AC 2012-4553: ON A CLIENT-CENTERED, SOPHOMORE DESIGN COURSE SEQUENCE

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Olga Pierrakos is an Associate Professor and founding faculty member in the School of Engineering, which is graduating its inaugural class May 2012, at James Madison University. Pierrakos holds a B.S. in engineering science and mechanics, an M.S. in engineering mechanics, and a Ph.D. in biomedical engineering from Virginia Tech. Her interests in engineering education research center around recruitment and retention, engineering design instruction and methodology, learning through service (NSF EFELTS project), understanding engineering students through the lens of identity theory (NSF BRIGE grant), advancing problem-based learning methodologies (NSF CCLI grant), assessing student learning, and understanding and integrating complex problem solving in undergraduate engineering education (NSF CAREER grant). Her other research interests lie in cardiovascular fluid mechanics, sustainability, and K-12 engineering outreach.

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On a Client-Centered, Sophomore Design Course Sequence

Abstract

Often engineering design instruction based on real-world, client-based projects is relegated to a final year capstone course. Our engineering program, however, emphasizes these real-world, client-based design experiences, and places them throughout our six-course engineering design sequence. Our six-course design sequence begins with a two-course sophomore design sequence that is meant to enable mastery through both directed and non-directed learning and exploration of the design process and design tools. At the sophomore level, we aim to provide students with the foundational knowledge necessary to tackle problem-based learning modules throughout our engineering program. To that end, students work in both small (4-5) and large (10-11) teams to complete a year-long design project. The course project is woven with instruction in design theory and methodology; sustainable engineering design concepts; individual cognitive processes, thinking, and communication skills; decision making; sustainable (environmental, social, economic, and technical) design practices; problem solving; engineering design software; and project management. Students’ overarching task during the first semester is to follow the design process to generate numerous conceptual designs viable to meet the specific user needs. During the second semester, students work to reiterate on the conceptual phase of the design process before prototyping, testing, and refining a design for the client. The project culminates with the students demonstrating their final product to the client, the client’s family, the University, and the local community. Knowing that they will have this public demonstration day seems to motivate the students to succeed.

Our engineering program is currently in its fourth year, and the sophomore engineering design sequence is currently in its third run. In this paper, we will reflect on the lessons learned as we have taught these two courses. A mixed-methods approach, which includes surveys and questionnaires, was used to collect data related to project learning goals, program learning outcomes (which map to ABET a-k criteria), student performance evaluations, and project evaluations. We present the assessment data we have used to inform our course sequence iterations and support the lessons we have learned.

We believe that providing these experiences early and often not only challenges students on multiple dimensions, but also exposes them, and consequently better prepares them, for their eventual role as a practicing engineer. Our goal in this paper is to present our model for integrating real-world, client-based projects into the sophomore year. We do not mean to present our approach as an all or nothing model, but instead, we aim to report on our approach to teaching design as a collection of elements where one or more may be appropriate for another institution.

Introduction

In order for our future engineers to be able to work toward a sustainable future, they must be trained to think flexibly and to be adaptive as it is unlikely that their future will have them working in one domain. They must, instead, be versatilists. Versatilists, as popularized by
Friedman, can “apply depth of skill to a progressively widening scope of situations and experiences, gaining new competencies, building relationships, and assuming new roles,” p. 291

The School of Engineering (SOE) at James Madison University (JMU) has been developed from the ground up to provide this general engineering training with an emphasis on engineering design, systems thinking, and sustainability. Our goal is to train this engineering versatilist. We believe that exposure to engineering design can help students develop their problem solving skills, teach them to better synthesize information, and exercise skills required to integrate and analyze knowledge. Consequently, courses in engineering design represent the spine (bolded courses with a white background in Figure 1) of our integrated engineering curriculum.

Students are first exposed to engineering design during their freshman year with reverse engineering modules in our Introduction to Engineering course. Then, sophomore through senior year, students enroll sequentially in our six-course design sequence. The design curriculum culminates in a two year (four semester) capstone experience taken during the junior and senior years.

Figure 1: The engineering curriculum places instruction into engineering design at its core.

Our goal in this paper is to present our model for integrating real-world, client-based projects into a two-course, sophomore design sequence. We believe that providing these experiences early and often not only challenges students on multiple dimensions, but also exposes them, and consequently better prepares them, for their eventual role as a practicing engineer.
Background

An education in engineering design can give students the skills required to creatively solve real-world problems. Following the second World War, however, courses focusing on engineering design (as well as those focusing on shop and manufacturing methods) began to be removed from the typical engineering curriculum in favor of engineering science theory. This pendulum swing left students without the hands-on design expertise required to be work-ready engineers. Consequently, engineering programs were built on engineering science where analysis is the focus and mathematics is the language. With direction from the Accreditation Board for Engineering and Technology (ABET) and pressure from industrial companies, engineering design has been reintroduced into the standard engineering curriculum—first through capstone (senior-level) design courses and then through cornerstone (freshman-level) design courses.

While there seems to be a general understanding toward the value toward engineering design instruction within engineering curriculums, curriculum-wide integrations of engineering design instruction and project work are still far from common-place. Perhaps the original such program was the Design Program at Stanford University which offers both BS and MS degrees and “combines an emphasis on creativity, technology and design methodology with a concern for human values and the needs of society.” The Segal Design Institute at Northwestern offers design courses spanning freshman through senior year, and offers both a certificate in engineering design as well as a bachelor of science focusing on manufacturing and engineering design. The Institute for Complex Engineering Systems at Carnegie Mellon University offers an engineering design minor with the goal of providing a foundation in design to undergraduate engineering students through a combination of design focused courses and interdisciplinary design project work. At the University of Maryland, design thinking and problem solving have been integrated into courses throughout the engineering curriculum including statics, strength of materials, introduction to engineering design, and product engineering and manufacturing. Harvey Mudd College, which offers a single unspecialized engineering degree, similarly maintains a strong engineering design focus through their curriculum beginning “from students’ first year through engineering majors’ Clinic project—and strongly emphasizes a hands-on approach to ‘real world’ problems.”

At Daniel Webster University, design is taught across a three course sequence with students learning the design process, computer aided design software, manufacturing skills, as well as applicable engineering science skills required to complete projects. Louisiana Tech University, has similarly developed a three course sequence providing an immersive, laboratory-based experience; the third course in this sequence focuses on the engineering design process and follows the IDEO design process. At Rowan University, an engineering clinic course sequence (which is comprised of one course per term for all four academic years) provides immersive laboratory based experiences for students across all engineering majors. The sophomore clinic begins during the fall term with a disciplinary design experience and culminating during the spring term with multidisciplinary design experiences. Compared to the first four programs mentioned, the last four programs mentioned are smaller and offer an immersive, more integrated engineering design experience, which is the hallmark of the JMU design course sequence. In the sophomore year, JMU students are immersed in learning the design process and tools, while in the junior and senior years, during capstone, students are immersed in applying the design process and tools.
The sophomore design courses (Engineering Design I and II) in the School of Engineering at James Madison University represent the cornerstone of our six course design sequence. The objective of this course sequence is to not only teach students the design process, but also to drive students toward ownership of the engineering design process. Our approach to teaching the design process combines directed and non-directed, group-based and independent, structured and unstructured, problem-based learning experiences that incrementally expose and reiterate the design process with a client-based design.

**Sophomore Design Course Structure**

The Engineering Design I and II course sequence is meant to provide students with the base knowledge to begin their capstone projects. To that end, a year-long design project is woven into instruction on design theory and methodology. Throughout the project, students interact with an actual client to design an actual product; the project for the last two years has been a custom, pedaled vehicle for a client with cerebral palsy.\(^\text{15}\) We believe, based on empirical evidence gathered through hours spent in the studio working with the students, that having a client and working on a tangible, real-world problem helps motivate students to learn the design process and complete the project with a working prototype. Upon completion of the sophomore design sequence, students should be able to:

- Identify and describe the stages of the design process
- Identify, describe, and discuss the customer needs which inform an engineered product
- Research and establish target specifications to describe the customer needs
- Describe and discuss creative engineering design practices
- Identify and analyze sustainability in contexts from case studies
- Demonstrate basic cognitive processes and problem solving skills for decision making
- Construct and assess designs using elementary physical prototypes
- Demonstrate basic computer aided design skills
- Demonstrate basic project management skills
- Demonstrate safe and appropriate design studio behavior
- Perform basic tool skills needed to complete design projects
- Explore, analyze, and evaluate conceptual designs using decision-making strategies, sustainability principles, and customer needs
- Test and iterate to demonstrate achievement of target specifications
- Communicate through documentation and presentation a project plan, execution strategies, and a final selected design concept
- Work effectively in a team setting

Course structure and modules have been developed to meet the overall course objectives. The course is structured across two semesters, allowing for directed and non-directed instruction in the design process. Coverage of the design process (based on Ulrich and Eppinger’s *Product Design and Development*\(^\text{16}\)), illustrated in Figure 2, begins during the first semester as a directed learning experience where the students are incrementally walked through the first two phases. During this first semester, students are taught how to ask questions and to gather customer needs; rank-order customer needs with an affinity diagram\(^\text{17}\); generate a functional model of their product; identify target specifications; generate concepts using approaches such as
morphological analysis\textsuperscript{18}, e-sketch\textsuperscript{19}, and design-by-analogy\textsuperscript{20}; iterate and select a final concept with Pugh charts\textsuperscript{21} and decision matrices; and assess design sustainability\textsuperscript{22}. The students complete the first semester with a report detailing their selected final concept.

These first two phases of the design process, arguably the most ambiguous of the five phases, are often difficult for the students to grasp. Consequently, these first two phases are covered twice through the course sequence helping to solidify their importance. The second coverage occurs during the first third of the second semester and is non-directed. Students are “turned loose” and told to repeat the process; now, however, they are free to explore the design process and design tools learned in the prior semester. Also, as the semester changes, the teams change allowing students to experience a new group dynamic, learn from a new set of team members, gain new roles, learn new skills (from team members with whom they might not have interacted), and build confidence in their skill set learned during the prior semester.

Throughout the course sequence, students work in teams on the project-based activities. During the first semester, students work in small (4-5) teams to complete the first two phases of the design process. During the second semester, however, when the amount of work increases considerably (due to physical prototype construction) the students work in large (10-11) teams. To ensure that students are still individually learning the design process, case studies and essay based, take-home exams assess (as well as teach and solidify) student understanding of the design process through independent reflection on how to apply the design process to new and unrelated design challenges. Design tools are taught during class meetings, and both project-based (full-team and partial-team) as well as individual assignments are used throughout the semester.

Once students reach the end of phase two of the design process (about the third week of Engineering Design II), they are taught about prototyping and detailed design. Students are taught to use SolidWorks\textsuperscript{23} and to convert their hand sketches into engineering drawings. CAD models as well as physical proof-of-concept prototypes of various vehicle subsystems help the students to understand the limitations of their designs. The students are taught to benchmark their designs, explore design catalogs, and generate a bill of materials. Consultation periods between student teams and course instructors provide an opportunity for open dialog to discuss progress and roadblocks. The students work with a local field expert for guidance while building their alpha and beta design prototypes. Students use a PowerTap\textsuperscript{24} and MatLab\textsuperscript{25} during the testing and refinement phase of the design process to explore the power requirements of their designs. The project culminates with the students demonstrating their final product (a beta prototype) to the client and his or her family as well as the University and the local community.
Sophomore Design Course Project

The project for the last two and a half years (first three runs of the course) has required students to design and construct a human-powered vehicle for a client with cerebral palsy. Each year, however, we have changed the client which has resulted in different customer needs and target specifications related to each of the different client’s manifestations of cerebral palsy. Overall, this has resulted in very different final concepts each year. The first year’s bike was designed to use both the upper and lower body. The final completed prototype from 2009-2010 academic year (the first year for the project) is provided in Part A of Figure 3. The second and third year’s designs will use primarily the lower body. The final completed prototype from 2010-2011 academic year (the second year for the project) is provided in Part B of Figure 3. The students are provided with the following information about the vehicle at the beginning of the project:

A client with cerebral palsy would like a human-powered vehicle to use for exercise purposes. The design should accommodate his or her unique needs allowing for both inside stationary use and outside transportation use. The seat should be adjustable to allow for future growth spurts, and the bike should provide adjustable tensioning to allow for strength training. The bike should have brakes on all wheels, storage appropriate for the client’s intended use, and should include all safety devices appropriate for operation on residential roads.

Students follow the design process, use the design tools taught during the course, and meet directly with the clients to gain more information on the desired final product. Over the course of the semester, students collect an average of 75 customer needs and develop an equivalent number of target specifications. These customer needs and target specifications inform their design and provide the basis for the students’ application of the design tools taught during the course (mentioned above).

Figure 3: Human-powered vehicles A) completed during the 2009-2010 sophomore design course, and B) completed during the 2010-2011 sophomore design course (Image courtesy of Travis Knight, 2011).
Assessment

A mixed-methods approach (consisting of both qualitative and quantitative methods) is used to evaluate problem-based learning experiences as well as assess course learning outcomes, project learning outcomes, and program learning outcomes. A mixed-methods approach is appropriate as it enables us to neutralize the disadvantages inherent in all types of methods and to understand the complexities of social phenomenon such as how people learn and interact with their environments. The advantages of this approach include (a) strengths inherent in one method will offset the weaknesses of other methods, (b) frequent results of well-validated and substantiated data in research literature, (c) shorter data collection time, and (d) extensive use by social science researchers. The limitations include the effort, time, and expertise required to utilize two methods instead of one, and it can be difficult to compare two different forms of data.

Assessment instruments that are administered in the sophomore design course sequence include (a) Project Evaluation, (b) Course Evaluation, and (c) Student Performance Evaluation. The following subsections describe the assessment instruments and significant assessment data (for brevity) we have used to inform our course sequence iterations. In addition to continuous course improvement, our assessment efforts are also part of our program accreditation (ABET) efforts.

Administration and Timeline of Assessment Instruments
Of the three assessment instruments applied to the sophomore design course sequence, one is in the form of a survey and two are questionnaires. Surveys are conducted electronically and correspond to over 95% response rate because students receive course credit for completion. Questionnaires are given in multiple formats. Course Evaluations are conducted electronically, while Student Performance Evaluations are conducted as a pencil and paper assignment. Both the surveys and questionnaires are administered at the end of the semester, which results in data captured mid-way through and at the end of the course project. As much as possible, instructions for each instrument are consistent from year to year, and the rewards for participation and effort are uniform across sections.

The Project Evaluation Survey
Project Evaluation aims to understand students’ perspective on the course project and measure how well the problem-based learning experience enabled them to meet the program goals (which map to ABET a through k). This instrument has had the greatest impact on our course sequence iterations as the project is woven throughout the course sequence and is a driving factor in the students’ learning the design process. From this instrument, we have learned what the students perceive about the course project and how well they were prepared to meet the objectives. This instrument targets the following ten characteristics related to the course project:

- Skills and knowledge required to complete the course project
- Difficulty in obtaining the necessary knowledge and skills
- Difficulty associated with following the design process
- Course project aspects that were difficult, challenging, or easy
- Weaknesses in classroom instruction (e.g., how defined or explicit was the knowledge and skills needed to complete the project, how defined were the steps or path to complete the project, how much instruction on the steps or path to complete the project was given)
• Students’ ability to achieve a number of skills as a result of the course project experience
• Other skills or learning outcomes that were gained through the course project experience that were not listed
• Agreement on how well the course project enabled students to meet the program goals
• What the students found most and least valuable about the course project
• How the course project prepared students for becoming an engineer

Table 1 provides the self-reported data by the students as related to the program outcomes (which, as previously stated, map to ABET a through k). When administered this survey, students were asked to rate their agreement with how well the bike project enabled them to meet the School of Engineering program goals. Students were asked to read each statement and consider the following “This project enabled me to ……”

Table 1: Summary of sophomore students’ evaluation of skills learned as a result of the bike project experience for the 2009-2010 academic year.

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
<th>N</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply knowledge of mathematics, science, and engineering</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>35</td>
<td>9</td>
<td>46</td>
<td>4.15</td>
</tr>
<tr>
<td>Design and conduct experiments, as well as to analyze and interpret data</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>30</td>
<td>10</td>
<td>46</td>
<td>4.04</td>
</tr>
<tr>
<td>Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>25</td>
<td>19</td>
<td>46</td>
<td>4.37</td>
</tr>
<tr>
<td>Function on multidisciplinary team(s)</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>26</td>
<td>12</td>
<td>46</td>
<td>4.02</td>
</tr>
<tr>
<td>Identify, formulate, and solve engineering problems</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>27</td>
<td>18</td>
<td>46</td>
<td>4.35</td>
</tr>
<tr>
<td>Acquire an understanding of professional and ethical responsibility</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>24</td>
<td>16</td>
<td>46</td>
<td>4.22</td>
</tr>
<tr>
<td>Communicate effectively</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>20</td>
<td>17</td>
<td>46</td>
<td>4.13</td>
</tr>
<tr>
<td>Understand the impact of engineering solutions in a global, economic, environmental, and societal context</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>28</td>
<td>12</td>
<td>46</td>
<td>4.13</td>
</tr>
<tr>
<td>Recognize the need for, and an ability to engage in life-long learning</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>27</td>
<td>12</td>
<td>46</td>
<td>4.09</td>
</tr>
<tr>
<td>Gain knowledge of contemporary issues</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>26</td>
<td>10</td>
<td>46</td>
<td>3.89</td>
</tr>
<tr>
<td>Use the techniques, skills, and modern engineering tools necessary for engineering practice</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>31</td>
<td>15</td>
<td>46</td>
<td>4.33</td>
</tr>
</tbody>
</table>
At the completion of the course sequence, students are asked to gauge their experience with working on the team by rating their agreement with the level of cooperation, the value in the project learning experience, the motivation toward learning as a result of the project, and the overall satisfaction with their project experience. Figure 4 provides the results of this survey. We find that in all categories students at least agree, and in the category of value, students strongly agree. We believe that these results, while not directly correlating, help to support our empirical evidence that the students seem to be driven toward success through this client-based design experience.

![Figure 4: Students’ agreement toward the gauges on their experience with the design project for the 2010-2011 academic year.](image)

Through our design sequence, students are exposed to varying problem-based learning experiences that increase in complexity and decrease in structure with increasing academic level. Our goal is to transition students from “black and white” text book problems to problems that more realistically mimic real-world engineering practice, which itself is well-known to require engineers to solve complex and ill-structured problems\textsuperscript{15,28}. We use a set of indicators to measure the complexity and structuredness of each design problem used in the design curriculum. Structuredness is a dimension that measures how well a problem is defined or identified as well as how well the problem solving process is structured in terms of the methods and analysis used (e.g., a typical homework problem in engineering science courses has a well-defined problem statement and a well-structured solving process since such problems often follow specified concepts and principles)\textsuperscript{29}. Complexity is a dimension that looks into the required domain knowledge to solve the problem, the intricacy of the solution path, and the depth of integration of varying domains. In a sense, complexity lets us gain insight into the cognitive load imposed on the problem solver\textsuperscript{29}.

Tables 2 and 3 show sophomore students’ complexity and structuredness ratings for the course project. Students rated the relative amount of perceived effort required to solve the project using a five-point Likert scale. Increasing score correlates to increasing perceived effort. In general,
the students rate the project as both somewhat complex but also fairly structured. These results are as we hoped, considering this is the students’ first real-world engineering design project. The students realize the complexity of the project (multiple solutions, no concrete right or wrong answers, et cetera), but also, since we are very deliberately walking the students through the design process, they are not faced simultaneously with the unstructuredness typical of the real-world engineering problems they will experience once graduated. Such findings suggest that we are indeed challenging our sophomores with authentic and meaningful projects and appropriately designing them to meet their developmental learning needs. It should be noted, albeit a topic for another paper, that our junior and senior engineering students, when completing the same survey on their capstone projects, rank their capstone project as both highly complex and very unstructured.

Table 2: Summary of sophomore students' ratings of project complexity.

<table>
<thead>
<tr>
<th>Complexity Statement</th>
<th>Sophomores Mean (N=44)</th>
<th>Sophomores St. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much knowledge and skills did you have to gain to complete this project?</td>
<td>3.93</td>
<td>0.73</td>
</tr>
<tr>
<td>How difficult was this new knowledge and skills that you had to gain?</td>
<td>3.09</td>
<td>0.56</td>
</tr>
<tr>
<td>How many ways could this project be completed?</td>
<td>3.93</td>
<td>1.09</td>
</tr>
<tr>
<td>How difficult were the steps or path to complete the project?</td>
<td>3.43</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Table 3: Summary of sophomore students' ratings of project structuredness.

<table>
<thead>
<tr>
<th>Structuredness Statement</th>
<th>Sophomores Mean (N=44)</th>
<th>Sophomores St. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much of the knowledge and skills needed to complete the project were provided?</td>
<td>3.91</td>
<td>0.56</td>
</tr>
<tr>
<td>How defined or explicit were the knowledge and skills needed to complete the project?</td>
<td>3.20</td>
<td>0.67</td>
</tr>
<tr>
<td>How much instruction on the steps or path to complete the project did you receive?</td>
<td>3.66</td>
<td>0.78</td>
</tr>
<tr>
<td>How defined were the steps or path to complete the project?</td>
<td>3.27</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Course Evaluations
As a portion of the standard course evaluation, students are asked to assess the difficulty and the value associated with projects, activities, and assignments in the course. This information provides feedback allowing us to gauge how well we met the educational objectives and to aid with course evolution. Table 4 demonstrates that while the course project is considered the most difficult activity in both the spring and fall semesters, it is also considered the most valuable out of all course activities. Feedback indicates that while the students find this course of generally average difficulty, they also find it valuable (1 to 5 scale).
Table 4: Summary of course evaluation data for the 2010-2011 academic year.

<table>
<thead>
<tr>
<th>Projects/Activities/Assignments</th>
<th>Fall 2010</th>
<th>Spring 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Difficulty</td>
<td>Average Value</td>
</tr>
<tr>
<td>Design of a Human-Powered Vehicle</td>
<td>3.77</td>
<td>4.36</td>
</tr>
<tr>
<td>Balloon Vehicle Project</td>
<td>2.09</td>
<td>3.14</td>
</tr>
<tr>
<td>Computation Design Tools (SolidWorks &amp; MatLab)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>In-class Design Process &amp; Design Tools Activities</td>
<td>2.54</td>
<td>3.86</td>
</tr>
<tr>
<td>Sustainability Discussions &amp; Activities</td>
<td>2.41</td>
<td>3.68</td>
</tr>
</tbody>
</table>

Course evaluations have also provided insight into phases of the design process where students struggled. Specifically, students have struggled with gathering customer needs and correctly using prototypes to inform their decisions. Students found it challenging to interact with their customer (client) and to ask questions specifically designed to obtain customer needs. To address these issues with gathering customer needs, the lecture on customer needs gathering, given in Design I, was lengthened to a full class period and two in-class learning activities were added focusing on designing questions. Regarding prototyping, students tended to build a prototype design, and when it did not work, they would start over from scratch rather than learn from it, or students tended to build vague prototypes of the entire design rather than test a smaller piece of the design that needed verification and testing. To address the misunderstanding about prototypes and to teach the students how to get the most out of a prototype, we added a new lecture, given in Engineering Design II, that covers the general purpose of and detailed aspects of prototyping. Students are provided sample prompts of various design problems, and are asked to select the best sub-systems to prototype to solve the design problem.

**Student Performance Evaluations**

Student performance evaluations include peer- and self-evaluations of team participation and project management. Each student is asked to write the top three contributions for each team member, including himself or herself, and to rate each team member’s contributions using a 5-point Likert scale. The ratings are factored into the participation grade for each individual student, and have provided insight into issues associated with both the small (4-5) and large (10-11) members. In an effort to address team dynamics issues, we added another full lecture this year on teams and team structures as well as an activity to encourage students to learn how to work effectively together and recognize each other’s strengths. The result is we have gone from spending zero time to spending two and half class periods on team dynamics. While it is too early to know the results of these changes in our current 2011-2012 course sequence run, empirical evidence demonstrates these changes have been successful.

**Discussion—Our Lessons Learned**

Through periodic reflection on the design sequence courses, many lessons have been learned about teaching design as an integrated component of an engineering curriculum. The following
list outlines the lessons that have been learned while teaching the sophomore design course sequence:

1. The instructor must be flexible when working with a real client. It can be difficult to follow the syllabus exactly or require students to interact with the client as the client’s schedule may change frequently.
2. The instructor should constantly remind students that they are working with a real client and that they need to remain flexible throughout the project.
3. Engaging students in a client-based design project at the sophomore level broadens their skill set and perspective on engineering. More specifically, the sophomore design project enables students to gain teamwork skills, project management skills, design skills, and communication skills as well as foster personal growth (e.g., awareness of strengths and weaknesses, and critical self-assessment).
4. Students gain a deeper understanding of the engineering design process by working through each phase of the design process to learn it—both through lecture and through the course project.
5. By focusing the engineering curriculum around problem-based learning experiences and exposing students to diverse projects/problems starting from freshman year and continuing every semester through the senior year, we are seeing strong impacts on student learning outcomes as well as strong alignment with these projects aiding us in meeting program goals.
6. The importance of appropriately designing problem-based learning projects and activities with the right amount of complexity and structuredness.
7. The need to approach course design and instruction of engineering design in the curriculum holistically, rather than as individual courses.
8. The need for stronger integration of design courses and design instruction with engineering science courses.

Conclusion

The courses in our engineering curriculum plus the learning environment we create have a focus on problem-based learning and real-world problem solving in order to expose students to the practice of becoming engineers and to help us meet the program goals, which in an engineering program, is most effectively done via practice and projects. Our sophomore design course sequence challenges students on multiple dimensions and engages them through continuous application of the engineering design process. We believe that providing these experiences early and often not only challenges students on multiple dimensions, but also exposes them, and consequently better prepares them, for their eventual role as a practicing engineer.

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