AC 2010-1181: DESIGN AS THE PRIORITY IN ENGINEERING EDUCATION: AN IMPLEMENTATION IN A SENIOR PROJECT COURSE

Angkee Sripakagorn, Chulalongkorn University

Angkee Sripakagorn is an Assistant Professor in Mechanical Engineering at Chulalongkorn University, Thailand. He earned a Ph.D. from the University of Washington, an M.S. from Oregon State University, and a B.Eng. from Chulalongkorn University, all in Mechanical Engineering. His area of expertise is thermal science.

Kuntinee Maneeratana, Chulalongkorn University

Kuntinee Maneeratana is an Associate Professor in Mechanical Engineering at Chulalongkorn University, Thailand. She earned a Ph.D. and a B.Eng. in Mechanical Engineering, both from Imperial College of Science, Technology and Medicine, UK as well as a B.Ed. in Educational Measurement and Evaluation from Sukhothai Thammathirat Open University, Thailand. Her area of expertise is computational mechanics.

Design as the Priority for Engineering Education: An Implementation in a Senior Project Course

BACKGROUND

This work originated from a restructuring effort at the Mechanical Engineering Department, Chulalongkorn University, Thailand to revise the curriculum in the face of challenges from the transformation of the status of the University into an autonomous university, competition for students, and Washington Accord regulations.

PURPOSE (HYPOTHESIS)

This paper describes experience in implementing design as the means to the eventual goal of an engineering program – to empower the students to flourish to be capable engineers – via a capstone design course.

DESIGN/METHOD

The course administrative committee redesigned the course to provide the design experience as the integrative, capstone event of an engineering program. The design experience that is expected to deliver the desired outcomes is discussed and concluded into three main features for this framework. Then, the required ingredients for such design experience are discussed, including types of design projects, interrelation among main stakeholders, cultural norms and roles of the administrative committee. The assessment framework, comprising of outcomes, assessment tools, assessment criteria and evaluators, are also described.

RESULTS

There was a quick adaptation of the working processes between students and project advisors towards this new framework. By challenging students, this course succeeded in raising awareness in soft skills, such as working in teams and project management. In terms of the stakeholders, the examination panel plays a crucial role in initiating the changes while students are the key to negotiate changes. For the assessment framework itself, a check and balance between the advisor and examination panel is observed. The overall assessment demonstrates its ability to differentiate the quality of bad and good works such that distinctive features of best projects can be observed. This self-regulated approach of readjusting the guidelines from best practices and evolving characteristics of good works to suit the grading rules works remarkably well. A major problem found in students is the tendency to avoid analyses in the decision-making processes and rely primarily on creativity or black-box engineering tools in contrast to the high analytical skills obtained by students in lecture courses.

CONCLUSIONS

This paper demonstrates a continuous improvement in design project course in a curriculum. Management, inevitably, plays a crucial role in adjusting the workload/reward policy and bringing in financial and other supports such that the execution of the design experience in engineering education can continue and flourish.

KEYWORDS

Capstone design, senior project, mechanical engineering

I. Introduction

Presently, the operation of the mechanical engineering program at Chulalongkorn University, Thailand is under a number of constraints. Firstly, the curriculum has to comply with all requirements and desired outcomes from the governing bodies, both academic and professional. These regulations have profound impacts on the flexibility of the program structure due to the different emphases on contents and outcomes. In addition, the 2008 Chulalongkorn University Act transformed the status of the university from a public university into an autonomous university. The loss of fiscal security and benefits also brought further challenges. Moreover, the competition for students from local institutions and globalization present new threats, challenges and opportunities that a program has to accept and adapt [1]. Thus, it is clear that the methods of teaching and learning must be radically changed in order to ensure the success of the program.

This paper describes an experience in implementing design as the integrative experience of an engineering program via a capstone design course: 2103-499 Mechanical Engineering Project. Prior to this work, the learning experience and assessment in this course was entirely under discretion of faculty members. Project topics included design, programming, industry-related academic services. Even for projects involving design, students, in many cases, never went beyond conceptual design and analyses, hence, missing the integrative experience that this capstone course was supposed to deliver. With the new framework in which design become the priority, the restructuring process was launched in 2006, by Associate Professor Thitima Jintanawan with the authors as members of the administrative committee.

II. Design as an Integrative Experience in an Engineering Program

According to ABET, the operation of a program can be viewed as a two-loop process (Figure 1). A program delivers program outcomes by instilling knowledge and skills to students. When students graduated and go to workplaces, the program monitors and tries to ensure that competencies, described by program educational objectives, are developed during the work experience [2]. At present, the department has moved along a continuous change towards meeting the challenge of completing the program operation in Figure 1. In addition, the program itself is in the process of curriculum revision. The 2103-499 takes this opportunity to close the big loop with the immediate goal of commencing the processes that are deemed lacking, which are denoted by stars in Figure 1.

The two-loop process described in Figure 1 is very general. In terms of design issues in engineering education, however, ABET seems to be much more specific. While ABET is certainly aware of the less-than-major contribution of design in engineering profession [3-6], it picked design as an ultimate goal of engineering education. Very much in the same direction, JABEE stated that “Engineering design cannot be learned simply through class instruction in a few subject courses. In other words, engineering design integrates all aspects of engineering education [7].” The authors, as members of the administrative committee in charge, took up this challenge by initiating and implementing the new framework for the 2103-499. This senior project course has been restructured to provide the design experience as an integrative event of an engineering program.

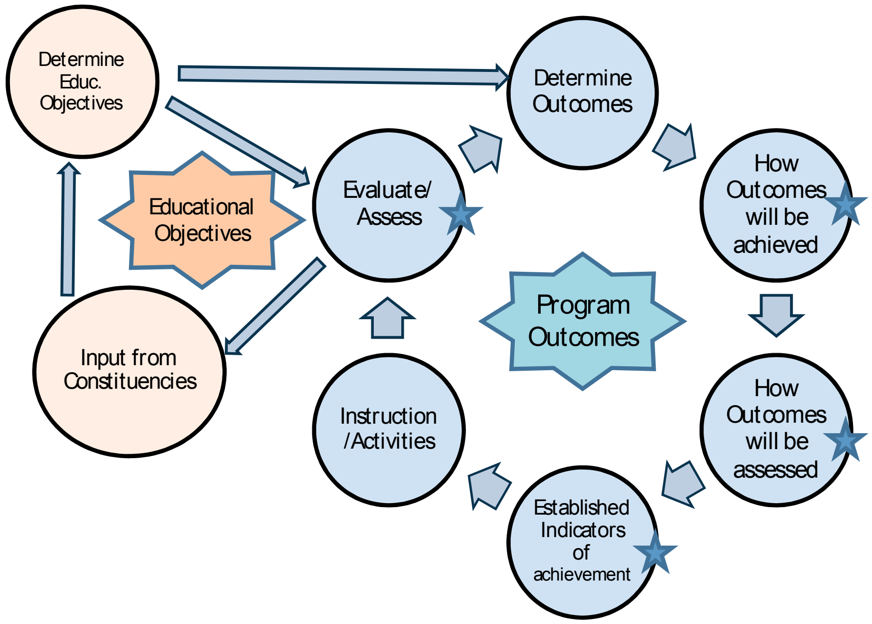

Figure 1. The “two-loop” process of the program operation according to ABET.

III. Implementation Strategies

The following is our interpretation of the ends and means of engineering education in terms of design. First, the intended design experience that is expected to deliver the desired outcomes to the students is described. Then, the required ingredients for such design experience are discussed, including types of design projects, interrelation among stakeholders, cultural norms and roles of the administrative committee.

A. Intended Design Experience

To avoid the prior shortcoming of this course, the importance of practicing the design process in full cycle must not be overlooked. Figure 2 illustrates an example of the design process. The width of the ring thickness in the background represents the relative degree of physical realism during the design process. Prior to this new framework, students usually ended up running out of time, effort or money before completing the design cycle. To be specific, in senior projects, many students never went beyond design specifications, conceptual design and analyses which were typical design experiences in upstream design courses. And, according to Figure 2, the situation they ended up with was as far from physical reality as a design process could get. Students who had been loaded with theory were left with chaotic abstraction of theoretical analyses.

With renewed focus on design, together with time and resources invested in 2103-499, all students are expected, at last, to complete a full design cycle, including realization and verification processes. This way, the student realizes the complexity of real world problems as well as the applicability and limitations of theories. Design provides a probe to the integrated delivery of all the knowledge and skills from earlier courses. Answers to accreditation bodies, both local and international, waits purposefully in design practices submitted by students.

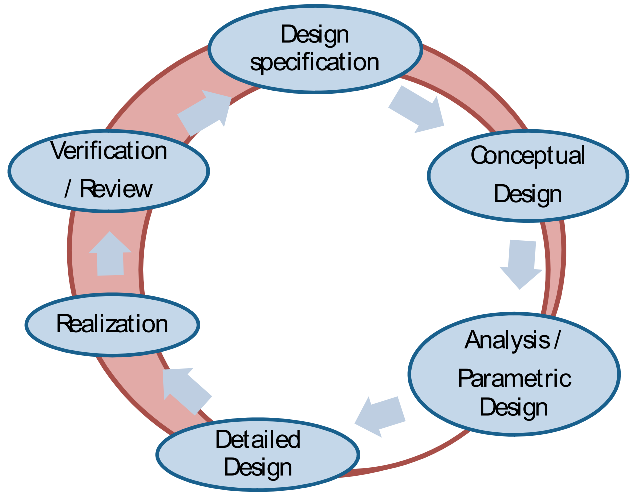

Figure 2. An example of the design process.

Consideration of realistic constraints is also important. Completing the full design cycle with realistic constraints may, at first glance, seem to make a project more difficult. On the contrary, this direction, from our experience, encourages advisors to see through and better prepare the projects. And while still kept open-ended, projects are well-posed and not endless. Nevertheless, should a project become too simplistic and lack challenges, students are also less likely to be aware of and develop soft skills such as working in team and project management.

At this point, it can be said that the design experience must be set up such that students are challenged to use and/or develop their knowledge and skills. But in hindsight, this is the very first time they go through the entire design process. Therefore, if the advisor loses focus and becomes too critical of whether the student demonstrates good design practices, the student will fail anyhow and their confidence will certainly be hurt. Instead, to build their confidence while ensure the development of their design practice, the focus of the assessment framework (Section IV) is to make sure students follow the steps in the design process and learn to apply knowledge and skills through those steps.

As a result, the way design experience is defined and assessed can be summed up into the three strategic approaches for this course:

a) Ensure that students go through the complete design cycle including realization and verification processes.
b) Encourage the development of soft skills such as working in team and project management by specifying well-posed yet challenging topics.
c) Focus on the experience in going through the design process, not on the professionalism of the results.

B. Types of Design Problems

To make the intended design experience possible, the first key issue is the specification of design problems. Currently, projects are classified into 3 areas of study, namely 1) applied mechanics

AM, 2) automotives AU and 3) thermo-fluids TF. These projects can be alternatively characterized into 2 types by the nature of their work, i.e., design and technical investigations. A design project concentrates on design experiences and ideally resembles a senior capstone design project [8]. However, unlike the trend in industrialized countries [9], these design projects have less industrial involvement and sponsorship. One of the reasons comes from the nature of the local industry which tends to be labor intensive and technology buyer. Another reason may be that the industrial initiation/co-funding is not mandatory for this course as few other institutes have imposed.

Meanwhile, the technical investigation focuses more on research, requiring systematic application of engineering science to analyze and/or synthesize systems or phenomena. Similar to other institutions, faculty members are presently being pushed to produce academic papers. Incidentally, our best students are undergraduate students. Therefore, some faculty members recruit students to help on research work and count research experience in the credit of 2103-499. On one hand, it is clear that research experience is not equivalent to design experience in the view of ABET. On the other hand, the department is expected to produce output with available resources. As a result, research experience is allowed in 2103-499 in the technical investigation category at present. Nevertheless, it must be ensured that the project includes the realization and verification processes. Technical usage is highlighted and the research work involves open-ended design tasks rather than strict procedural steps of work.

In the academic year 2008, 94 students registered for the course. The numbers of groups, classified by areas and types, are shown in Table 1. In recent years, on average, over 70% of all projects belonged to the design type. The data in Table 1 reflects this general trend.

Table 1. Number of Groups by Areas and Types

Area \ Type	Design	Investigation	Total
AM	8	3	11
AU	7	1	8
TF	7	4	11
Total	22	8	30

C. Advisor, Students and the Examination Panel

Another crucial aspect of implementation is the roles of concerned stakeholders. Key personal, besides the administrative committee implementing the framework, are advisors, students, and the examination panel. Like in any large department, faculty members, in our department, can be roughly divided into divisions – solid mechanics, thermo-fluids, and robotics and control. They also come from different backgrounds – research faculty, faculty working in industry and teaching faculty. A faculty member becomes an advisor by initiating projects or bringing projects from industry for students to choose from. In many cases, students themselves also come to a faculty member with possible projects that fit the lecturer's background. As the design experience occurs primarily via advisor-student interaction, the understanding and acceptance of faculty members toward the new framework is crucial to the success of this course. From our experience, the faculty member buy-in process has proved to be long, involving students, grading rules and the examination panel. This rather indirect and circuitous channel working with an enforceable carrot-and-stick approach is chosen.

Prior to the implementation of the new framework, the learning process was only between the advisor and the students. After the launch of this framework, two things are placed between – grading rules and the examination panel. The grading rules are changed to directly represent the course outcomes and equally rely on the examination panel as well as the advisor. The examination panel consists of volunteered faculty members. They were recruited as early adopters of the ideas and involved in the setup of the new framework. Many panel members are closer to students than the committee and better understand students' concerns about this framework. Through regular communication with the administrative committee, the examination panel provides valuable feedback to the committee regarding this new framework. In return, some of the panel members who are project advisors get the intimate knowledge of the assessment framework and can better prepare their students.

Equally important, students also play an important role in the adoption of this framework. They accept the rules rather well. And since the grading rules and impacts on their final grades are made clear, they show much interest in the minute details of this new framework and are proven to be quick learners. Some advisors are found to be indirectly influenced by students and also by their fellow faculty members who are in the panel to accept the new framework.

D. Cultural Norms

During the implementation, the cultural norms became an issue in more than one circumstance. First, most of our faculty members work individually or in small groups with very flat management. In the view of making changes to a course operation, this nature of working present obstacles in terms of getting messages across or making changes. However, due to their close working relationship with students, faculty members can be indirectly influenced by students as already mentioned. In addition, by not being forced to participate as a duty, volunteers, including the administrative committee and the examination panel, work best.

For the students, they accept the dominant position of the administrative committee and the new rules rather well as long as they understand and receive updated information about the course. The most frequent complaints from the 2008 course evaluation were communication. In a separate study on teamwork [10], students were rather comfortable with working in teams. This might be a result of self-selected teams. But after working together through challenging tasks, some students did report conflicts and a tendency to avoid working together in the future despite the cultural norms of not directly criticizing their peers.

In hindsight, these management practices conform to the Thai culture [11]. Even though social system is strongly hierarchical, self-esteem, individualism and interpersonal relationship are important. Thais are also moderately comfortable with uncertainty, fairly tolerant and flexible. This makes Thai culture somewhat different from other Asian cultures and, thus, typical management tactics used in such capstone courses must be adapted to suit local conditions.

E. Roles of the Committee

Lastly, the roles of the committee can not be underestimated as it is responsible for all management duty, ranging from setting framework and guidelines to conducting course evaluations by all stakeholders and implementing changes from feedbacks.

With the decision to embrace design as the synthesis event and integrating all aspects of the educational experience, the committee set up a clear and concise direction for the framework. After that, the committee avoids setting de facto standards on desired attribution from the design practices. Instead, the committee picks out the best works according to the course outcomes and uses these works in the communication with those who are still lagging behind.

The committee avoids forcing changes through a strict set of rules or regulations. Instead, the committee facilitates changes, values good works and negotiates with below-par works. For example, the committee arranges regular communications with advisors and examination panels. There are clinic sessions for students to consult about their proposal and oral exam preparation within a laid-back environment. To further motivate the advisors and students, the committee also arranged the best project competition to honor the group of students and advisors who delivered best practices.

IV. The Assessment Framework

Once all aspects of operation are included in the consideration and discussed among stakeholders, the main implementation of the educational experience is possible via the assessment framework, comprising of outcomes, assessment tools, assessment criteria and evaluators. These outcomes are:

#1: Work with and complete a mechanical engineering project that contains the complete design cycle, including realization and verification processes.
#2: Use engineering knowledge in the design decisions.
#3: Demonstrate the ability to work in teams.
#4: Manage the project to progress with adequate pace and finish on time.
#5: Communicate effectively in both oral and written communication.

Table 2 describes the assessment framework for 2103-499. Overall, 50% are awarded by the advisor and 50% by the examination panel. The first two outcomes, which are the completion of the full design cycle and the use of engineering knowledge in design decision, accounts for 60%. The remaining 40% come from soft skills, including working in teams, project management and communication skills. From a different perspective, the grading framework places 40% on the initiation and the progress of a project while 60% is awarded to the final results.

At the start of the academic year, the administrative committee works with the advisors through the students to come up with the project proposal that, most importantly, covers the intended design experience. As discussed earlier, the key is to include design realization and verification processes. In addition, students need to plan the project well, including task distribution among the team members, scheduling and budgeting. These issues become the commitment that will be tracked and graded as a part of assessment in the project management (Outcome #4).

Table 2. The assessment framework for 2103-499

Evaluator	Advisor		Digest #1	Digest #2		Digest #3	Digest #4			Final Report
	Examination Panel	Proposal			Progress Exam			Final Exam	Extended Abstract	
Outcome	1: Completion		×	×	×	×	×	×	×	×
	2: Eng. Know.		×	×	×	×	×	×	×	×
	3: Teamwork		×	×		×	×			
	4: Proj. Mgmt.		×	×	×	×	×			
	5: Comm.	×							×	×

After that, assessment tools include four digests, two oral exams and two formal documents. The digest is a short summary of the progress assessed by the students themselves and submitted to be graded by the advisor. These digests are formal documents which must include technical highlights such that the examination panel may use as supplementary materials in the two oral exams. Half way through the year-long period, the examination panel encourages the working progress with the progress exam. This progress exam coincides with the timing where, for most projects, conceptual design and design analysis should be completed. Students are graded on project management and completion of work as committed in the proposal as well as the use of engineering knowledge.

At the end of the academic year, the final oral exam focuses on the completion of the full design cycle. Students are also expected to explicitly demonstrate their experience in applying engineering knowledge in making design decisions. The student also wraps things up in the final report which is graded by the advisor according to the common grading guideline provided by the administrative committee. The additional extended abstract is requested so that students have to concisely demonstrate their accomplishment as well as the written communication skill. This extended abstract is graded by the examination panel. A guideline and examples of best practices are provided to the students such that they are clearly aware of the expectation and ways to meet that. This abstract is also used as a supplementary material in the final oral exam as well as collected as a publicity material for the department.

The assessment results are evaluated via rubrics. Admittedly, these rubrics can be quite abstract for students and even faculty members alike. Collection of best practices on every deliverables is therefore available for students to further elucidate the course expectations. Table 3 shows an example of the rubric employed for the final oral exam. The rubric gauges accomplishment by: (1) meeting the goals under the deadline, committed by students themselves, and (2) demonstrating the use of engineering knowledge in decision making processes. It should be noted that the key idea is to demonstrate the use of knowledge. The appropriate use of knowledge is up to the project advisor. The student can get feedback on their design practice as well as being graded upon via the four digests. The panel only ensures that the use of knowledge in engineering decision is carried out in practice.

Table 3: An example of the rubric for the final oral examination

Outcome	Weight	Question
1: Completion	40%, average all objectives equally.	Does this project meet objectives specified in the proposal? [Yes, perfectly = A(82.5%), Yes = C(62.5%), No = F(47.5%)]
2: Eng. knowledge	60% 20% total	Do the students consider major issues adequately to ensure objectives are met? [Yes, completely = 100%, No, they lack __________ = –50%]
	40% total (Q1-Q2)	Q1) The use of engineering knowledge in the undertaking of the project. [Yes, perfectly = A(82.5%), Yes, adequately = C(62.5%), Minimal use = F(47.5%)]
		Q2) The use of engineering knowledge is logical and practical. [Yes = no deduction, No = 10% total deduction]

V. Results

In this section, major findings from this work to implement design as the major experience in a capstone course are described in terms of design experiences, emerged best practices, personnel management and issues that need improvement.

By the way the design experience is defined – clear and concise, virtually all projects complete a full cycle of the design process at present. For some projects, the design problems may appear, at first, to be too simplistic. But indeed, they are rather well-posed and provide a decent platform for learning. For the development of soft skills, via formal meetings and informal demonstration of actual examples of best practices, students appear to be more familiar and aware of issues in project management and working in teams. Another finding is that, after this restructuring, virtually all groups managed to finish the projects on time. This is probably due to the better-prepared proposal, the well-thought project as well as the pressure from the framework and peers. This trend is good for students in the view of their career placement or graduate school applications.

After the initial period, features of best projects start to emerge and can be divided into three areas. The first is the industry related projects, especially with co-funding or sponsorship. With a well-defined and well-scheduled proposal from industry as well as strong financial and other supports, this kind of project usually excels. Similarly, the research-oriented projects initiated from an established research laboratories also usually succeed. Lastly, many projects are involved in major, and in many cases, international competitions. Faced with major challenges, many of these projects are successful due to students' motivation and determination as well as from support from their advisors.

In terms of the personnel management, the examination panel plays a crucial role in initiating the changes while the student is the key to negotiate changes. Via close and continued communication, there is a strong consistency in grading results among faculty members in the examination panel. The check and balance between the scores from advisors and the examination panel is observed in Figure 3 where the distribution of grading from Academic Year 2008 is shown. The diagonal line indicates the equal score from both the advisor and the panel. The graph shows that the data mostly stays on the left of the diagonal line, meaning that the examination panel is generally more critical on the grading than the advisors. An interesting finding is that, should the advisors relax on the grading, only some groups do have chance to get a good total score as a result of the grading from the panel. On the contrary, for projects with more critical advisors, they are more likely to get good scores from the examination panel as well as good total scores. This might also be an indication of closer supervision and guidance from the advisors during the working process.

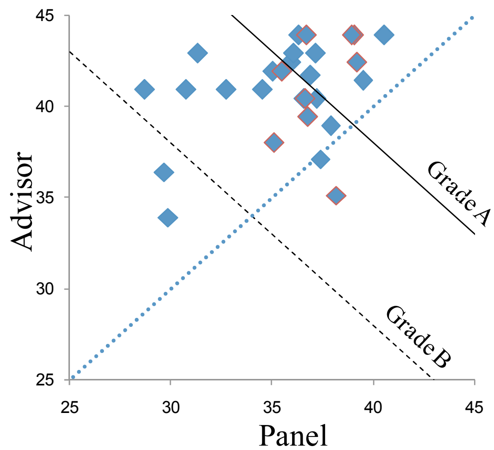

Figure 3. Advisor vs. Panel grading distribution from the academic year 2008.

At the end, however, it is the students who move this framework forward. Even with clear specifications of course outcomes, the grading rules and rubrics were vague at best at the start. Little by little, students adapt to the grading framework and start to deliver ingredients of the best practices. This self-regulated approach of readjusting the guidelines from best practices and evolving characteristics of good works to suit the grading rules works remarkably well in this course. From words of students and the imminent standard set by the best practices from previous years, advisors that were not directly involved in the first place started to pick up the changes. This evolving framework, while meeting the predetermined outcomes, become satisfying and clear to students and advisors alike.

From the assessment results, an important issue that needs improvement is the use of knowledge in the decision-making process. In view of lecture courses, students may appear rather keen on analytical skills. But by gleaning from their reports or listening to their presentation, there exists a tendency to avoid analysis. Anecdotal evidences indicate that in between learning and applying theories in design projects, students usually get lost in two ways. First, they may have tried to apply theory to practice and yet not be encouraged to follow through. Secondly, some may have tried and lose their way or arrived at an endless quest of nothing. Although it is typical that the first trial is a failed trial, this kind of experience and feeling might discourage these future engineers to engage in design practice in their future profession. The panel as well as the advisor can play an important role in providing positive comments on the ways to attack practical problems or interpreting results of the analyses.

VI. Conclusions

Engineering education needs design as an integrative event to accomplish the eventual goal which is to instill in students the knowledge and skill building blocks while leaving them empowered and ready to grow to be capable engineers. This paper demonstrated three key approaches toward successful design experience in a senior project course. Students, who as quick learners, and the examination panels, who volunteered as early adopters on the new framework, are found to influence the project advisors to move towards the desired change. A clear and consistent assessment framework helps to properly set up the intended design experience and to negotiate discrepancies in the final grading between the panel and the advisor. The collection and distribution of best practices produced by students themselves works well in moving this framework forwards in a two-way communication between the administrative committee and the students. For the future work, the assessment tool is to be adjusted to further encourage the use of knowledge in decision making processes. The rubric, though covering all assessments, has to be continuously improved as a guideline for desired design experience and expected deliverables. Management, inevitably, plays a crucial role in adjusting the workload/reward policy and bringing in the financial and other supports such that the execution of the design experience in engineering education can continue and flourish.

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