AC 2012-3309: EFFECTIVE ASSESSMENT OF ENGINEERING DESIGN IN AN EXAM ENVIRONMENT

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Effective Assessment of Engineering Design in an Exam Environment

Abstract

One of the most difficult aspects of engineering is the effective teaching of engineering design. While it is paramount that every engineering student be exposed to engineering design, it can be difficult to assess the design skills of individual students. Most design assessment is typically conducted at the project or team level, and many assessments of design effectiveness only use the capstone experience. This is clearly inadequate. Instead, what is needed is an effective method that can be used to partially assess the design capabilities of individual students in an exam setting.

This article will discuss an approach to assessing design skills in the exam environment. It allows for the effective assessment of some design skills and practices in an exam environment without placing undue stress upon the student. The approach involves a short case study provided to the students as part of an exam review sheet, the construction of design questions based upon the case study, the definition of detailed rubrics to assess the quality of the design, and the administration of the exam in a controlled setting. Student achievement is discussed, as well as the advantages and disadvantages of this approach to assessing design skills.

Introduction

The teaching of design skills to engineering students is paramount to their success as an engineering professional. ABET outcome C specifically states that graduates of an engineering program must have "Ability to design a system, component, or process to meet desired needs" and outcome k states that graduates of an engineering program must have an "Ability to use the techniques, skills and modern engineering tools necessary for engineering practice."[1]

Many different people have commented on issues related to the lack of engineering design education in current educational programs[2] and indicated that a stronger emphasis on design and design skills is necessary for current students to be successful in a global workforce[3,4]. In essence, teaching design is difficult, as most engineering faculty members are neither design practitioners nor have significant experience actually performing engineering design as a professional[4].

This leads to the question of how we can best teach design skills to undergraduate students. Traditionally, most engineering programs have incorporated a capstone engineering course into their program and used this as a place to make all assessments about student design skills and student teamwork. The problem with solely relying on this mechanism is that students need to be taught how to design and how to work in teams. To counter this, programs have adopted freshman engineering design sequences whereby students work in teams on a domain neutral problem[5,6,7].

While these programs are very effective, it is often hard to assess individual student's performance within this environment. Class sizes must be small, or else it is possible for an individual's contribution to be lost to the team atmosphere. Even with small class sizes, aside from an exit survey, it can be difficult to assess the design skill of any given student.

Design Outcome Distinction

True design requires open ended problem solvers, exhibiting the following attributes[8,9]:

- Are willing to spend time reading, gathering information, and defining the problem.
- Uses processes, as well as a variety of tactics and heuristics to tackle problems
- Monitor their problem solving process and reflect upon its effectiveness
- Emphasize accuracy rather than speed
- Write down ideas and create charts / figures, while solving a problem
- Are organized and systematic
- Are flexible (keep options open, can view a situation from different perspectives / points of view
- Draw on the pertinent subject knowledge and objectively and critically assess the quality, accuracy, and pertinence of that knowledge / data
- Are willing to risk and cope with ambiguity, welcoming change and managing stress
- Use an overall approach that emphasizes fundamentals rather than trying to combine various memorized sample solutions.

As has been described by Davis et al.[10], design education outcomes can be split into three distinct areas, namely design knowledge, design processes, and design products. Design knowledge represents terminology, concepts, and relationships between design inputs and design outputs. Design processes are the steps necessary to create design products. Design products are the items created as a result of a design activity and include the resulting software, systems, materials, or objects. In a typical curriculum, the percent of material taught in each year will vary, as is shown in Figure 3. This, in general, represents the shift toward high Bloom level in later courses.

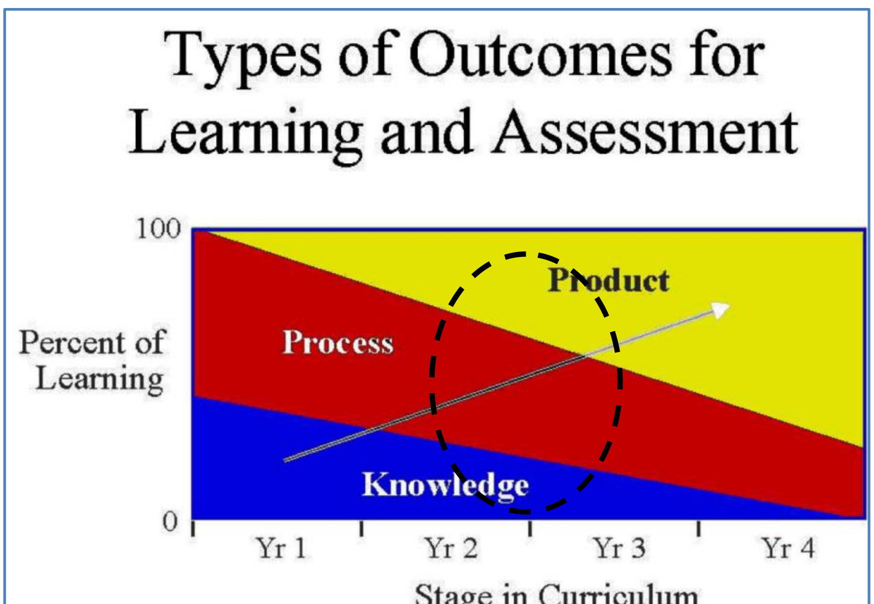

Figure 1 Design Outcomes versus Educational Stage[3]

Challenges of Assessing Design in an Exam Setting

For many aspects of engineering, the traditional exam setting is the perfect environment to assess student understanding of concepts. This is generally true for concepts of Knowledge, comprehension, application, and analysis within Bloom's taxonomy. However, as one approaches high levels of Blooms taxonomy, the traditional exam may be replaced with a take home exam. This allows students to not be in a time crunch when working the exam as well as using the appropriate resources to master the exam. In general, however, take home exams tend to result in lower student performance versus in class exams[11,12]. The other obvious problem is maintaining the academic integrity of the exam.

With these issues, it is obvious that some form of a hybrid approach to testing is required. The approach must recognize that design is a creative process and may require multiple iterations. It also must recognize that multiple students may not come up with the same exact design. Meeting these criteria requires a more advanced and structured approach to designing an exam. The design problem domain must be chosen appropriately in order that the student can understand the problem as it is presented to them. Furthermore, for students to be prepared, they need to have an idea of the scope of the problem prior to the exam in order that they can properly prepare.

Exam approach

The approach described here has been successfully used for a sophomore software engineering practices course. In this particular course, students are being taught a software design process which is based upon industrial practices. Students have been shown design examples in lecture and have completed design activities in lab. In both of these cases, however, the activities were carried out as a small group, not as individuals.

The first step of the exam process is to carefully construct the design problem. This typically requires multiple iterations and revisions by the instructor in order to develop a problem which is neither too complex nor too simple. The problem itself must have expected student outcomes that are to be assessed, and these outcomes must be quantified through the construction of a grading rubric. Construction of the exam problem also involves writing a case study explaining the problem, as well as developing a detailed grading rubric.

Example problem

Student preparation for the exam begins with a traditional exam review guide. This exam review guide (or review sheet) lists the course outcomes from which the instructor will be selecting questions for the given exam. These outcomes generally can be taken directly from the daily learning outcomes used to plan the syllabus.

Students at MSOE have a lot of meetings, especially as senior design gets closer. This makes scheduling meetings very tough. To help improve this situation, a decision has been made to create an automated meeting scheduler system. The system will use the existing Exchange server in Outlook and an iPhone application.

To schedule a meeting, a student creates a meeting request using their iPhone application. The request includes the people who need to be at the meeting as well as the agenda for the meeting. The user also sets a deadline for when the meeting is to be scheduled (for example, “no later than Friday, May 31.”) The system will then determine the optimal time for the meeting and send meeting invitations to all meeting attendees. Meeting attendees will be given the opportunity to either accept or decline the given meeting. If the user accepts the meeting, the meeting is added to their calendar on the Exchange server. Once a meeting is requested, the meeting organizer can also have the system automatically reserve an appropriate room in the AdAstra system MSOE’s room reservations system). If necessary, meeting organizers can cancel a given meeting or request a reschedule of a meeting.

Users of the system can configure times that they are available and willing to have meetings, as well as “blackout periods” where no meetings can be scheduled. Users can also configure how they wish to be reminded (for example, text messages, e-mail messages, voice mail messages, etc.) Users can also block other users from including them in meetings. A user who is abusing the system can also be reported to the administration. Administrators can add and remove users from the system as well as cancel meetings found to be in violation of university principles.

Authentication for the system is handled via a user name and password combination. This information is stored on an existing LDAP server, and is the same username and password used to access all other MSOE records.

Figure 2 Sample Problem Scenario given to students as part of a review guide for an exam.

However, in addition to the outcomes, there also is a written scenario. The scenario describes the scope and purpose for a more in depth system which the students will use extensively on the exam. Figure 2 shows a sample scenario given to students as part of an exam guide. Note that, in essence, it describes a software system. Students are expected to read the scenario in advance and start to think about the problem based on the design techniques taught in class. Students are also free to ask questions of the instructor about the design concept as well, and in study sessions, they may discuss the problem with fellow classmates. All of these activities are intended to start the brainstorming thought process for the exam.

On the exam, students are then given one or more open-ended design questions which are related to the design scenario provided. These questions may involve the analysis of a systems usage, the architecture for such a system, or any number of specific questions related to the design approach for the given system. Two example questions based upon this scenario are given in Figure 3.

6. (12 points) Given the previous description, draw a use case diagram for the system, making certain that all Actors involved in the system are accounted for, the system is labeled appropriately, and associations between actors and use cases are documented.
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7. (15 points) Given the previous system description, write a complete use case scenario for the "Schedule Meeting" use case scenario. Be certain to include preconditions, a high level description, associated actors, normal flow, and alternate flows.

Figure 3 Sample Problem Scenario given to students as part of a review guide for an exam.

Grading

Because these problems are, by their very nature, opened ended, there is a vast variance in answers. This is not uncommon for a properly implemented design, as proper implementation of a design requires significant analysis and decision making skills to be applied by the designer. Small differences during this decision making process may lead to radically different resulting designs.

When grading a design problem, it is important to determine the effective weight to be placed upon both adherences to the design process as well as meeting the needs for the design. This ensures that the student is demonstrating both the appropriate thought process (ideally the process taught in the design course) as well as meeting the needs of the system. Figure 4 provides a sample grading rubric used to assess problems 6 and 7. For the problem 6 rubric, note that 5 points are assigned to the representation of the design (the documentation for the design) while 7 points have been assigned to the quality aspects of the design. A similar ratio holds true for problem 7, where 8 of the points are assigned to the design representation and 7 of the points are assigned to the quality of the artifact.

6. (12 points) Given the previous description, draw a use case diagram for the system, making certain that all Actors involves in the system are accounted for, the system is labeled, and associations between actors and use cases are documented.

Grading Rubric:

Grouping	**Description**	**Points / Ratings**
Design Representation	Use case diagram correctly associates between the actors and the use cases	(Fully, partially, incompletely)- 2
	Use case diagram properly shows the extent of the designed system	(Present, absent) - 1
	Use case diagram properly reflects the system actors	(Fully, partially, incompletely) – 2
Design Process	Appropriate system actors have been identified	(Fully, partially, incompletely) - 2
	Appropriate names have been applied to actors based on system scenario	(Fully, partially, incompletely) - 2
	Use cases are appropriate to the system given the system's description	(Fully, partially, incompletely) - 2
	Use cases are appropriately associated with other use cases when associations make design sense	(Completely if necessary, absent if necessary) - 1

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7. (15 points) Given the previous system description, write a complete use case scenario for the "Schedule Meeting" use case scenario. Be certain to include preconditions, a high level description, associated actors, normal flow, and alternate flows as they may exist.

Grading Rubric:

Grouping	**Description**	**Points / Ratings**
Design Representation	Appropriate name given to use case scenario	(Complete / Incomplete) – 1
	Involved actors for the use case scenario properly identified	(Fully, partially, incompletely)- 2
	High Level Scenario reflects the purpose for the use case in succinct terms without providing overly specific details	(Fully, partially, incompletely)- 2
	Preconditions identified for the use case scenario	(Fully, partially, incompletely)- 2
	Flow text provide for both the main flow and the alternate flows through the use case scenario.	(Fully, partially, incompletely)- 1
Design Flow / Quality	Main flow provides appropriate level of detail to understand the purpose for the use case	(Fully, partially, incompletely)- 2
	Main flow properly completes the use case as appropriate	(Fully, partially, incompletely)- 2
	Alternate flows appropriately represent the problematic flows through the use case scenario	(Fully, partially, incompletely)- 2
	Alternate flows clearly represent systemic errors rather than a combination of multiple use cases.	(Valid / Invalid) - 1

Figure 4 Sample Problem Scenario given to students as part of a review guide for an exam.

Assessment of Effectiveness

With any teaching technique, it is vital that the technique be assessed for effectiveness. This testing technique has been used in one sophomore level course for two years. Prior to introducing this technique, students were expected to perform design tasks on the midterm and final exam. However, students were simply provided with a traditional exam sheet, listing the objectives that were covered on the exam. In general, students did poorly on these questions. Students also had difficulty finishing the exam in the allotted timeframe.

Figure 5 provides assessment data on the effectiveness of this technique at assessing student design skill in an exam setting. In all three years, problems testing the same three course objectives were given on both the midterm exam and on the final exam, and for each of the three years, the same general grading rubric was used to assess the design problems, though the weights on the exam were shifted slightly over the three years, ranging between 30% and 40% of the overall exam content. To assess the effectiveness of the technique, student performance was assessed as exceptional if the student scored greater than a 90% on the design related questions, competent if the student scored greater than 75% on the design related questions, marginal if the student scored greater than a 55% on the design related content, and inadequate if the student scored less than or equal to 55%.

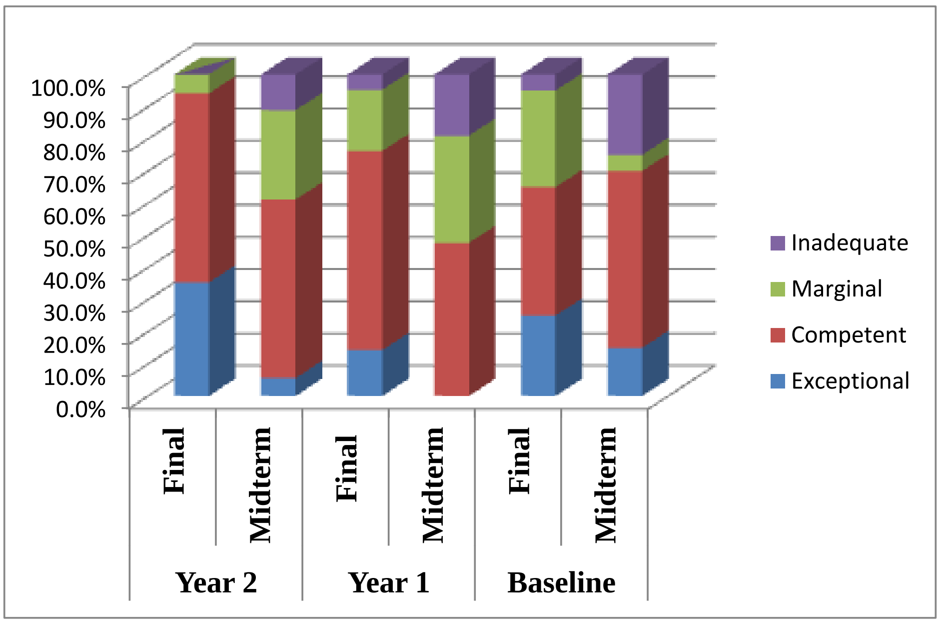

Figure 5 Exam Assessment Results over 3 year period.

Table 1 Design Assessment Data.

	Year 2		Year 1		Baseline	
	Final	Midterm	Final	Midterm	Final	Midterm
Annual Change Exceptional + Competent	17.9%	13.5%	11.2%	-22.4%		
Midterm to Final Change Exceptional + Competent	33.0%		28.6%		-5.0%	
Overall Change Exceptional + Competent	29.1%	-8.9%				

Table 1 provides data relative to the change in student performance over the three years profiled. In the first year, there is no change in performance between the midterm and the final exam on these design related questions, and overall, the assessment of student performance is the lowest of the three sampled years. In the second year, there is a strong performance improvement between the midterm and the final exam, indicating the students may not have been completely comfortable with the material at midterm time but by the final exam they better understood the material. This shift principally involves students moving out of the marginal performance category. More importantly, the final exam scores for design content were significantly higher in Year 1 and Year 2 versus the baseline year. This pattern again repeats in the third year. A qualitative judgment can also be made relative to the difficulty of the exam. During the baseline year, many students complained that the exam was too long and too hard. This comment was received less often during Year 1 and Year 2.

Conclusions

This article has presented a mechanism that can be used under certain circumstances to assess students' design capabilities in an exam setting. The mechanism requires minimal modification to the traditional exam structure yet significantly improves the ability of students to demonstrate individual design capabilities.

While an initial study of effectiveness has been provided, there are still grounds for significant future work. One aspect that needs to be investigated is the relationship between performance in an early class and performance in a capstone design course. The assumption is that students who do well in this early assessment would also do well on capstone projects. However, due to changes in domain and problem scale, this correlation may not be strong.

It is also important to compare the effectiveness of this mechanism versus the take home exam. While the take home exam does have significant issues, on an open ended design problem, it may be that that environment is more effective from a time aspects than a traditional exam setting.

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