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Jay R. Goldberg
Marquette University, jay.goldberg@marquette.edu

Vikram Cariapa
Marquette University, vikram.cariapa@marquette.edu

George Corliss
Marquette University, george.corliss@marquette.edu

Kate Kaiser
Marquette University, kate.kaiser@marquette.edu

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Benefits of Industry Involvement in Multidisciplinary Capstone Design Courses*

JAY GOLDBERG, VIKRAM CARIAPA, GEORGE CORLISS and KATE KAISER
Marquette University, PO Box 1881, Milwaukee, WI 53201-1881, USA. E-mail: jay.goldberg@mu.edu, vikram.cariapa@mu.edu, george.corliss@mu.edu, kate.kaiser@mu.edu

Opportunities for industry involvement in capstone design courses go beyond industry sponsorship of capstone design projects. Representatives from industry can serve as guest lecturers, curriculum advisors, and design project sponsors and team mentors. Since 2000, industry participation has been a core part of the capstone design course at Marquette University. Practicing engineers provide a relevant, practical real-world perspective of their topic, reinforcing its importance to professional engineering practice. Students and faculty benefit from the up-to-date treatment of the topic provided by guest speakers from industry who have expertise in the topic and are willing to share their experiences with students. Students benefit from industry sponsorship of senior design projects through the opportunity to work on real-world problems of importance to industry, exposure to industry and company-specific project management and product development processes, and familiarity with economic, legal, and regulatory design constraints. This paper provides a brief description of the Multidisciplinary Capstone Design course at Marquette University, examples of industry involvement in the course, and the observed benefits of industry involvement to students, the university, and industry participants. It presents examples of current practices used at other schools as well as helpful recommendations for managing industry participation in capstone design courses.

Keywords: capstone design; industry involvement; career preparation; design education

1. Introduction

Many capstone design programs involve industry in some way. The most common form of involvement may be through industry sponsorship of design projects, which often includes mentorship and funding of projects and project teams. According to a 2005 study of capstone design courses in the United States, 71% of the courses included industry-sponsored projects [1]. The average level of industry funding per project from industrial sponsors varied within individual programs. Many projects received less than $500 per project (48%) and 12% received more than $5000 for at least one project.

Accreditation of undergraduate engineering programs requires a ''meaningful design experience'' along with a focus on meeting customer needs [2]. Many programs recognize the value of industry partners in the capstone design course in preparing students for careers in engineering and other technical fields. Farr, et. al. stated ''relevant, industry-partnered design is an important part of the undergraduate education experience for tomorrow's engineers'' [3]. Pembridge and Paretti state that faculty view capstone design courses as a way of providing students with an opportunity to apply what they have learned in previous years through an open-ended design problem that simulates the real world. They also state ''such an emphasis suggests a strong need for faculty themselves to have such experience or to integrate partners from industry or elsewhere who can provide perspective'' [4]. Howe, et. al. surveyed capstone design faculty, students, and industry employers regarding course content [5]. Results indicated a difference in how each group perceived the importance of a variety of professional skills and knowledge areas in preparing students for careers in engineering. These results and those of other studies suggest that industry involvement in capstone design courses can provide benefits to students, faculty, and industry participants.

2. Capstone design at Marquette University

The multidisciplinary capstone design course at Marquette University includes biomedical, electrical, computer, and mechanical engineering, computer science, and information technology students. Five faculty members from three colleges within the University representing each of the disciplines involved teach the course over two semesters. The senior instructor among this group has fourteen years of industry experience in design and product development. In the fall semester information technology (IT) students participate, and in the spring semester industrial design students from the Milwaukee Institute of Art and Design collaborate with six of the project teams [6, 7].

Course enrollment is around 180 students in two sections. The course meets twice a week for lectures

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on various topics important to student projects and professional engineering practice. The focus of the course is on the design project of which there are typically thirty-five project teams consisting of three to six students from the mix of disciplines enrolled in the course. Project teams are formed according to student choices subject to constraints such as co-op schedules, required expertise and skills, and team size. Approximately half of the projects are industry sponsored, with some proposed by students, some by faculty, and others requested on behalf of clients with disabilities.

The course schedule and required team deliverables are based on the design control requirements of ISO 9001 and reflect the design process used in industry. Required team deliverables include the Project Definition, Customer Needs/Target Specifications Document, Generated/Final Concepts Document, Formal Proposal, Prototype/Mock-Up, Project Notebook, Oral Proposal, and Peer Review in the fall semester. A Project Schedule/Risk Analysis, Experimental Verification Document, Prototype, Project Notebook, Peer Review, Oral Report, and Final Report are required during the spring semester.

Team performance is assessed through team deliverables. Individual student performance is assessed through online quizzes, class participation, attendance, and peer reviews. The final course grade is based on team and individual student performance.

3. Industry involvement

Representatives from industry participate in the multidisciplinary capstone design course as guest lecturers, curriculum advisors, and design project sponsors and team mentors. This collaboration provides many benefits to students and industry participants. Marquette University has benefitted from industry involvement in capstone design courses through the building of relationships with industry (which has lead to research collaborations and grants), maintenance of a high quality senior design course and project experience, and addition of resources available to students to complete their design projects [7].

3.1 Guest lecturers

As guest lecturers, practicing engineers and other technical professionals provide a relevant, practical real-world perspective of their topic, reinforcing its importance to professional engineering practice. Students (and course faculty) benefit from the up-to-date treatment of the topic provided by guest speakers from industry who have expertise in the topic and are willing to share their experiences with students. Serving as a guest lecturer is considered an honor and is viewed by many employers as a professional development activity. In our capstone design course, guest speakers from industry present almost half of the lectures. All industry speakers are sent a set of guidelines to follow when preparing their presentations. These guidelines ask speakers to present a general overview of their topic including examples of applications, make students aware of the importance of their topic to professional practice, and address the applicability of the topic to all engineering disciplines represented in the classroom, not just one. Topics addressed by guest speakers from industry include project management, patents, teamwork, human factors in design, design for the environment, software validation, globalization, risk management, and personal and professional liability. Speakers are encouraged to incorporate active learning components into their lectures such as in-class activities and classroom demonstrations to increase the level of student engagement.

3.2 Curriculum advisors

Feedback from engineers working in industry can be very helpful in ensuring that the content and objectives of the capstone design course are up-to-date and relevant to the practice of engineering and other technical disciplines, and are helping to prepare students for careers in these areas. A periodic review of course objectives, lecture topics, and required course deliverables by members of an industrial advisory committee can help fine-tune the course curriculum. At Marquette University, two of the participating engineering departments (biomedical and mechanical engineering) hold meetings with their respective Industrial Advisory Boards (IAB) during which feedback on the capstone design course is solicited. For example, at a recent IAB meeting industry representatives confirmed the value of aligning capstone course deliverables with design control requirements contained in ISO 9001. This helps course instructors maintain a course curriculum that better prepares students for work in industry. At other IAB meetings, topics such as the use of electronic vs. paper based project notebooks used to document project activities, and the value of virtual project teams in preparing students for work in industry were discussed.

In past years, students participated in a college-wide poster competition at the end of the two-semester capstone design sequence. A few members from the Milwaukee area chapter of the College of Engineering Alumni Association served as judges along with faculty to provide an industry perspective to the judging process.

3.3 Industry sponsors and mentors

Industry sponsors are required to identify a company representative to act as an advisor to the project. The industry advisor acts as the company contact for the team and is required to be available to advise teams on issues involving customer needs, provide technical expertise and advice, and approve design concepts and prototypes. Faculty advisors are responsible for administrative issues (grading, monitoring progress of teams, dealing with personnel issues, etc.) and providing guidance to the team. Communication between the team and the industry advisor can be in person or by telephone, e-mail, or videoconferencing. The industry advisor determines the frequency of communication with the team as well as the need for travel.

At the start of the course, we assign a team of students to each project for two semesters. Our senior design teams are required to construct and test prototypes to verify that their design solves the sponsors' problems and meets the sponsors' needs. Students typically have access to the university's computer network, libraries, machine shops, and laboratories. Construction of functional prototypes can be costly and testing of prototypes may require specialized test equipment or software not available to students. Depending upon the complexity of the design and the requirements of the sponsoring company, some prototypes can be made of parts obtained from local hardware stores and easily assembled in a dormitory room or local prototype shop (Discovery Learning Laboratory). Other prototypes may require access to a machine shop for lathes, mills, drill presses, etc., or must be made of materials that require casting, molding, or other processes that might not be available to students in an academic setting. In these situations, industry sponsors are requested to provide the necessary resources (prototyping facilities and/or personnel, laboratories and test equipment) for the project team to complete their projects. We require sponsors to provide the financial and technical resources necessary for the team to complete their projects, as needed.

At the end of the course, industry sponsors are invited to attend final oral presentations. Those that do attend are often asked to provide feedback on the oral presentations as well as the overall project results however; they are not asked to grade the projects. Final deliverables such as prototypes, final reports, and project notebooks are transferred to the industry sponsor.

Grading of course deliverables follows the industry model based on objectives and expected performance typically used in performance reviews. Guidelines and grading rubrics for each team deliverable are presented to students during the first week of class and define the expected levels of performance for each team deliverable. Meeting expectations earns a score of 85. Exceeding expectations can earn a higher score, and failing to meet expectations warrants a lower score. This grading model reflects how performance is evaluated in industry and prepares students for how their performance will be evaluated by employers.

The level of industry involvement in evaluating design projects at Marquette University is similar to that observed nationally. In a 2010 study of capstone design instructors, it was reported that industrial advisory boards rarely participated in project evaluation. Similarly, industry sponsors were not involved in project evaluation in 54% of courses included in the survey [4].

4. Industry involvement at other institutions

Representatives from industry participate in capstone design courses around the country. Many serve in similar roles as those previously described at Marquette University. Others serve in different ways to benefit stakeholders.

At the University of North Texas, industry involvement plays a major role in the Construction Engineering Technology Program [8]. The goals of this collaboration include providing students with experiences not available in the conventional classroom setting and exposing them to cutting edge technology currently in use by progressive companies. The interaction of industry mentors with students has bridged the gap between what is learned in the engineering curriculum and what is expected of graduates when they work in industry. By working with professionals in the field, students learn how professional engineers use what they learn not only in their capstone courses, but also during their undergraduate programs.

The Construction Engineering Advisory Board at the University of North Texas consists of construction engineering professionals and educators. This board advises the program on curricular issues, recruitment, and advertising, and plays a role in the accreditation process. They help keep the curriculum up-to-date and relevant, ensuring that graduates are prepared for entry-level positions in construction engineering firms. Members of the board also sponsor projects, provide site visits and field trip opportunities, serve as guest speakers, and hear and provide feedback on final project presentations. They also assist students in finding internships, summer jobs, and employment after graduation.

Waddah describes industry involvement in teaching civil engineering design through a capstone

design course at an international university (not identified) [9]. Practitioners played a major role in the planning and teaching of this course, which exposed students to professional practice and provided guidance to faculty as to curriculum design and expected capabilities of graduates. This approach also helped in establishing relationships with the industrial sector. The course was co-taught by engineers from a local consulting firm. In addition to providing funding, equipment, and expertise to project teams, industry partners provided awards and other incentives to students who performed well.

At the University of San Diego, an Electrical Engineering Advisory Board was formed with members representing local industry and alumni. The purpose of this board was to apply their industry perspective to enhancing the electrical engineering capstone course. Industry representatives provided input on which practical technical topics and professional issues should be presented during class meetings. Often, board members agreed to serve as guest speakers for specific topics [10].

At the Georgia Tech Stewart School of Industrial and Systems Engineering (ISyE), information from industry executives regarding the communication skills they consider critical for employment and professional advancement were embedded into the senior design class [11]. Workforce interviews of industry executives were translated into techniques for use in audience analysis, presentation, and writing, and these were taught as part of the capstone design course. The ISyE Workforce Communication Program has incorporated executive panels into the capstone design course to align student skills with executive expectations with the goal of raising student awareness of the importance of communication to workplace success [12]. In these panels, executives interact directly with students about workforce communication, career advancement, and the communication skills they consider most critical. This example of industry involvement in capstone design has led to the creation of a rubric to measure student communication skills in engineering [13]. The rubric is based on input from industry executives and is employed as part of the capstone design course.

In a review of the literature on project oriented capstone courses, it was found that industrial involvement in capstone design courses could include financial support, equipment, materials, technical consulting, design awards, and assistance in evaluating teams and projects [14]. Most sponsors provided a liaison engineer to advise students and monitor project progress. The frequency of interaction between the liaison engineer and the student team often had a significant impact on the success of industry-sponsored projects.

5. Benefits of industry involvement

As previously discussed, representatives from industry can contribute to capstone design courses in several ways. Industry involvement is beneficial to sponsoring companies, students, and faculty.

5.1 Benefits to industry

Industry sponsors benefit by receiving additional technical resources dedicated towards solving a technical problem at a lower cost. At Marquette University, industry sponsors are asked to reimburse students for all project expenses incurred by students during the course. This might include assistance in building prototypes or providing access to test equipment. The highest level of industry support for capstone design projects at Marquette University was $20,000 to cover materials and machining for two projects. Both projects were entered into an international student design competition in South Korea and both won awards. The sponsoring company further benefitted from the publicity associated with the awards, and it has continued to support capstone design projects. Continued involvement in the course in the form of project sponsorship is an indication that the company's needs were met.

Industry sponsors of capstone design projects recently were asked: "How did you or your company benefit from sponsorship of a senior design project?" A few responses are shown below:

> "We were able to engage the students in thinking in new ways about an existing problem. We continue to be interested in supporting senior design projects and possibly other research."

> "I'd say we benefitted from the additional labor (resources). The power supply was used for technical development in our lab on the 128-channel mock-up and was also used to support reliability testing, troubleshooting of existing product, etc. This was a great contribution to the future development of clinically relevant MR scanners. On a personal level, I always enjoy mentoring young engineers because I get to see things from a fresh perspective."

> "Participating in a senior design project has allowed our company to both benefit directly and assist in the development of design students, a mutual benefit. The company gained additional resources to increase speed to market on our product, and we provided an opportunity for both professional development and education of the new engineers that worked on our project. It was a great experience worth pursuing!"

> "Educating students on our products and tools created more awareness of our company within the school, higher visibility among seniors entering the workplace (with hope they will use our products), and mentorship/education opportunities for alumni."

> "I believe that involvement in the Senior Design Project raised some awareness with the graduating class about our company. We are interested in hiring top talent from a graduating class, and this program did bring in some resumes from the senior design team and other graduating seniors. The fact that our employees are directly involved with the project gives us some insight into the caliber of students working on the project and their abilities regarding any prospective employment. Watching some of the other projects that are presented is also another way to evaluate some of the applicants. It is helpful to have a new team look at a problem with a fresh perspective and augment our development program. There are some unique ideas that are worth exploring and I believe the Senior Design team does that. The presentation of ideas and concepts that I saw this last fall was great. We are certainly interested in new products to sell and the Senior Design program helps us get one step closer to bringing them to market."

These responses indicate that industry sponsorship can benefit companies with limited technical resources and allow companies to make progress on lower priority projects without diluting their in-house resources allocated to higher priority projects. Working with engineering students can provide companies with a new way of looking at and solving problems. Project sponsorship allows companies to participate in the training of new engineers, advertise their companies on campus, and gain access to a pool of graduating engineers for recruitment.

5.2 Benefits to students

Students benefit from industry sponsorship of senior design projects through the opportunity to work on real-world problems of importance to industry, exposure to industry and company-specific project management and product development processes, and familiarity with economic, legal, and regulatory design constraints. It also provides resources to student teams that might not be available in our laboratories or prototype shop. Capstone design project experiences often lead to full-time employment for students with the sponsoring company after graduation. Graduates of the capstone course who worked on industry-sponsored projects recently were asked: "Did having an industry sponsor enhance your capstone design project experience?" A few responses are shown below:

> "I got to experience what it is like to work directly with an industry customer and gain experience dealing with professionals within the industry and their suppliers. The company was also driven to see the project come to fruition, which meant that resources were available from the company to get tasks done (machining, materials requisition). The project helped to demonstrate that not only am I capable of working on a team based development project, but additionally, I can work with outside suppliers and customers (including the company itself). I think having a project that has a real entity to deliver to helps motivate the team, gives experience in dealing with a business and their respective suppliers, and helps bring the project to market."

> "Working with industry sponsors definitely enhanced my senior design project experience. Instead of just feeling like we were doing just another project for a grade, I felt like our project served a greater purpose, and was making a real difference. By having dentists who were actively treating pediatric patients help us on the project, I felt I was making a direct impact in the dental field. I loved having my sponsor be able to give us insight, and see firsthand how what we were doing was easing his work. Not only did we work with one dentist, we also worked with the Radiology department, as well as a manufacturer and supplier of dental equipment."

These responses indicate that students benefitted from industry sponsorship of their capstone design projects. Students reported that the experience gave them a sense of purpose and a feeling that they were making a difference as they solved a real-world problem of interest to industry. The experience also gave them confidence in their project management and design skills and their ability to work on a team.

Students also benefit from hearing guest speakers from industry. Graduates of the capstone design course recently were asked: "Did you find value in having guest speakers from industry talk about various topics in the course?" A few responses are shown below:

> "I certainly found value and benefits in lectures given by industry professionals. I recall attending lectures that were given by industry professionals that covered a wide range of subjects, from team management, product testing, documentation process, various design strategies, and experience-based best practices. Many of the topics were immediately applicable to our project. For example, our team increased the frequency of our tests and customer involvement based on a lecture about software testing strategy. Another lecture discussing system integration pointed out technical and non-technical risks of a system integration process. This motivated our team to document a plan to reduce non-technical project risks. Some lectures did not directly apply to my project, but were useful after senior design when I was seeking career opportunities after graduation."

> "Absolutely valuable. As I was a senior trying to figure out what I wanted to do post-college, it was helpful to hear about different companies and different roles to which my degree could translate. While the 2003 market was very soft compared to previous years, it helped me make the decision to go to graduate school and further hone my skills for another two years."

> "I did find value from having many guest speakers from industry take part in the course. I really enjoyed learning about the different engineering possibilities after graduation. Hearing from patent lawyers to people more in a CEO type position really elicited the true potential of what is possible after graduation. I remember appreciating that the selection of speakers was well rounded, from different engineering and non-

> engineering jobs, and as I worked on my senior design project I was able to think about the possibility of starting up a company and the process involved in getting a product out commercially. Finally, it has also helped after graduation for situations where I need to work with people from different fields and/or specialties. Understanding what certain people do and the challenges they go through have helped the projects that I have worked on, since senior design, go a lot more smoothly.''
>
> ''Yes, having industry speakers was a valuable part of the course. Even to this day, I enjoy listening to others talk about their work experience, their processes at work, their management style, etc. I feel we can all learn from each other, whether we are students or out in the working world. In today's world, where networking is so important, these speakers add even more value to the class.''

These responses indicate that students benefitted from guest lecturers from industry. The topics presented were useful not only for their capstone design projects, but also for their careers. Students appreciated learning how lecture topics applied to real world situations, understanding how people deal with certain problems and issues, and learning about the various career paths available to them as graduate engineers.

5.3 Benefits to faculty

Faculty advisors benefit from advising project teams working on industry sponsored capstone design projects. They recently were asked: ''What are the benefits to you as a senior design project advisor from this type of collaboration with industry?'' A few responses are shown below:

> ''There have been numerous benefits of advising an industry-sponsored senior design project. Two of the projects led to further collaboration with the company, with one resulting in a joint research publication. The additional networking from the senior design collaboration was one of the factors that lead to a funded research project with one company. In general, it has been a good networking experience and an opportunity to be better connected with local industry. It also helps me keep informed about the newest products in my field.''
>
> ''I think that the benefit of industry involvement in capstone design projects is primarily to our senior students. In particular, industry involvement helps me prepare my students - most of who do go into industrial positions after matriculation - for their first professional positions after graduation. Anything that can facilitate or enhance my preparation of the students is a benefit to me.''

These responses indicate that faculty recognize the value of industry-sponsored projects in preparing students for careers in engineering. Some faculty appreciate the networking and potential research funding and publication opportunities that interaction with an industry sponsor can provide.

Not all capstone design faculty agree on the value of industry sponsored design projects. Those in favor of industry sponsored projects argue that students need to work on real-world problems to understand what real engineering is like. Those opposed to these projects argue that they do not represent ''true engineering'' and often require minimal levels of analyses that do not develop students' knowledge and skills. There is also the concern that industry sponsors are not sensitive to students' schedules, course loads, and other commitments and restrictions that could interfere with project completion [8]. We feel that with proper project and sponsor selection, these objections can be overcome and the benefits of industry sponsorship can be realized.

6. Challenges with industry sponsorship

Industry sponsored projects present challenges regarding intellectual property. Intellectual property policies vary greatly between institutions [7]. At Marquette University, students own their intellectual property and can voluntarily sign nondisclosure and patent assignment agreements with sponsoring companies as a condition for sponsorship. Each year, a few of our sponsoring companies do not allow any public disclosure (classroom presentation) of the results of the projects they sponsor. These requests for confidentiality are accommodated through private team presentations to one of the course instructors and the faculty project advisor, both whom have signed nondisclosure agreements with the sponsor.

Typical problems with industry sponsored projects include company contacts not being available to teams when needed, industry sponsors changing scope of the project once the project is defined (scope creep), unrealistic expectations as to the amount of work and level of quality that a project team is capable of delivering in two semesters, and sponsor expectations that do not match with the course requirements (time, scope of projects, order of steps in design process, etc.). Recommendations for dealing with some of these challenges are presented in the next section.

7. Recommendations

The collective experiences of the authors with the two-semester multidisciplinary capstone design course at Marquette University has shown that certain types of projects are best suited for industry sponsorship. Faculty should try to solicit projects that require and allow the application of knowledge obtained in courses taken prior to the capstone design course. We have found the following to

meet the needs of industry sponsors and students, as well as the requirements of our course:

- Lower priority projects for which the company lacks resources. This is attractive to start-up companies with few technical resources.
- Projects that can be completed in eight months or less (required for a two-semester design course sequence).
- Projects involving the development of new-to-the-world products (may be difficult to complete in two semesters), improvements to existing products (new features, revised packaging, new materials, etc.), or process improvements.
- Projects requiring the development of test procedures and the design of test equipment.

When soliciting potential industry sponsors, we recommend the following:

- Discuss funding expectations with sponsors. Will they reimburse for team expenses or provide an account from which to pay for needed items?
- Discuss goals, timetable, and required deliverables of the course. Sponsors need to understand the desired learning outcomes of the course, what the course deliverables are, and when they are due.
- Sponsors need to understand their roles in the project. They need to be available to students for background information, guidance, and design feedback when students need them to be able to meet course deadlines. Sponsors must be aware of required time commitments and students need to respect the time of their industry sponsors. Sponsors and students should agree on the frequency of meetings and decide if travel is necessary.
- Manage sponsor expectations. Do not allow 1) scope changes (scope creep) that will require additional time and possibly delay completion of the project beyond the end of the course, 2) sponsors to require additional deliverables beyond what is required by the course, or 3) sponsors to require students to complete the project prior to the end of the course.

When considering the use of guest speakers from industry, we recommend the following:

- Find people who are good speakers, can engage the students, are experts on their subjects, and can share examples of how their topics are relevant to and used in various engineering disciplines and other technical areas. This is particularly important for courses that include students from more than one engineering or technical discipline.
- Encourage interactive presentations.
- Ask speakers to create an awareness of their topic so students understand why the topic is important to professional practice. Speakers should not attempt nor expect to create experts on the topic after one lecture.
- Consider recruiting recent alumni of the capstone design course. Students often relate well to fellow alumni who completed the same course, are close in age to the students, and can discuss how they used what they learned in the course in their careers.

When considering creating an industrial advisory board, we recommend the following:

- Find participants who are good communicators, willing to share ideas.
- Do not make financial contributions a requirement of membership on the board. The purpose of this board should be to collect feedback and advice on how to improve and maintain a relevant, up-to-date curriculum, not fundraising.
- Make good use of board members' time. Ask specific questions of the board at meetings; get feedback on new programs, ideas, etc.
- Include people with design and project management experience. Try to recruit technical personnel who have "worked in the trenches" and understand what engineers and other technical personnel need to prepare them for professional practice. Do not assume that all CEO's have had this experience nor understand the requirements of professional engineering practice. This is in agreement with others who recommend that the "ideal" member of an industrial advisory board was someone with experience as a lead engineer on projects, but not so senior as to be removed from the current hands-on technical work of his or her company [10].

8. Conclusions

Industry involvement can provide many benefits to students, faculty, and participating companies. Industry partners can serve as project sponsors and mentors, guest speakers, and members of industrial advisory boards. They can provide students with experience in solving real-world problems of interest to industry, provide up-to-date presentations of various topics important to professional engineering practice, and help maintain a relevant, up-to-date engineering curriculum to best prepare students for careers in engineering.

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Jay R. Goldberg, P.E. is Director of the Healthcare Technologies Management Program at Marquette University and the Medical College of Wisconsin (Milwaukee), Associate Professor of Biomedical Engineering, and a Lafferty Professor of Engineering. He teaches courses involving design and new product development (*Multidisciplinary Capstone Design, Clinical Issues in Biomedical Engineering Design,* and *Product Development of Medical Devices*). Dr. Goldberg's interests include medical device design, surface engineering, engineering management, student centered learning, and design education. His experience includes development of new products in urology, orthopedics, gastroenterology, and dentistry. Dr. Goldberg graduated with a BS in general engineering from the University of Illinois and an MS in bioengineering from the University of Michigan. He has a master's degree in engineering management and a PhD in Biomedical Engineering (biomaterials) from Northwestern University. Before moving into academia, Dr. Goldberg was Director of Technology and Quality Assurance for Milestone Scientific Inc. (Deerfield, IL), a start-up dental product company. Prior to that, he worked for three medical device companies. He writes a column on senior design courses for *IEEE Pulse Magazine*, published two books on capstone design courses, and is the 2012 recipient of the National Society of Professional Engineers *Engineering Educator Excellence Award* for linking professional practice to engineering education.

Vikram Cariapa is an Associate Professor of Mechanical Engineering. He teaches courses involving design and new product development (Multidisciplinary Capstone Design) and Dynamics. Dr. Cariapa's interests include analysis of surface finishing processes, design of implements for spinal cord patients, and learning strategies for engineering students. His experience includes design and development of tooling for high pressure boilers and nuclear generators and extremity pumps for spinal cord patients. He is a licensed Professional Engineer in Wisconsin. He is a reviewer for the International Journal of Advanced Manufacturing Technology and the International Journal of Production Research. Dr. Cariapa graduated with a B. Tech. in mechanical general engineering from the Indian Institute of Technology, Madras, India. He has a master's and PhD degree in industrial engineering from the University of Arkansas. Before moving into academia, Dr. Cariapa was Head of Tool design in Bharat Heavy Electricals, Tiruchy, India.

George Corliss is Professor of Electrical and Computer Engineering at Marquette University and is currently serving as senior scientist at Marquette University's GasDay Labs. He teaches a variety of computer science/engineering courses, as well as the Multidisciplinary Capstone Design course. In addition to academic employment, he has worked for a software consulting firm, a healthcare provider, a national research laboratory, and a nautical equipment firm. He obtained his PhD in Mathematics from Michigan State University in 1974. His research areas include scientific computing, interval analysis to provide guaranteed error bounds, mathematical modeling, forecasting energy consumption.

Kate M. Kaiser is Emerita IT faculty at Marquette University. She has studied IT skill needs and the impact of offshore outsourcing from Ireland, Russia, and India through research grants from the Sloan Foundation, 3M Foundation, and the U. S. State Dept. as a Fulbright Scholar. Kate led the IT Workforce Research Team for seven years, was a member of the Association for Computing Machinery IS Model Curriculum 2010 Task Force, and worked for Giga Information group on the Y2K team. She has published in a variety of practitioner and academic journals such as *MIS Quarterly, Communications of the ACM, Academy of Management Journal*, *MIS Quarterly Executive, Information Systems Management, and Communications of the Association for Information Systems,* among others, and presented IT skills research in many countries. Her B.A. and MBA are from Kent State University and Ph.D. from the University of Pittsburgh.