2011

A Catholic and Marianist Engineering Education

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Chapter Three

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The School of Engineering at the University of Dayton (UD), a Catholic and Marianist University, boasts large enrollments of 1,300 undergraduate and 350 graduate students out of a total of 7,000 undergraduates and 3,000 graduate students. It also boasts a faculty very active in research, which, under the umbrella of the University of Dayton Research Institute, is funded at a level of $100 million per year. In our region, we are looked at as one of the premier engineering programs in terms of the quality of the graduates we produce.

In the last decade, the University of Dayton has sought to better articulate the impact of its Catholic and Marianist traditions, and faculty have been challenged to embody these traditions. University mission statements and unit strategic plans have also evolved to make better connections. In this context, our paper explores the historical and present connections to these traditions, and then more importantly presents a vision for better integration of them into the education of our students. The visioning really represents an early foray into thinking about greater embodiment of mission into the engineering education at Catholic universities. Finally, we envision what a specific application of the principles to a course in thermodynamics would look like and consider extension to all engineering courses.

WHAT HAS CATHOLIC AND MARIANIST MEANT IN THE PAST?

Engineering found its foothold at the University of Dayton in the early 1900s, with the establishment of the Departments of Chemical and Electrical Engineering in 1911 and Mechanical and Civil Engineering in 1914. This addition was relatively early for Catholic universities, owing to the desire of the Marianists to provide "practical" education to the Dayton region, which was already well on its way to becoming a vibrant technology center. But, in its inception, there was a bifurcation of Catholic identity and the technical training provided to engineers. For example, in the 1914 University of Dayton catalog, twenty-two periods of class (forty-five minutes each) per week were required. These included a 1½ hour course per week in Christian Doctrine that was taught only by vowed religious. In a four-year sequence, this course was sequentially focused on Catholic morals, Catholic dogma, apologetics, and rational theology. The only other non-engineering courses required were mathematics, sciences, English, German, and French. According to our most senior alumni, Catholic was the domain of the theology education our students received.

This curricular scenario changed little through the 1950s. To be fair, however, the "helping" environment created by the Marianist educators did influence the teaching of the lay faculty to create a student-centered and nurturing educational environment. In the 1960s, the University of Dayton, like other Catholic universities, sought to flex its intellectual muscles relative to secular universities. Thus, there was greater pressure to achieve success in engineering relative to the same metrics of success employed by secular universities.[1] The formation of the University of Dayton Research Institute, fundamentally connected to the School of Engineering, in response to Wright-Patterson Air Force Base's desire to contract out research services, is illustrative of the university's response to this pressure. Further, the university established a Ph.D. program in 1973 because the Ph.D. was said to represent "the highest recognition of scholarly achievement."[2]

Vatican II may have also led to substantive changes that affected the education of Dayton's engineering students. The introductory section of the 1973–74 Bulletin rarely spoke of Catholic and Marianist traditions, and instead emphasized "varied religious, social, and cultural opportunities," and described UD as a "church-related institution of higher learning, where academic freedom was sought." Such language conveys a strong sense that the university was not sufficiently attending to its Catholic and Marianist heritage.

The University of Dayton apparently was not unique. As described by Phillip Gleason, during this time Catholic universities appeared to have lost sight of their identity.[3] At the same time, the number of vowed religious experienced a dramatic decline. Increasingly, church organization and university administration shifted to lay leadership. Yet in the initial years after Vatican II, short of the continuing caring and nurturing environment created by the faculty in engineering, Catholic and Marianist mission continued to remain the responsibility of the dwindling numbers of vowed religious.[4]

In the 1980s, the educational "heart" of the University of Dayton was defined to be the humanities, and a new, more integrated general education program was established. In its development, as described through conversations with its developers, only a slight Catholic and Marianist filter was applied, seen primarily in the creation of a Humanities Base curriculum, for which the organizing question was "What does it mean to be human?" Still in existence, the curriculum more explicitly integrates Catholic and Marianist themes.

As documented by David O'Brien, the 1980s and '90s saw a fervent attempt by Catholic universities to define themselves more clearly.[5] The University of Dayton's articulation of this rejuvenation was its Vision 2005 document in the mid-1990s, which was described as a roadmap for transforming all elements of the University of Dayton through a pattern of lay ownership of mission. Faculty in the professional schools were then challenged to think about how they might connect to this mission. But it did not immediately happen. For example, the

1997 School of Engineering response to the Vision 2005 document envisioned primarily an improved scholarly reputation relative to secular universities, primarily calling for more resources in support of graduate students. This request was dismissed as being unrealistic by then President Raymond Fitz, S.M.

Since 1997, however, there have been profound changes. Our students' and recent alumni understanding and commitment to ethical behavior in a national survey instrument used for assessment is number one in the US. Further, after our ABET (Accreditation Board of Engineering and Technology) accreditation visit in the fall of 2004, the ABET team lead who was finishing twenty-five years of service with ABET, in closing with our dean's staff, said with tears in his eyes that he and his team "had been blessed by the warmth of our students, faculty, and staff, and by the deep commitment to educating our students." The mechanical engineering program evaluator, with whom we primarily interacted, a committed Catholic at a small state college, likewise offered, "It was nice to see a university with stated values that are lived." Within this context, this chapter discusses the ways in which engineering education at the University of Dayton has evolved and might continue to evolve to embrace its Catholic and Marianist traditions.

WHAT DOES CATHOLIC AND MARIANIST MEAN NOW?

Until the relevance to the curriculum of being Catholic and Marianist could be established, it was impossible to envision how the engineering curriculum might be influenced by this mission. Through the early 1990s, this was the case. While one could honestly say that there was something different here, that difference was hard to describe even for some of the vowed Marianists. In 1996, significant effort was invested into the creation of a document describing the characteristics of Marianist Universities.[6] The resulting publication was a collaborative effort between the three Marianist universities in the United States (University of Dayton, Chaminade University, and St. Mary's University). Five characteristic elements of the Marianist approach to education were identified, including:

- educate for formation in faith
- provide an integral quality education
- education in family spirit
- educate for service, justice, and peace
- educate for adaptation and change

The implicit impact of these on education was detailed in the document. Education for formation in faith means that the Catholic character of the university is vital and helps to produce distinctive graduates. It also means that both faith and reason are emphasized and that faith must be in dialogue with and in service to culture. By an integral quality education, education of the whole person is implicit, as is the search for knowledge. Education is also seen as not simply the domain of the classroom, but of the whole of the experience. Education in family spirit starts with a climate of acceptance, and a recognition of the importance of building community both within and outside of the university. Education for service, justice, and peace stresses an almost vocational perspective for work and particular concern for the poor and marginalized. These elements are not seen as separate from the curriculum. Finally, relative to education for adaptation and change, there is a call for education that envisions changes to culture and adapts accordingly, prepares graduates to live in a pluralistic society, and develops critical thinking skills in the search for truth.

As far as what is meant by Catholic, there is much variation of opinion. What is consistent among all Catholic institutions is service to the community—local, regional, and global.[7] The constitution of the communities served and the nature of the learning from such experiences is of course varied. In terms of education and scholarship, there is also wide variation. For example, Franciscan University of Steubenville, Ohio requires a strict adherence to a distinctively conservative Catholic teaching in all areas of college life. However, this strict adherence to a certain form of religiously affiliated education may arguably stifle the development of critical thinking. Further, such a model may not fare well using success metrics employed by secular universities.

Others have suggested broader interpretations of a Catholic university that permit distinctiveness relative to secular institutions, while at the same time offering a competitive product relative to academic/professional as well as public/government organizations.[8] For engineers graduating from Catholic universities, "a competitive product" means simply that, beyond preparation in accordance with the mission of the institution, they must be both employable and prepared for advanced study within and outside of their profession. Catholic universities that have striven for rich scholarship have argued that the search for knowledge in itself is good, as all knowledge is a revelation of God.[9] Such a pedagogy fosters acceptance of disciplinary separation and national success according to metrics used by secular institutions that reward demonstration of disciplinary expertise. Others have suggested the establishment of Catholic studies or Catholic intellectual tradition studies for all students,[10] going beyond the typically nonintellectually based campus ministry activities. James Heft, S.M., has further advocated for incorporation of the Catholic intellectual tradition into the research and teaching of all disciplines.[11] Along these same lines, historian James Turner suggests that "Catholic colleges have seldom encouraged their students to think seriously and flexibly about their faith."[12] David O'Brien offers that Catholic education should educate to create *disciples and citizens*.[13] Graduates would then be filled with a sense of religious inspiration to serve the world positively. Finally, Patrick Byrne has posited that a vocational exploration should be part and parcel of the education of students (and faculty) in all disciplines.[14]

A Catholic education encourages commitment to a few basic principles. First, it emphasizes a reliance of faith and reason. This implies that knowing is not simply logical and intuitive. Thomas Groome has suggested that this commitment also implies that a humanizing education is an "aspect of the work of our salvation."[15] It can also have a love-based and intuitive component. For engineers, this linkage between faith and reason would translate to "passion" behind the profession, to the *why* for being an engineer, encouraging an education that inspires students to view their profession as a service to the common good.

A Catholic education also recognizes the dignity of each person. For engineers, such an education would require consideration of the effects their labor has on the whole of society and would implicitly define the relationships they ought to have with colleagues and clients. As Groome suggests, Catholicity is an inclusive concern.[16]

Third, a Catholic education recognizes the sacramentality of creation. For engineers, this facet of education inevitably leads to a commitment toward protecting the gifts of creation. Sustainability, as an integral philosophy for engineering, seems a likely end-goal of this vision of sacramentality. As Thomas Landy describes, sustainability, since it focuses primarily on human, social goods, stresses a "responsibility and a greater sense of common good, and relies on stewardship more than on boundaries between humans and nature."[17]

Fourth, a Catholic education recognizes the unity of knowledge. From a professional school standpoint, this would place importance both on establishing an environment that provides students with breadth of knowledge and on connecting such knowledge.

Finally, Catholic education considers that both scripture and tradition are important. While scripture may reveal fundamental underlying truths, tradition recognizes their meaning in different periods of history. Relative to engineering, faculty generally have little understanding of both the history of the specialized knowledge they teach and the history of engineering in practice. Engineering for the world involves continuous *feedback loops*. We design, we make, we learn, we redesign. We design, we make, we change society, and we redesign. Rarely does engineering education provide even a glimpse of these feedback loops or a glimpse of the amazing impacts—not all of which are positive—of our efforts to either engineering or non-engineering students.

Collectively then, as we see it, the theological educational impacts of our Catholic and Marianist traditions applied to engineering would at least include the following elements:

- developing and living the passion for the profession (the faith behind the reason)
- integration of knowledge and problem solving across disciplinary boundaries (unity of knowledge)
- building and educating for community (educate in the family spirit)

- working as servant leaders striving for justice within and outside of profession
- a focus on sustainable engineering practices (sacramentality of creation)
- preparing for adaptation and change

It is interesting to note that none of these educational outcomes is included in outcomes required by ABET. While ABET includes outcomes related to multidisciplinary teamwork, continuous learning, knowledge of the social and cultural environment in which engineers work, and ethical understanding, such outcomes are pale reflections of those described above.

THE GOALS OF A CATHOLIC ENGINEERING EDUCATION

Developing and Living a Passion for the Profession of Engineering

As the Catholic and Marianist voice has gained strength, there have been numerous faculty development activities aimed at helping them gain familiarity with these traditions. A number of engineering faculty have participated in seminars on Religion and Ethics in the Professions. Further, in the past five years, our annual School of Engineering faculty meeting has routinely asked faculty to talk about the ramifications of the terms "Catholic" and "Marianist" on our mission in engineering. Finally, our 2005 Strategic Plan offers a very connected vision to the mission defined by our religious traditions. In addition, many (not all) department heads have participated in retreats focused on "hiring for mission," and many have since been working on bringing in new faculty who choose the University of Dayton because of the opportunity to connect their passion to our mission. It is exciting also that we are now rethinking our School of Engineering promotion and tenure document to officially credit our faculty for connecting to mission.

With respect to students, we have found that many, if not a majority of our students are seeking to find deeper meaning in their profession. In our mechanical engineering program, from our Introduction to Mechanical Engineering course to our junior/senior seminars and capstone design courses, students are reminded of the "greater good" role of their profession. Such connection is made primarily by applying engineering problems to societal context. While not all accept this role, those who seek to learn more can do so through mentoring from faculty who they recognize as more connected to our religious traditions. Truthfully, at present, the primary means by which students are able to connect their passion with their professional identity is through this mentoring.

Integration of Knowledge and Problem Solving across Disciplinary Boundaries

The Catholic notion of unity of knowledge, which derives from the belief that all things come from God and thus all knowledge represents a special revelation from God, embodies the importance of learning across disciplines. We have examples of such integration, but not nearly to the degree that it could be. Our EGR 103—Engineering Innovation I course routinely asks students to think of the connection between a product they are "inventing" and its impact on society (market) and ethics.[18] In recent semesters, our junior/senior capstone design courses have been completely integrated. Civil, computer, electrical, and mechanical engineering students (and others) routinely team on industrial sponsored projects, bringing with them the expertise from their respective disciplines. In the context of these courses, the design teams are required to consider seriously marketing, social, cultural, ethical, and environmental impacts and influences. A design decision analysis is used to evaluate variable designs from these perspectives and ultimately to help pick the best design.[19]

A second means for integration has been through the context in which the knowledge learned in a course may be applied. We offer only two brief examples of what this might mean. Our EGR 202—Engineering Thermodynamics course has involved students in the development of new hybrid energy automobiles with energy harvesting of the waste heat for productive use, the design of solar driven steam power generation systems, and the design of a net-zero energy residence over the past few years. In doing so, their grasp of thermodynamics was improved, but moreover their vision of the need to work on and solve problems aimed at improving energy effectiveness in society was expanded. Some students later indicated that the project helped them for the first time to connect their heart to engineering. Our MEE 312L—Materials course for several years has involved all mechanical engineering students in a project oriented to the evaluation of building materials for cheap, cleaner, and more efficient wood stoves in the developing world. As an introduction to this project, students are presented an orientation to the culture and needs of the poor in the developing world. Ideally then, they are asked to connect engineering knowledge, cultural knowledge, and Catholic social justice ideas.

Outside of engineering, we require our students to take a three-course cluster in themes related to: values, technology, and society; women and culture; cross-cultural, Marianist thought; and the Catholic intellectual tradition, among others. For a cluster, students must take three courses connected by the theme from different domains of knowledge (such as religion, philosophy, history, social science, or the arts). These clusters ideally help students connect knowledge across disciplines. Unfortunately, these clusters have not been looked at fondly by our students. However, there have been some recent experiments of connected engineering/humanities courses that have succeeded. A Civil Engineering/Arts faculty–created course called Constructing Civilization has been well received. In the 2004–2005 academic year, engineering faculty teamed with faculty from religion, science, social science, and business on a course focused on the issue of global warming. Presently, engineering faculty are involved in two multidisciplinary course developments. First is an initiative focused on the theme of Perspectives of Cities. This multidisciplinary initiative involves faculty from engineering, business, social science, the humanities, and our Center for Leadership in Community. This cluster incorporates five courses, each involving multidisciplinary teaching and all seeking to draw connections between the disciplines. It is particularly exciting that engineering is involved in this initiative. Second, is an initiative entitled By Design. This course, to be team taught by engineering and religious studies faculty members, utilizes the design process to evaluate problems in engineering ethics. Both of these latter two initiatives include capstone design projects, requiring connection of knowledge across disciplines and oriented toward some notion of the common good.

A final exceptional example of curriculum related to the unity of knowledge is our junior/senior Professional Development seminar. This seminar exposes students to professional job opportunities, international influences, leadership and teamwork, professional service obligations, and a variety of non-engineering influences on one's career.

While many other examples exist, the truth is that our curriculum still tends to be silo oriented—with separate classes and separate learning experiences. Further, there has been little thought about the developmental path of our students and the connectedness between the different years in the curriculum.

Building and Educating for Community

Among faculty, community building requires faculty who can cross the boundaries existing between the School of Engineering and the rest of the university. We believe that the interaction between our faculty and those outside of engineering is very unusual. In the department of Mechanical and Aerospace Engineering, almost all of our faculty have been involved in institutional curriculum development, academic governance, learning and living, and more. Our New Faculty Orientation Program offers new faculty an early opportunity to do this as well. Further, all new engineering faculty are asked to be involved in a year-long multidisciplinary Teaching Fellows program in their first few years to help them both to learn of various teaching approaches and to meet colleagues outside of engineering. In the past five years, four engineering faculty have also been part of a Humanities Fellows Program which asks for a partnership between an engineering faculty and a humanities faculty, usually in the development and teaching of a multidisciplinary course. Over the same time span, we have had more than a handful of faculty involved in the Catholic Intellectual Tradition Group and four seminars in Religion and Ethics in the Professions/Engineering. Finally, we have a Leadership Development Program that engages future faculty leaders across campus in leadership training from a distinctly Catholic and Marianist perspective. One faculty member from engineering is selected to participate yearly.

With respect to student community, many of our undergraduate students choose UD because of their perception of a strong community here. To create this environment, the university works very hard to get this started well. Our New Student Orientation Program begins the orientation process well before students arrive on campus using a virtual environment and continues with residential life faculty through their first semester on campus.

At a department level, community is also encouraged in all courses. For example, in our MEE 101—Introduction to Mechanical Engineering course, students are reminded of the importance of community and particularly of the importance of teamwork in terms of academic success and in terms of gaining employment downstream. Not surprisingly, employers recruiting our students routinely acknowledge our students' proficiency in teaming and communication.

But the most important aspect of student community is the involvement of students in extracurricular activities. Almost all of our students are involved in service, not because they are required to do so or because employers consider it positively, but because they believe it is important. A strong community among students is also reflected in strong professional student organizations. For example, our American Society of Mechanical Engineers student section has been rated number one in our region in all but two years since 1985, and consistently earned a top three ranking internationally. This merely is representative of the degree of involvement of our students. Our student chapters of professional organizations (including AIAA, AICHE, ASCE, SAMPE, and SAE) also have impressive records in national competitions. Additionally, we have a unique student organization called ETHOS—Engineers in Technical Humanitarian Opportunities for Service Learning. This organization was started by students and connects both to an international internship program in developing countries and local service-learning activities. Finally, engineering students founded the University of Dayton Sustainability Club, which has focused on and succeeded in moving the University of Dayton to more sustainable working and living practices.

At the graduate level, until 2008 there was little noticeable effort to establish community. Since then our Graduate School has been hosting social events. In addition, the establishment of a new masters-degree granting Program in Renewable and Clean Energy in 2009, with a driving, societally connected theme, has provided strong leverage for community development among at least the students now enrolled in this program (currently forty-five). This is an area that still requires improvement.

Community building requires that the boundaries between groups be minimized. Between faculty and students we promote an "open-door" policy, meaning that if students have questions of their faculty, they are encouraged to visit with her or him. In general, this policy is enacted, although the proliferation of e-mail has probably reduced class-related visits by students. Further, a majority of our faculty take very seriously their student advising. In this role, faculty are not merely there to make sure students check the boxes with respect to their degree requirements (we in fact do serve this role), but they are also looking to help students maximize their education and to help them move along paths that best prepare them for life and career goals.

Working as Servant Leaders Striving for Justice Within and Outside of Profession

The importance of educating engineers to understand fully the relevance of issues associated with social justice has become increasingly important as the engineering profession becomes more global. Many engineering schools, including the University of Dayton, have incorporated service learning into their curriculum to best address this theme. Some examples of this are the EPICS® program started at Purdue University and Engineers Without Borders started by Bernard Amadei of the University of Colorado–Boulder. Incorporating service learning into the engineering curriculum has been found to help students develop both technical and nontechnical skills, make connections between classes, develop racial and cultural sensitivity, enhance their commitment to civic responsibility, increase their ethical awareness and awareness of the impact of professional decisions on society and the environment, and see the human side of engineering.[20]

Two prominent manifestations of service learning stand out at the University of Dayton. In our New Engineer Program, a program focusing on the development of first-year students, students solicit as donations used bikes, provide the needed repairs, and ultimately deliver both bike and safety lessons to children from the Dayton community who have no bikes. The second example is our ETHOS program. This program has two main goals. One is to provide full-summer engineering service learning internships in Africa, Asia, and Latin and South America for cottage industries working to help the poor meet basic needs. The other is to contribute to the organizations being served, through first listening in order to assess needs and then acting to meet needs—and explicitly rejecting an approach of telling them what they need. Now, thirty to forty-five students travel internationally working on service projects. These experiences are truly life-changing, and have led to projects that have been integrated into our curriculum. The Materials Laboratory projects referred to earlier are the best example of these.

Faculty must also be models of servant leadership. This is most evident through mission consistent research. At least within our department, that of mechanical and aerospace engineering, much of our research falls under the umbrella of sustainable engineering. This research includes:

- Research and development of cost-effective net zero energy homes
- Industrial energy and waste management optimization
- Energy harvesting of waste heat from aircraft, automobiles, and other sources
- Development of cleaner fuels and more efficient combustors and for aircraft vehicles

Sustainable Engineering Education

The ideal of sustainable engineering education is really embodied in the previous three categories. Sustainability refers to a means of living and practice that insures that future generations can live similarly with resources that are not diminished. As we have perhaps reached the peak for cheap oil, this ideal is not merely an ideal, but a necessity for the future well-being of society. We now offer courses related to green building design, hazardous waste clean-up, design for environment, energy and industrial waste management, and renewable energy systems. Ultimately, these offerings led to the establishment of the program in renewable and clean energy, mentioned above. In addition, also described above, a few faculty have addressed sustainability in the context of required courses. Presently, this theme has found a place in a majority of mechanical engineering courses.

Preparing for Adaptation and Change

No graduate will be able to serve unless they have both knowledge of the global world in which we live and some idea of the action-feedback-response characteristics of society. Presently, our engineering graduates do not have a strong understanding of the modern world. They do not have a sound understanding of the social problems they can influence as engineers. They do not understand the social and cultural impact of technology. They do not understand the need to be adaptive and how to adapt. Instead, they are accustomed to being supplied the knowledge they need. In their engineering courses in particular, they are rarely challenged to be critics of their own solutions or those of others.

MEETING THE GOALS OF A CATHOLIC AND MARIANIST CURRICULUM

Anthony Bright and Clive Dym recently discussed the evolution of engineering education in the United States following the launch of Sputnik in 1957. They suggested that the tenor of the times very much dictated the analytical, science-based approach to engineering education.[21] They asked, "How would engineering education be different today, had the engineering curriculum be posed as a problem in engineering design." Such a design process would require:

- Articulation of properly drawn objectives (What do we want our students to know and do?)
- Articulation of the appropriate and realistic constraints (What restricts our actions?)
- Derivation of the functions that must be performed in order to realize the desired objectives subject to the given constraints (How do we get there?)
- Establishment of the metrics against which the achievement of the objectives can be measured and assessed (How do we know when we have succeeded?)

Bright and Dym further suggest that engineering curricula should be stated as a sum of skills that students are expected to master and a set of experiences in which they will participate. In the past, the focus has been on "What do we want our students to know?" rather than on "What do we want our students to do?"

With this context, we envision an engineering education that achieves distinctiveness through the Catholic and Marianist educational characteristics previously described. A curriculum designed best to address these characteristics must also recognize that constraints exist that may ultimately limit the solution developed, only some of which we consider truly fundamental. But we do not acknowledge constraints placed upon a curriculum by disciplinary silo: in order to achieve our objectives, knowledge silos cannot exist. As such, the following simple and obvious constraints are posed.

(1) Graduates must be employable.
(2) Graduates must be able to complete their education in eight semesters on campus.
(3) Graduates must be prepared to enter graduate school in engineering and other disciplines.
(4) ABET Program requirements must be met.
(5) The delivery of a curriculum to satisfy these objectives must be resource effective.

Constraints 1 and 3 can be addressed through proper consultation with industrial advisory committees and alumni. We certainly believe that if we can more effectively address the engineering implications of Catholic and Marianist theology, then our graduates will indeed be better for both the world and for the companies and organizations hiring our students.

Constraint 2 simply recognizes that the number of credit hours cannot be increased beyond the 132–38 that we presently have. Constraint 4 is easily achievable as ABET now permits universities to more distinctly define what they are.[22] Constraint 5 basically says that at the University of Dayton, in our present environment, we cannot increase the ratio of student credit hours/full-time equivalent faculty. In fact, we have been challenged by our provost to substantially decrease this ratio.

Now that we have identified objectives related to our Catholic and Marianist traditions as well as the constraints under which we must proceed, we can embark on the task of envisioning a functional path for achieving the objectives. The following provides our vision of the foundational basis for developing these objectives in our students throughout our curriculum. This vision is presented to begin the dialogue at the University of Dayton and in Catholic higher education about how to make better connection between engineering education and mission.

Objective 1—*Developing and Living a Passion for the Profession of Engineering*

While a passion for engineering may be present among some faculty, staff, and students, we do not uniformly address this characteristic of our educational goals. We believe that the model of developing a vocational commitment to profession, as provided by our Lilly Foundation–sponsored Program for Christian Leadership, offers a means to achieve this goal, among students, faculty, and staff. This program relies upon education and retreats to offer students knowledge of Catholic Church thinking about vocation. It also provides a forum for personal reflection and sharing, thereby permitting the "heart" to enter into the reason to pursue a profession. Interested faculty and staff could certainly be included in similar programs.

The context of problems in engineering courses is also an important factor in achieving this objective. When the context connects to common-good issues associated with safety and environment and truly helping all in society through the technology we develop, the passion for profession to serve the common good can be nurtured.

In the end, however, there must be a place for vocationally inspired students, faculty, and staff to work. Among students, it is important to help make them aware of the post-degree professional opportunities that best connect to their passion. We must help them to discern which companies and organizations have the value systems that best fit their passion and then provide advice about how to get there. To accomplish this, we should develop career design mentoring opportunities to formalize student thinking in this regard, so that, when they graduate, they have an idea of what they want in their career and how to get there. Moreover, we should work diligently to attract particularly these types of companies and organizations to recruit our students.[23] Among faculty, there must be forums for presenting research/teaching which is inspired by this passion for engineering. Perhaps the establishment of journals which address research crossing disciplinary boundaries and related to helping to support the common good is a necessity.

Objective 2—*Integration of Knowledge and Problem Solving across Disciplinary Boundaries*

The ability to integrate knowledge across disciplinary boundaries arguably is the most important. All other objectives defined build from this one. In order to achieve this objective in our graduates, six functional paths are envisioned to achieve this goal.

First, we need to look at the whole of our curriculum from a developmental perspective. If we say that we want students to develop with respect to the engineering applications of our Catholic and Marianist traditions, then we must continually reinforce this development. Knowledge learned early in the curriculum, both technical and general, should be repeatedly built upon in subsequent courses.

Second, we must have our students learn and solve problems across the curriculum. Most importantly, this objective requires that the learning experience of our students should be pervasive through our engineering courses. Our engineering faculty need to be fully cognizant of the "big picture" goals of the learning that our students are to take away from that part of their education that falls outside of engineering. These big picture goals, which are now more strongly connected to Catholic and Marianist traditions as a result of the recent Marianist Education Working Group initiative, are referred to and reinforced in the engineering curriculum. Faculty development activities certainly will be needed to get our faculty up to speed with respect to these goals and then to provide guidance about how these might be addressed in engineering courses. Examples created by early adopters will undoubtedly be helpful. As described shortly, design may be the best vehicle for delivering on this objective.

Third, engineering faculty need to be far more involved in shaping the general education of all students. Dr. Shirley Jackson, President of Rensalaer Polytechnic University, recently spoke about the lost connection between the "liberal arts" and the "arts" (and humanities). In its inception, she notes, a liberal education included the quadrivium—namely, arithmetic, geometry, astronomy, and music. Later it included the basic sciences of the day, with emphasis on mathematics. Dr. Jackson concludes that: (1) liberal education has generally lost a linkage to the sciences and mathematics, and (2) it has not remained adaptive. Technology, she says, dominates our society, yet most liberally educated people know little about its function and influence on society. Rather than simply offering technology literacy courses for non-engineers, we also need to recognize that engineering notions of system dynamics, feedback, systems, and design have relevance to the general education of all students. Now is the time to begin thinking about educating our populace about the importance and impact of technology in society. Engineering faculty (and students) need to be active players in helping to further shape this education.

Fourth, engineering design—the glue which pulls an engineering education together—must be in everything, and not just in engineering. Clive Dym of Harvey Mudd College has emphasized the place for design in a true liberal education.[24] Dym further suggests that when we rethink engineering education in terms of both knowledge and doing, then design must be everywhere. Learning without applying to new problems helps develop engineers who really do not understand the knowledge we wish them to learn. As Billy Koen has suggested in his book defining engineering, *Discussion of the Method,* engineering is not simply the collection of knowledge, but is the art of solving problems using heuristics that are only occasionally physics and mathematics based.[25] Design activities integrated throughout the curriculum permit development in regard to heuristics of all types (for example, design process, dialogue, persuasive skills, defining *best,* and a host of others).

In a Catholic and Marianist context, design provides the best vehicle for problem solving that relies upon both traditional physics-based engineering knowledge and knowledge normally considered outside of the engineering discipline. The context of the design problems must inevitably ask students to consider obvious common good issues such as environment and safety, but it must also force them to at times ask "If this design is successful, how might it change society? Do I believe in this change? Does the design help the poor or does it further disenfranchise them? Does the design enrich life or will it push more materialism on society?" An engineering faculty truly knowledgeable of the general education "big picture" goals can remind students to consider these and other questions in the context of developing designs.

As much as possible, these design projects must ask students to think about community building among their team and with affected constituencies. They should at least at times ask our students to interact with people who are not the same as themselves. They must work with non-engineering students, industry sponsors, and community organizations. True multidisciplinary experiences will permit students to learn the value of knowledge outside of their discipline in their problem solving.

Design should also be present in the general experience of our students. As a great example, Worcester Polytechnic University students are required to complete a capstone project in the humanities and a project addressing an issue related to technology and society, in addition to an in-major design project.

Fifth, we need to ask students to both identify and solve problems in which they pull together knowledge from multiple disciplines. Problem identification is one of the most important aspects of engineering in professional practice, yet one of the least addressed in universities. Most problems given to students are laid out neatly for them. Even our industrial sponsored design projects begin with a needs statement from the sponsor.

We envision at least two paths for achieving this objective among our students.

- Even when problems are neatly laid out for students, students must be continuously challenged to consider and imagine difficulties inherent to the problem formation. To do this right, they must consider the broader dimensions of problems. They need to be able to say, "OK, we've been asked to solve this problem, but in doing so we will be ignoring issues that likely are important to the development of a better solution." After such analysis, they need to imagine how to frame the problem more holistically and then solve based upon their more holistic definition.
- At the completion of a problem or design, students must be critical evaluators of their solution(s). They must again be challenged to identify problems with their solutions and offer recommendations for solution improvements. They should also learn to be critics of their faculty and their peers, but in a positive, loving sense. We need to help our students gain comfort in sharing and receiving criticism in respectful dialogue with their peers.

Sixth, we need to rethink boundaries between our engineering courses and the rest of the curriculum. Harvey Mudd College, for example, does not produce mechanical, electrical, civil, computer, or chemical engineers. They develop *general* engineers who may have a slight focus in a particular area. But, in general, they have structured their curriculum to emphasize the commonality between disciplines. We have developed an *engineering core* that would provide a common experience for all engineering students through the first two years. Do not all engineers need to understand system dynamics and feedback control systems? If yes, then do we really need each engineering program to address this subject separately? Are there not processes and practices that all engineers do?

As importantly, we need to ask, "Can there be a Catholic engineering thermodynamics?" Mike Sain, an electrical engineering professor at the University of Notre Dame, and Barbara Sain, an assistant professor in theology at St. Thomas University, recently developed a course at Notre Dame drawing analogies between Catholic theology and feedback control systems. In so doing, they learned that such a course offered at least two benefits. One, it helped connect engineering thinking and visualization to the discernment/decision-making process of moral theology. Second, and perhaps most importantly, it helped the students understand that there could be connections between engineering systems analysis and theological analysis.[26]

Objective 3—*Building and Educating for Community*

Given that a vast majority of engineering students are involved in extracurricular and service activities and that teamwork is included in many of our courses, we must understand that community building education is important. At UD, our Center for Leadership in Community has voiced that for *community building* to occur properly, the following characteristics must be present.

- Respect for each individual and their gifts
- A shared vision of both utilitarian goals of the project and teamwork goals
- Time to nurture the social capital of the communities
- Assessment and adaptability
- Skills at engaging in dialogue and deliberation

The starting point in defining how this might be achieved, both curricularly and extracurricularly, is to first define what we mean by community in a Catholic and Marianist context. At the University of Dayton, our Center for Leadership in Community, led by Richard Ferguson and Raymond Fitz, S.M. (former President of the University of Dayton and a former professor of Electrical Engineering), have engaged in thinking about teamwork (community) and leadership from this perspective. In their paper, "Advancing Justice in the City through

Community Building: Themes and Practice Theories Emerging from the Center for Leadership in Community,"[27] which, while focused on community building relative to service learning in the local community, offers generally applicable insight into community and leadership from a Catholic and Marianist perspective. A number of themes are emphasized. Relative to *community building,* the following characteristics are identified.

- Respect for other individuals or groups is implicit. A Catholic viewpoint lifts up the dignity of the individual within community. Respecting others requires an assessment of the assets that the individual or group brings to a team. Ferguson and Fitz suggest that an "assets mapping" be created at the onset of a project. Through this method, each person must be aware of the strengths and knowledge that others may bring to a process. For example, in engineering team activities, some have suggested the importance of the Meyers-Briggs personality survey as a means to do so.[28]
- There must be a shared vision. The vision may be focused not only on the utilitarian output of a project, but also on where the community (team) envisions itself to be in terms of the type of community they have created during the course of a project.
- Mutuality should exist. Individuals working in a functioning community that recognizes the assets of each individual and group understand that they have something to offer to others and have something to learn from others.
- In the early stages of community development, there should be time to nurture the social capital. Relationships matter! Team building activities have value in connecting the community.
- Communities must be adaptive. There must be a periodic evaluation of the technical goals of a problem and in the process being employed. The periodic evaluation should also permit adaptation of the community functioning itself. A community should always be asking, "Are we working together as well as we might be?"
- In order to properly function, a community must have individuals who have the skill to engage in dialogue and deliberation. These skills have not generally been developed in students.

Objective 4—*Working as Servant Leaders Striving for Justice Within and Outside of Profession*

Like many engineering programs, we have a course in engineering ethics. Ethical commitment is best addressed in the context of what we do as engineers—for example, in the context for problems posed to our students and in the context of design problems. We believe our engineering ethics course would be much more effective if it represented a culminating experience for our senior students. In such a course, seniors would employ the knowledge they had acquired in all aspects of their curriculum and, in most cases, through their summer and co-op engineering experiences.

Service is likewise best addressed in the context of problem solving. Service learning experiences in and outside of the engineering curriculum is essential. In addition, our professional development seminars need to more strongly emphasize the obligation to service in our profession. Robert Greenleaf in his very influential 1973 book *Servant as Leader* provided the following definition of a servant leader.

> The servant-leader is servant first. . . . It begins with the natural feeling that one wants to serve, to serve first. Then conscious choice brings one to aspire to lead. . . . The best test, and difficult to administer, is: do those served grow as persons; do they, while being served, become healthier, wiser, freer, more autonomous, more likely themselves to become servants?[29]

These questions also help to provide a metric for assessing the servant leadership abilities of our students.

Further, this type of leadership builds upon the community characteristics described in the previous section with another distinctive feature: leaders must balance inquiry and advocacy to achieve the best solution. This type of leadership understands the importance of facilitating understanding rather than simply winning an argument. Ferguson and Fitz offer further insight about advocacy and inquiry. They say,

> Productive advocacy reveals one's thinking behind points of view and offers examples. Likewise, productive inquiry explores others'

> thinking or assumptions and suspends judgment until these are considered. The willingness to engage others' ideas with a sincere desire to understand their points of view is, in our experience, an essential community building skill. Such active listening requires most of us to suspend judgment long enough to listen fully to ideas, explanations, and underlying convictions.[30]

There must also be education about and opportunities to practice servant leadership throughout the curriculum.

Objective 5—*Sustainable Engineering Education*

Sustainability connects to everything we do in educating engineers. It relates to our use of materials, manufacturing, traffic, construction, energy and transport, and design. Sustainability should be a theme integrated into all of our engineering courses, primarily through context. It should also be present in the common educational experiences. Finally, it should be present in our living and working environments. Catholic universities should be leaders in campus energy efficiency and ecological action, not second-class citizens relative to public universities.

Objective 6—*Preparing for Adaptation and Change*

Preparing students to be adaptive requires first that students should better understand the context of the world in which they will work, and particularly those social justice issues relevant to their practice as engineers. Students must particularly understand the impact of their profession on the world today, on all world communities—and particularly the poor and marginalized. Relative to the functioning of the world, students must learn the connection of feedback, action, and change. It also means that we must ask students to at times both learn their discipline and influencing disciplines on their own. Adaptation cannot occur without continuous learning. We do a grave disservice to our students by always providing them the knowledge they need to solve problems. Our students must be both active identifiers of the learning they need and active learners of the knowledge (from multiple disciplines).

Next, design projects throughout the curriculum should be used to provide practice for our students to consider larger issues in their problems. Problems must be posed that require development of potential solutions for a rapidly changing global environment. Students must ask questions such as, "What if oil prices double? How will that affect the solution?"

Moreover, students should learn that design represents an iterative process. Students must be asked to evaluate continuously their solutions and alter and upgrade their ideas as they learn more and as they assess their ideas. They must also continuously assess the processes they are using.

CAN THERE BE A CATHOLIC THERMODYNAMICS?

At the conference panel session led by Father James Heft, describing the most recent incarnation of a seminar on Religion and Ethics in Engineering at the University of Dayton, Brad Duncan, a colleague, friend, and faculty member in the Electrical Engineering Department, offered thoughtful and articulate reflections on the seminar. He further described that the culmination of his participation in the seminar would be an assessment of the degree of embodiment of Catholic and Marianist traditions by engineering faculty at UD. In describing the research he was doing, he acknowledged that while the educational implications of our traditions were important, there could not be a Catholic thermodynamics or circuits. Of course, he was right. Sure, he was right.

This comment, however, has percolated since then. If the characteristics describing the Catholic and Marianist traditions as applied to engineering had true meaning, then it seemed logical to believe that there could indeed be a Catholic thermodynamics course.

If such a course could exist, what would it be?

A Catholic thermodynamics course would minimally rely upon context in problems and projects to draw in common good issues. Addressing these issues could inevitably fuel the search for a passion in the profession. It could also provide a forum for community building in team activities. These we had already imagined.

But other thoughts emerged. The course described above, created by Mike Sain and Barbara Sain, a course that used analogy to draw connections between concepts in theology and engineering feedback and controls, in our opinion, was brilliant. Analogy, we reasoned, could be used to draw connection from engineering to all knowledge and particularly to theology, history, philosophy, economics, and the social sciences, and in a variety of ways. Thermodynamics deals with the identification of systems and the tracking of flows of mass, energy, and entropy into and out of systems. The most difficult aspect of this course for engineering students is associated with identifying the system needed to solve a problem. The greatest harm we do as educators to students is by posing problems where the selection of the system is easy, where the linkages to the world are incorrectly filtered from the problem. Analogy to all of these other disciplines, where systems for analysis are routinely identified, often with much difficulty, could readily be used to help engineering students gain a better sense of how to draw their system boundaries for properly posed engineering problems, for example, where the choice of the system boundary is not so easily imagined and where there is much extraneous information.

A Catholic thermodynamics course could also bring into question the scientific "laws" that we are using, thereby challenging engineering students to question all that they are learning, a necessary characteristic of critical thinking. Einstein's theory of relativity, for example, has proven that the law associated with conservation of mass is at times untrue. Further, despite Einstein's expressed confidence that the second law of thermodynamics (related to the increasing entropy of the universe) was one rule of science that would never be invalidated, the last ten years have seen a proliferation of research at the nanoscale that have yielded such contradictions. Drawing light to these contradictions will help students see a parallel to the *imprecise* theories of history, social science, theology, and philosophy.

A Catholic thermodynamics course could also show how the laws governing thermodynamics have been applied to fields outside of engineering. For example, the first law of thermodynamics has immediate application to electrical and structural engineering, and the second law has been used to describe biological evolution and economic and social science systems. What opportunities exist in other courses to connect engineering knowledge to other fields of knowledge?

A Catholic thermodynamics course could also be based upon the idea that real engineering problems will never be based only on the energy, entropy, and mass balances of a system. Given real problems, students will need to identify the other flows in and out of the system as well as the external system interactions. As an example, consider a design project that might ask students to improve the efficiency of a particular system. Students must imagine the consequences of that efficiency improvement. While engineers have been doing this since the beginning of the industrial revolution, they have rarely sought to glimpse the impact. Energy efficiency improvements have inevitably reduced product cost, thereby permitting people to buy more things. Energy efficiency improvements have also permitted population growth. Our common good goal of saving energy may have actually fueled increased materialism. This visioning is what was called for by conference keynote speaker John Staudenmaier. He suggested that engineers must think about the ramifications of a successful design in the society in which it will be used.[31] They must inevitably rationalize if such a successful design is indeed what they wish for society.

Another element of a Catholic thermodynamics course would be associated with the pedagogy of learning and knowing. How do we know thermodynamics? How do we know theology or philosophy? An approach used by one of us asks students to develop an intuitive understanding of thermodynamics before a mathematical language is used to describe it. We suspect that there easily could be analogies to learning outside of engineering.

A final element of a Catholic thermodynamics course that we can imagine is associated with the notion of best or ideal. A Carnot efficiency defines the best for thermodynamic systems. Can a parallel to best be drawn to theological, philosophical, social, or political systems? This is probably difficult to imagine when the engineering system analysis only considers energy flows. But what happens to "best" once the system is broadened to include flows of things other than mass, energy, and entropy, which are harder to describe mathematically?

We frankly imagine that each engineering course could be thought of similarly. The notions of design, systems, dynamics, energy, and flow all seem ripe for analogy to knowledge outside of engineering.

The real question then would be, "If we did this, would the education of our students be better?" Would we muddy the engineering concepts so much that they would walk away from the course knowing little of these? Or would they better understand these concepts? Would they truly be able to think more broadly and in a more connected way? Would they in the end be better engineers? While much thinking is required to make such a course a reality, we think it worth a try. In the end, we are confident that the answer to the final question is yes.

NOTES

1. David J. O'Brien, *From the Heart of the American Church: Catholic Higher Education and American Culture* (Maryknoll, NY: Orbis Books, 1994).

2. School of Engineering, Proposal for Ph.D. Program, 1973.

3. Phillip Gleason, "American Catholic Higher Education, 1970–1990: The Ideological Context," in *The Secularization of the Academy*, ed. George Marsden, 234–58 (New York: Oxford University Press, 1992).

4. The 2004–2005 Bulletin is far more explicit in identifying the source of UD's educational heritage. The first sentence gives strong life to the Catholic and Marianist traditions: "The University of Dayton is a private, coeducational school founded and directed by the Society of Mary (the Marianists), a Roman Catholic teaching order."

5. David J. O'Brien, *From the Heart of the American Church*.

6. "Characteristics of Marianist Universities: A Resource Paper," 1999, available at http://www.chaminade.edu/marianists/documents/cmu.pdf.

7. Public universities also serve communities but generally not nearly to the degree of engagement at Catholic universities.

8. O'Brien, *From the Heart of the American Church*, 43.

9. Ibid., 105.

10. David J. O'Brien, "A Catholic Future for Higher Education? The State of the Question?" *A Journal of Inquiry and Practice* 1, no. 1 (Sept. 1997): 49.

11. James L. Heft, S.M., "Ethics and Religion in Professional Education: An Interdisciplinary Seminar," in *Enhancing Religious Identity: Best Practices from Catholic Campuses*, ed. John Wilcox and Irene King, 175–99 (Washington DC: Georgetown University Press, 2000).

12. As quoted in O'Brien, *From the Heart of the American Church*, 170.

13. Ibid., 173.

14. Patrick H. Byrne, "The Vocation of the University and Religious Horizons," in *Proceedings of the Center for Catholic Studies: Religious Horizons and the Vocation of a University*, Seton Hall University (2000).

15. Thomas H. Groome, "What Makes a School Catholic?" in *The Contemporary Catholic School: Context, Identity, and Diversity,* ed. Terence McLaughlin, Joseph O'Keefe, S.J., and Bernadette O'Keeffe, 106–24 (London: Falmer Press, 1996).

16. Groome, "What Makes a School Catholic?" 123.

17. Thomas M. Landy, "Environmentalism and Catholic Social Thought: Some Background, Challenges, and Opportunities," *New Theological Review* 9, no. 2 (May 1996): 20–32.

18. K. P. Hallinan, M. Daniels, and S. Safferman, "Balancing the Technical with Social and Ethical: A New First Year Interdisciplinary Design Course," *Technology and Society,* 20, no. 1 (2001): 4–14.

19. Arguably, ABET requires all programs to address these issues in the context of capstone design experiences. However, a checkbox approach aimed at insuring at least minimal consideration of a given issue, as opposed to an integrated one, is most common.

20. E. Tsang, ed., *Projects that Matter: Concepts and Models for Service Learning in Engineering* (Washington DC: American Association for Higher Education, 1999); J. Duffy "Service Learning in a Variety of Engineering Courses," in *Projects that Matter,* ed.Tsang, 75–88; P. H. Wright, *Introduction to Engineering,* 3rd ed. (New York: John Wiley & Sons, 2003); and G. Eisman, "What I Never Learned in Class: Lessons from Community Based Learning," in *Projects that Matter,* ed. Tsang, 13–26.

21. Anthony Bright and Clive L. Dym, "General Engineering at Harvey Mudd: 1957–2003," Proceedings of the 2004 American Society for Engineering Education, Annual Conference and Exposition, St. Louis, MO.

22. The ABET EC-2000 requirements expect that students will demonstrate at least the following outcomes: (i) an ability to apply math and science; (ii) an ability to identify and solve problems; (iii) an ability to design; (iv) an ability to design and conduct experiments; (v) an understanding of ethics; (vi) an ability to communicate; (vi) an ability to function in teams; (viii) an understanding of the global and cultural fabric in which engineering takes place; (ix) an ability to utilize modern tools; and (x) a commitment to life-long learning. Each university has free reign to identify additional outcomes or expand upon those stated by ABET. For example, our present outcome related to understanding ethics is stated instead as: "Our graduates will demonstrate an understanding of and commitment to ethical practice and service inside and outside of their profession."

23. Already, companies and organizations recruiting our students do so because of their perception of differences in our graduates in terms of teamwork, leadership, and ethical commitment. A deepening of these characteristics can only help further in this regard.

24. Clive Dym, "Learning Engineering: Design, Languages, and Experiences," white paper, Harvey Mudd College, 2003.

25. Billy Koen, *Discussion of the Method: Conducting the Engineer's Approach to Problem Solving* (New York: Oxford University Press, 2003).

26. M. Sain and B. Sain, "A Course in Integration: Faith, Engineering, and Feedback" (paper presented at a conference on the Role of Engineering at Catholic Universities, University of Dayton School of Engineering, Dayton, OH, September 22–24, 2005).

27. Richard Ferguson and Raymond Fitz, "Advancing Justice in the City through Community Building: Themes and Practice Theories Emerging from the Center for Leadership in Community," paper delivered at the Catholic Social Thought Across the Curriculum Conference at the University of St. Thomas in St. Paul, MN, October 23–25, 2003.

28. Robert Stone and Nancy Hubing, "Striking a Balance: Bringing Engineering Disciplines Together for a Senior Design Sequence," *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, American Society for Engineering Education, 2002.

29. Robert Greenleaf, *The Servant as Leader* (Cambridge, MA: Center for Applied Studies, 1973).

30. Ferguson and Fitz, "Advancing Justice."

31. John Staudenmaier, "Elegant Design Not Enough: Embracing the Tangled 'We' to Critique Technology," paper delivered at a conference on the Role of Engineering at Catholic Universities, University of Dayton School of Engineering, Dayton, OH, September 22–24, 2005).