world. This is done by invitation from a local group in the developing world that has a project they would like to see developed. The EMI volunteer engineers then design a solution to the problem while here in the United States, and it is then implemented by others. Many of their projects are related to infrastructure and require civil engineering expertise.

3. **Using engineering projects to build credibility and openness with governmental officials.** Western engineers are welcome to go to many countries where professional missionaries are not allowed. By our example, and by our low key witness, people can be shown the reality of Christianity. This does not mean the Christian engineers deceive anyone about what they are trying to accomplish. It does mean that they emphasize the technical aspects of their work in public statements and in their interaction with governmental leaders.

   The work done by Bridge to Rwanda is an example of this. In addition to approaches one and two mentioned above, they have had as a goal the desire to help the local government increase its involvement with community development. As a result of this the President of Rwanda has appointed a Presidential...
Advisory Council (PAC). The PAC includes fourteen individuals committed to using their professional expertise, leadership, networks and influence to help Rwanda achieve its Vision 2020 National Development Plan. The group includes leaders in business, church and academia and experts in global competitiveness from Rwanda, Rwanda’s Diaspora, US, Canada, Australia and the UK. Several people from Bridge to Rwanda are part of this council.

4. Using engineering projects to build up the local church.
   It is the goal of the author to work in Rwanda with Bridge to Rwanda. Using engineering skills from our students will assist the local church in fulfilling their goals of Christian community development.

All of the above approaches can be used with engineering missions. Many people, including the authors, have done projects largely using only approach number one above. While these can be very beneficial, engineers should consider a more broad based approach.

The first approach to engineering as mission mentioned above is very similar to Evans’ reference to purely vocational Christian scholarship. The last approach mentioned above is very similar to what Evans called explicit Christian scholarship. The two approaches in the middle (2 and 3) are not exactly the same as implicit Christian scholarship, but are very close to that concept.

International Engineering Projects as a Scholarly Pursuit

In engineering academia scholarship is usually related to publications (refereed journal articles and sometimes conference presentations) or funded research. This can still be true for international projects. For example, the first author’s work in Honduras was done as part of an externally sponsored research project. This project’s work is being presented in summer 2009 at a professional conference. In addition, one graduate student did his Master’s project based on the work in Honduras.

However, we would like to take a broader view and state the scholarly pursuits can include things that would not necessarily be publishable or fundable by a governmental agency. As long as significant intellectual effort is involved it can be called scholarly. [As a Department Chair and a Dean, we recognize that such scholarship will not weigh heavily in most tenure/promotion decisions. What should count for those purposes is a very different question that we will not pursue in this paper.]

We can make more of our international activities countable by our universities by publishing the results that we have obtained. This will involve extra work after the international portion of the project may be over. We may be tempted to come home and relax after the pressure of the international work. However, it is important to our disciplines that we document these things in publications so that others can learn from what we are doing, and also to become motivated to do these things as well.

Applying Evans’ Concepts to International Projects

We now wish to apply Evans’ concept to international projects. We will use examples from our own work.

1. Purely Vocational Christian Scholarship
   The second author’s work in Southeast Asia is an example of purely vocational Christian scholarship. This project involves teaching a course, Engineering Biomechanics, for and to students at the Hanoi University of Technology in Vietnam. This work is sponsored by a U.S. federal agency, the Vietnam Education Foundation (VEF) that has the mission of helping to build Vietnamese science and engineering capacity through teaching and related research activities. VEF was established by the U.S. Congress under the Clinton administration in 2000 and enabled by the Bush administration in 2003. VEF’s first activities were to provide scholarships for Vietnamese science and engineering graduate students to study at U.S. institutions. Later VEF began to send Vietnamese faculty members to study and conduct research at U.S. universities. In 2009, VEF initiated the U.S. Faculty Scholars program, whereby four U.S. faculty
members were selected to teach courses in English for Vietnamese higher education institutions, either completely onsite or through a combination of onsite and interactive video conferencing. The Hanoi University of Technology (HUT- Đại Học Bách Khoa Hà Nội) was selected because it is the preeminent engineering institution in Vietnam, and one of the few that offers a biomedical engineering instruction. In Vietnam, most biomedical engineering graduates work in hospitals to maintain and specify hospital instrumentation, and therefore their studies emphasize biomedical electronics and instrumentation. The Vietnamese government recently selected and funded HUT to initiate an Advanced BME program to raise the curriculum, laboratories and teaching approaches to international standards. This combination of need by HUT, and the second author’s expertise in biomechanics, combined for a winning approach and proposal.

Among the limiting factors of the Vietnamese higher education system is the availability and affordability of resources, both for the institutions and students. The average per annual capita income in Vietnam is around $1,000 USD and students often cannot afford to buy textbooks. Further, most textbooks are aimed at the needs of the Western world and may not readily be adapted to developing countries. For these reasons, and with the help of a Baylor biomedical engineering graduate student, a customized textbook was prepared for this course. This book includes not only copies of the PowerPoint lecture slides, but also relevant readings from open-source resources, and homework assignments. This book is now posted and available on the Vietnam Open Courseware system.

The first two and last two weeks of the course were offered onsite (Figure 1). The intervening eleven weeks were offered from Baylor using the Elluminate Live platform (Figure 2). This system permits live video and audio feeds, a chat box, downloading of PowerPoint slides, and an interactive whiteboard interface. This Engineering Biomechanics course also comprises several of the elements identified to be lacking in the Vietnamese higher education system. For example, it is not usual for Vietnamese students to interact openly with faculty members, for courses to incorporate practical applications, and for the development of professional skills such as oral and written communication. Approaches to address some of these shortcomings included rewarding students who asked questions with a piece of (American) candy, and centering the content of the course around the design of an orthopedic appliance, in this case a bone plate, complete with a team design report and presentation.
The description of this effort in Vietnam is consistent with Evans’ concept of *purely vocational Christian Scholarship*. This effort is engineering as mission, with a motivation to help those in need, whatever their worldview perspective.

There are other more than tangential Christian motives relating to this project that are not as readily apparent. For example, the second author who is conducting this work, and his wife, adopted a three-year-old orphan boy from Vietnam almost 15 years ago. The relationship to this overt act of Christian concern is the driving motivation behind the project’s location. Further, in developing the grant proposal, many potential ties to Vietnam were explored. One of these resulted in contact with Northwood Church in Keller, Texas, and their outreach arm, Glocal Ventures, which has an extensive service presence in Vietnam. While no direct academic connection came from that inquiry, a follow-on relationship developed to take advantage of and combine efforts in Vietnam. Glocal Ventures is working with the Hanoi Young Business Association to sponsor a business conference in Hanoi with the theme, “Foundation for Business Growth – Corporate Social Responsibility”.

As the date of this conference coincides with the dates of the onsite portion of the biomechanics course, the second author will be a principal presenter at the business conference, speaking on education and training. Glocal Ventures is also employing the elements of *purely vocational Christian Scholarship* through their sponsorship and organization of this conference.

2. *Implicit Christian Scholarship*

The first author’s work in Central America is an example of *implicit Christian scholarship*. Most of this work has been sponsored by a secular foundation. However, our contacts in the local villages are usually pastors in those communities. Our motives are Christian, and the choice of local villages is often based upon local Christian pastors who know each other. On the other hand, the actual implementation is not different than what a non-Christian group might do. We have reported on this work in several locations.

Our university has sent several teams around the world execute do engineering projects that help the poor. Recently the student group has started focusing on the country of Honduras. During this first trip and following trip the students did site survey work, design, construction and installation of a battery charging station. However, there was a failure to leave behind a completed business structure that resulted in a lack of accountability to ensure the business and operational objectives of the project were continued. This resulted in a nearly complete “business” failure, in part because the technology was not really what they wanted, and that resulted in a lack of societal uptake and therefore a lack of societal acceptance of the battery charging station. Their strong preference was to be able to use appliances that required more power and higher voltages than was practical with a battery charging system. Also during this trip, we did not have the vision or plans to try and spread the technology around to other towns in similar situations.

Reference [26] described our second try at developing an electrical system in Honduras. We have learned much from our first try and from further research in the area, and although we have a similar purpose, this time we have a totally different set of directions, goals and methodologies. This time around we want to make the system sustainable in as many ways as possible, and we do want to spread this technology around to affect as many people as possible.

Design, whether in engineering or in business, is about filling an unmet need. In this situation we have a physical need that can only be sustainably filled with a combination of business and engineering. Without the engineering we would not have the ability to design the power generation and distribution systems in the villages. Without the business we would not have the ability to determine what is needed financially to build, support and sustain the operations over a period of time. In this project we are utilizing many off-the-shelf engineering components, and many common business concepts to operate effectively. We are, however, applying the engineering components and business concepts in slightly novel ways.

For example, hydro power is commonly employed around the world, but we are operating in the micro-hydro segment of the market that has not received a lot of attention from the large commercial vendors.
On the business side of things we are using the very familiar concept of a franchise in a new way, by applying it to the very small scale as a micro-franchise model, which allows local people to potentially own the electric grid in their village.

Our system will utilize these modified common design principles to address the problems that we have observed in Honduras that are keeping people from being connected to the national grid. The solution we are presenting will produce power locally to be delivered to local people. We are utilizing natural resources that are abundant and non-polluting to generate our power and that have very low costs of operation. We are utilizing local people to build and maintain the system, which keeps costs low. We have also built in checks and balances in our paperwork system to prevent theft and corruption. And finally and most importantly we are set up to serve small customers with small amounts of power.

This project was inherently one that required significant scholarly thinking. It has also resulted in more traditional scholarly results. So far there have been two conference publications and one Master’s project develop from this project. The graduate student is now working with us to turn the project into a sustainable business that can replicate this village energy concept in other villages throughout the country.

3. **Explicit Christian Scholarship**

The first author’s work in Kenya and Rwanda is an example of explicit Christian scholarship. In Kenya we installed a water purification device and a solar powered electrical system in a Christian school for deaf orphans. In this case we came at the invitation of a Christian group and worked with local Christians in ways that could better their lives. We have previously reported on this work.\(^{11}\)

The first author is just beginning to do work in Rwanda that is also a form of explicit Christian scholarship. We have been invited by Bridge to Rwanda\(^{27}\) to assist them with several projects at the Sonrise School near Musanze, Rwanda. Bridge to Rwanda is an overtly Christian organization whose mission includes the education of “young people committed to Jesus.” Sonrise is an excellent school that was originally created largely to teach children who were orphaned in the 1994 genocide. They now teach many other children as well. They have needs for purifying their water. Currently they boil it in wood charcoal-based stoves, which takes much work and pollute the kitchen area. They also have problems with electricity. Their source is not stable and very expensive. They are trying to use computer labs and need a better source of cheap electricity that is also stable. A photograph of part of their school is shown below. In May 2009 we will work with them to improve both their electrical and their water systems.

![Sonrise School near Musane, Rwanda](image)

**Figure 3: Sonrise School near Musane, Rwanda**

\(^{11}\) © 2009 CEEC Proceedings
Conclusions

Engineering as mission is much more than just taking engineering students on a plane trip to a developing country and trying to implement an engineering project. In a similar way Christian scholarship in an international setting is much more than just going on an international trip and then coming home and writing a paper upon it.

We believe that the three pronged approach to Christian scholarship that has been developed by Stephen Evans can give us insight into why we do international engineering projects. This can also encourage the Christian professor by showing that Christian scholarship does not always have to be explicitly Christian. Vocational Christian scholarship and implicit Christian scholarship are equally legitimate and valuable. This approach also gives us insight into ways that we can add more scholarship to international projects. In this way we can make international projects more relevant to the life of the typical engineering professor.

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Many influences weigh into a college senior’s career decision. For the first time in their lives, most seniors foresee that they

- are leaving the annual cycle of school, interrupted by summers of various activities,
- will be deciding where they will work, where they will live, whom they will choose as associates for near-term, intermediate, and long-term time horizons,
- will be making far more independent choices about how to structure their time, set their priorities, and decide about the values that they choose to live by, and
- are going to choose the vector on which to set their lives and that this choice can have an enormous effect on who and what they become.

These influences weigh heavily on their transition from their undergraduate degree to their next stage in life. Some stay in school, transitioning into graduate school in a related field but most pursue employment, often for the first time, in their field of education.

Engineering seniors follow this same pattern, but the selection of their first employment has a strong influence on their longer-term career success. For many years, Professor George Farris\(^1\) of Rutgers University has studied the career decisions of graduating technologists—principally, engineers—and the effect their career decision has on their career success. For Professor Farris, “career success” is characterized by a sense of doing meaningful work, sustained employment, professional or managerial advancement or both, progressively expanding real income, etc. Repeatedly, Professor Farris’ results show that the principal factor determining career success is successfully overcoming a significant professional challenge in the first two years of employment. Of course, this sweeping conclusion requires considerable context. For example, the challenge must be in the technological arena of the engineer’s education, the challenge must be appropriate for the training and development of the engineer in his or her early years, etc. Professor Farris’ studies show that an engineer’s contribution over his or her career life is significantly influenced by their first employment after their college years.

For senior engineering students, a major potential influence on their career direction is their Senior Design Project. This paper explores that relationship for one subset of students and projects. It contributes to the extensive database of knowledge in this arena and raises issues. It does not attempt to look across the span of many students in one college, one engineering profession, etc., i.e., large population or longitudinal analysis. It does not seek to review that database; this needs to be deferred to a later paper.

**Senior Design Projects**

At Calvin College, students—in teams of three to five, predominantly four—select their projects in the second semester of their junior year or in the first two weeks of their senior year. The projects develop throughout the entire senior year. The goal of each project is to deliver a design and working prototype of a technological contribution. For example, recent projects included:

- a 1 kW net shaft horsepower Stirling Cycle Engine driven by heat from a solar collector and cooled by forced ambient air,
- an LED-based lighting system that could deliver room illumination over a spectrum of user-chosen colors, and
- a plant design and economic analysis for new catalytic biotechnology to convert carbon dioxide in the presence of sunlight into fuel-grade ethanol.
Each project team must comprehensively define the three “S’s” of a project: Scope, Schedule and Spending. The scope document displays the project name, the student team members, the faculty mentor, key outside resources, etc. wrapped around the scope for the project; the scope is a statement of the need, the objectives and the results for the project. The scope for each project comes from a wide variety of sources. Some project scopes develop among the students during their earlier academic courses; some develop from specific requests from inside or outside of Calvin College; and, some develop from proposals by engineering professors. As Calvin College is distinctly Christian, ordinarily missions seeking preliminary designs for needed facilities will propose projects to the Engineering Department. Students select their projects and team members for nearly all projects. The project’s three S’s and the team members are subject to the approval of the Senior Design faculty. Faculty intervention is usually minor, affecting the three S’s of at most one-out-of about 15 projects and two-out-of about 65 students as team members.

Engineering students often select their senior projects based on the preliminary scope of the project, which is based on the project’s technology and customer base. Engineering students realize that their senior project will be the first integrating application of their engineering education. For many students, their principal experience base before this project is one or two internships in either academic research or industrial employment or both. In internships, the student’s technology and customer base options are limited by the opportunities granted by the employer and the technology and customer base. In their senior projects, the scope in terms of technology and customer base is far broader. All students realize that their senior project becomes a platform upon which they will articulate their vision of themselves and their career aspirations to graduate schools, potential employers, family and friends. Uniquely different from their previous experiences, their senior project becomes part of their definition of themselves.

The following looks at two related senior design projects that served people in developing countries and the relationship of the scope of these projects to the engineers’ career selection. For all projects, the technology arena was amaranth processing for people in developing countries.

**Amaranth Processing for Developing Countries**

Amaranth is a nutritious “pseudo-grain,” meaning that amaranth is the grain fruit of a plant that does not belong to the family of grasses. Similar grains in this class include book wheat and quinoa. One amaranth grain, used as a seed, grows a plant about two meters high with bushy heads producing about 6000 grains. Amaranth grains are much smaller (about 4000 grains per teaspoon) than most “normal” grains like wheat, corn, and rice (about 250 grains per teaspoon); conventional grain processing machinery requires modest modification to harvest amaranth—modifications about equivalent to harvesting sunflower seeds.

Amaranth grows well in difficult conditions; it tolerates moderate climates to desert climates; it thrives in poor or rich soil; it responds to variable quality water—including water containing salt, and it tolerates severe cycles of moisture and drought. A corn crop can easily be destroyed by a severe rain that floods the field for a few days cutting off the oxygen supply to the roots. Many other grains suffer similarly. A rice crop can be destroyed by a severe drought that removes the source of irrigating water.

Amaranth grain has twice the calcium of milk and five times the iron of wheat, amongst other nutrients. Amaranth’s true value is its high content of protein, methionine and lysine, normally lacking in true grains. Amaranth can be milled or popped. When amaranth is mixed with other more common grains, the mixture can be a complete protein comparable to that of red meat; these mixtures are commonly milled grain and are used in flours and porridges. Popped amaranth is even more nutritious—for reasons not totally understood, the human body better absorbs the nutrients from popped amaranth. Popped amaranth can be eaten as is—like popcorn, but more commonly, it is blended with nuts, honey, molasses, etc. to make a “health bar.”
Historically, amaranth is probably native to Mexico, where the Aztecs would mix the grains with honey and blood from human sacrifice ceremonies to form edible idols as part of their religious rituals. The Spanish conquistadores, either to stop the human sacrifices (thereby stifling the Aztecs’ religion), or because this practice struck them as similar to Christian communion and was therefore blasphemous, forbade the cultivation of the plant with very harsh penalties for violation of this directive. Amaranth grain has only been recently “rediscovered.” It is slowly making a comeback globally as a very nutritious food source; as God surely intended when He created it. In the mid-1900’s, agronomists identified amaranth as a potential food plant. Since then, numerous bodies have helped with its development, principally for deployment as a self-sufficient food source for people in developing countries. Amaranth can be seeded, grown and harvested like other grain crops (e.g., corn, wheat, rice and even sunflower seeds.) by large combines. In some parts of the industrialized world, including the US, amaranth grain is produced this way. However, in developing countries, the complexities of these systems are often not yet appropriate. For these situations, machinery is desired to help people improve their more rustic grain processing practices.

Because of amaranth’s ability to flourish in challenging-water environments and its nutritional qualities, the Christian Reformed World Relief Committee (CRWRC), and many others, encourages its development and expansion in developing countries. In 2004, one senior design team–consisting of four students in the mechanical engineering concentration–embraced the challenge from CRWRC to design an amaranth grain cleaner. Originally, their scope was to produce a winnower or “grain cleaner,” which would separate the grains from loose debris after the grains were already beaten from the stalk (threshed). As the design developed, they added—with the customer’s strong urging—a small threshing component. This post-thresher sought to separate the grain from any residual small stalks that passed along with the threshed grain; all of the grain fed to the “grain cleaner” passed through the thresher.

This team designed and built a prototype grain cleaner. Their design included one prototype machine that operated on locally-grown amaranth, complete design specifications, an operating manual, a maintenance manual, an assembly manual, and a shipping container design for the cleaner in a “knocked-down” or “broken-down” status. All of the manuals were totally in pictographic language, so they would be available to anyone in any language.

Critical specifications for this project included that:

- the sole source of power would be women and children (up to pre-teens), so somewhat less than 0.1 horsepower per person,
- the machine would be based principally on locally obtainable parts–certainly for all maintenance,
- the machine would be movable from field-to-field or village-to-village by two women without secondary transportation means (e.g., a cart),
- the grain recovery would be greater than 90% of the feed, and
- the grain cleanliness would meet typical industrialized world specifications.

Following the completion of their project, the prototype and design materials were taken over by Hillcrest Christian Reformed Church®. This church divided the design into 20 parts and recruited 20 people to make 12 copies each of the required parts. Then, on an agreed evening, all “parts makers” and the project coordinator assembled for a brief dinner, followed by the assembly, operational checkout, disassembling, and packaging into the shipping container 12 copies of the “grain cleaner.” (Henry Ford redux!) These 12 grain cleaners were shipped worldwide.
One of the challenges of any senior design project is that if the project is successful, follow-up on deployment of the project is a challenge. The College, the Church, the relief committee, et al., did not have resources to follow-up on the deployment of these grain cleaners, and not all have met with success. The principal challenge has been that many users saw the post-thresher as intended as a main thresher; it had no capacity for this work, but when it “failed” in their eyes, they rejected the entire machine. In hindsight, it is now evident that the pictographic manual needed to make explicitly clear that only thoroughly threshed amaranth was to be fed to this machine. Moreover, there is a need to include knowledgeable engineering resources in the deployment of a project.

In 2007, the Engineering Department was approached by a NGO-entrepreneur to design an amaranth popper that would process 50 lb/hr of amaranth grain. Five mechanical engineering concentration students responded to this request. The specifications on this project included the production rate, cost minimization, and the use of 220v-three phase power. After extensive testing, these students built and operated an amaranth popper that met the specifications. The students generated a completely documented design manual, including recommendations for improvement, and an operating manual. At the completion of their project, the students strongly recommended basing the popper design on fuel gas—such as propane, butane or natural gas. The NGO-entrepreneur took the prototype apparatus, with its details to his shop, modified the design to an appropriate fuel gas and is currently deploying popping machines into Uganda. At this volume rate, volumetric producers of amaranth health bars and other forms of popped amaranth will use these machines. One of the students from this team has continually been available to this NGO-entrepreneur throughout this process; although other engineers not previously involved with amaranth have supported most of the redesign and prototyping.

An interesting extension of this popping project is now in consideration. The NGO-entrepreneur has proposed that a senior design team design and build a prototype popping machine that could pop 5 lb of amaranth per hour and be deployed into homes in those countries in more advanced stages of development. Of course, the idea is to equip people to develop both “home cooking” devices, but also to encourage “cottage businesses” that make and sell healthy amaranth bars, nuggets, etc., much as we have boutique chocolate candy operations in developed countries. A team of two students with a chemical engineering concentration and two students with a mechanical engineering concentration have committed to this project in the 2009-2010 year.

This brief overview of amaranth and two senior design projects for amaranth machinery development for developing countries sets the basis for this report. Next, let us look at the connectivity between working on these important projects and the first employment career decisions made by the students who worked on these projects.

From Senior Design Project to Career Decision

The database afforded by these projects is nine senior engineering students. All nine elected to spend a considerable part of their academic life on projects to service the developing world. The developed world consists of about 1.5 billion people; most that read this study are deeply embedded in that population. Globally, we are rocketing toward 7 billion people in this world at a net addition rate of about one person per second. Most of these additions are being added to the 5.5 billion people in developing countries, people for whom healthy-acceptable drinking water is unavailable, people who do not get an adequate number of calories per day, people who do not often get even marginal nutrition. Calvin College has trained nine engineers and deployed them into projects that benefited people in developing countries. However, one project does not begin to touch the needs of a skyrocketing population of 5.5 billion people.

All of the students on these projects report that they took these projects because they would be able to work on a “real, meaningful” project that would help someone. However, how many of these engineers
took a career direction to continue to deploy their talents toward helping those in the developing countries?

Beginning with the first project—the amaranth grain cleaner: All four of the mechanical engineering concentration students on this project took employment with an industrial firm immediately following graduation; three became employed within a 75-mile radius of the college campus, with the fourth less than 500 miles away. None immediately went to graduate school. Three were married within one year; the fourth became espoused within 3 years and moved 2000 miles with her fiancé to fulfill the commitment, still employed by her initial industrial firm. While two former students were working for firms that made health care equipment, it would be a stretch to say that any became employed in a service that directly benefited those in the developing world; in essence, none of these students followed up to help directly the disadvantaged through the deployment of their engineering talents.

Moving next to the team that successfully developed the amaranth popper: This project involved five mechanical engineering concentration students. Four of the five took industrial employment immediately after completing their degree; one went to graduate school immediately. Three remained in the vicinity of the college for their employment; the graduate student was within less than 150 miles of the campus and one student returned to his native home area in southern Canada. Two of these were married within a year— one being the student that went to graduate school, who married another Calvin College graduate who is also attending the same graduate school.

All nine students have taken on professional challenges in their initial career choice. Following Professor Farris’ observed pattern, all are likely to stay with their initial career choice and advance within it.

Of these nine (mechanical) engineering students who had worked on a project to aid God’s people in developing countries, none immediately followed on to deploy their education, skills, and developed talents to benefit these people. Only one of the nine students was ever sought by anyone to work as an engineer on developing country projects, but this contact was solely as an occasional consultant. Most of the graduate engineers report this result ruefully. Essentially all of the graduate engineers continue to look out for opportunities to contribute in some way to people’s needs. Some mention possibly changing jobs to better satisfy this need. Several mention investing some of their own funds into advanced software and then working on solutions to problems that they hear about from people in developing countries on a “moonlight” basis. All respond to questioning that if a competitive employer, with a robust staff of experienced engineers who had a portfolio of projects to improve operations in developing countries approached them, they would likely respond positively.

This data drives many questions. First, how general is this? Much more data is needed, but based on similar local situations, this situation is almost typical. However, a few very rewarding counter stories exist. For example, one recent student in our civil engineering concentration worked on a project for a school in Cambodia and then visited Cambodia during the Interim Semester (3½ weeks in January). When he returned, he was committed to return to Cambodia to help those people. With great difficulty, he personally secured his own support to go to Cambodia after his graduation to work as a free-lance engineer. In Cambodia, consulted with those attempting to rebuild Cambodia after the Khmer Rouge disastrous years and set up a Christian school in Cambodia. However, he was the only one of a four-member team to pursue this career option; the others took U.S. industrial positions. Similarly, each year the College has one to three (out of about 65) graduates who are committed to join the Peace Corps or some NGO with a similar operating philosophy to help the disadvantaged through their engineering talents. Again, we average about three students over every 4 years that complete their engineering degree and progress directly into a seminary program. Their degrees are typically in civil or mechanical engineering concentrations; these students are clear that their objective has been to arm themselves to be effective managers and deployers of engineering talents when they have become missionaries in the field.
Isolated counter examples can be found, but the broader view is more like what we see on our amaranth projects.

A second question arises: How many of these students have been influenced—and will later in life elect—to take a position that directly deploys their education, and now robustly developed skills, orientation and talents to benefitting those in developing countries? This longitudinal study would be very useful to address the broad issues raised in this paper. However, considering the evidenced lineage of the students into the snares of geography, marriage, offspring, employment, life-style, mortgages, etc., this transition is very unlikely, though in a few instances, some make this transition. However, Professor Farris’ analyses would strongly weigh against this transition happening for most students.

A Better Path Forward?

Christian colleges shoulder most of the burden of educating and preparing students that can be most effective in deploying appropriate, effective and efficient technology to help God’s people trapped in the cyclone of the developing countries. Certainly, other colleges prepare engineers that can and do help with the development and deployment of appropriate technology into developing countries.

In shouldering that burden, the Christian colleges need to be more effective in teaching their students about the career opportunities, challenges, and rewards of working to alleviate the fundamental problems of over 5 billion people—problems of thirst, unhealthy water, hunger, malnutrition, lack of basic hygiene, infant mortality, etc. When students have worked for a school year or more on some aspect of these problems, the Christian colleges have a good opportunity to leverage the students’ experiences into careers directed toward improving the lives of those in developing countries.

For the engineering students on the amaranth projects, an employment path to continue their work for developing countries was not presented when they were making their career decisions. This issue can be addressed by maintaining a closer integration with the agencies and NGOs who can and do deploy engineers into projects that can benefit people in developing countries. For example, at Calvin College, we are developing a chapter of Engineers without Borders (EWB), which is expected to function much like another on-campus, engineering-led group called the Renewable Energy Organization (REO). REO takes on the study, development and deployment of renewable energy projects, aids in arranging for speakers and seminars on renewable energy technology, and supports other campus activities on sustainability. REO has been principally developed country focused. EWB chapters have been established on several campuses, including—as an example—Duke University. EWB brings not only its own thrusts, but serves as a coordinating body for several other organizations with more narrow focus for their services. EWB is not the only option for establishing these linkages. These student chapters help provide a focus on the needs of developing countries on the campus and contacts for students to find career choices to continue their contribution to the needs of developing countries.

Regular communication efforts in symposia or conferences, coordinated across all colleges with developing country interest would be beneficial. In 2004, Professor Walter Bradley stewarded Baylor’s “Symposium on Science and Appropriate Technology for Developing Countries” as “a first step toward formation of a center for appropriate technologies for developing countries at Baylor to design strategies for boosting economies of developing countries.” In the next month, Lipscomb University and Engineering Ministries International (eMi) are convening the first Christian Design Professionals Conference. Sustained and coordinated efforts like these could help to bring before a broader spectrum of engineering students the career opportunities possible in delivering appropriate technology to developing countries.

Senior Projects for developing countries often have only tentative success because they lack post-graduation continuing efforts to deploy their results to developing countries. This challenge is two-fold:
first, financing the escalating expenses that come with further development and deployment, and, second, marshalling the resources for deployment. In both of the past amaranth projects (and in the future amaranth project) these challenges have been addressed and the projects progressed toward successful deployment. Baylor is an example of an institution that has addressed these issues; the first issue is addressed through a graduate program and the second by forming a non-profit. Baylor has had an “Engineers with a Mission” group since the around 2004. Recently, this chapter expanded to “Global Appropriate Technology Ministries” to serve as a non-profit engineering consulting agency for foreign mission projects around the world,” stewarded by Brian Thomas, senior lecturer of electrical and computer engineering, who acts as the faculty adviser to Engineers with a Mission.

A 4-year institution like Calvin College is missing the graduate linkage needed to deploy this solution. However, Calvin College has formed an Entrepreneurship Center, which has as one of its goals to advance the development and deployment of technology that evolves from such campus activities as Engineering’s Senior Design Projects. The Entrepreneurship Center arose from a broader effort within Engineering at Calvin College to improve the entrepreneurial climate at Calvin College. This effort also encourages students to think about their developments as potential business opportunities either within existing companies or through startup businesses.

**Going Forward**

Looking at one pair of senior design projects for amaranth processing in developing countries and the career decisions made by the engineering students, the result was none of the nine students moved from school to careers serving the needs of developing countries. All were good candidates for engineering careers serving developing countries. Several steps can be taken to influence students toward careers that serve the needs of developing countries:

- Develop and maintain vigorous student groups or chapters on engineering campuses which
  - focus on projects for developing countries, and
  - arrange for speakers and seminars on engineering issues for developing countries,
- Generate regular, coordinated symposia and conferences which focus on various issues related to engineering for developing countries, including
  - Needs and priorities for projects,
  - Professional achievement awards,
  - Keys for success of engineering projects in schools,
  - Student chapters or groups, and
  - Student team competitions.
- Instill into the engineering program avenues to promote successfully engineering projects beyond the scope of the senior engineering design project.

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**References**

can be found at http://business.rutgers.edu/files/farriscvseotember2008.pdf. George Farris is a graduate of the study group that produced the famous Pelz and Andrews’ *Scientists in Organizations*.

[7] See http://ewb.pratt.duke.edu/?page_id=2 (accessed May 2009); EWB-Duke was started in 2005, has over 70 members (at last report), and incorporates members from UNC-Chapel Hill.  