International Journal of Engineering Education Vol. 28, No. 4, pp. 892–903, 2012
Printed in Great Britain
0949-149X/91 $3.00+0.00

The Value of Impromptu Design Exercises as an Approach in Design-Centric Engineering Education*

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To address the significant gap in engineering curricula regarding the teaching and learning of design, accrediting agencies and industry leaders have called for the integration of design experiences throughout engineering coursework. This paper shares the results of a study which examined the process of implementing impromptu design exercises in engineering science classes as one means of infusing design instruction throughout the curriculum. The paper shares both the challenges and benefits cited by instructors and students in using impromptu design activities to teach design. The authors conclude that impromptu design exercises hold considerable potential as an approach in design-centric curriculum, a potential not fully realized by their current use as icebreaker or team-building activities.

Keywords: impromptu design; design education; hands-on pedagogy

1. Introduction

A critical problem facing traditional engineering programs is the lack of curricular coherence regarding design education. The ability to design a system, component, or process to meet desired needs is a fundamental engineering skill, however, typical engineering programs emphasize design at the freshman level in *cornerstone* courses and then again, at the senior level, during *capstone* courses [1–7]. Sophomore and junior years are then devoted to engineering science courses intended to build a solid technical knowledge base, typically without giving students opportunities to practice design thinking [8–10]. Thus, design experiences comprise disjointed bookends in students' college careers. Consequently, when students reach senior year, they are often unprepared for their cognitively demanding, real-world-like senior design projects. The effects of this poor preparation are later felt as students enter the workforce [11–13]. To address this significant gap in the learning sequence, accrediting agencies (e.g. ABET) and industry leaders have called for a more *design-centric* education, where design is a central theme that is integrated throughout all four years of the engineering curriculum [14]. In response to this call, this paper presents the results of a study on the use of content-reinforcing impromptu design exercises [15–18] in engineering science courses as a means to integrate design education across the curriculum.

As the authors see it, the move towards more design-centric engineering education can take place in two ways. First, engineering programs can consider a large-scale curricular revision in which programs are restructured to focus more heavily on design, e.g., new design courses or studios [19–21], or by completely changing the typical engineering curriculum to focus entirely on design [22]. Second, aspects of design can be infused into existing engineering science classes [15–18, 23, 24], thus weaving design throughout the curriculum without drastically changing course requirements. If the goal is to integrate design into engineering curricula, a wholesale restructuring is perhaps the preferred option since it grounds the entire engineering program in design; however, this approach requires faculty-wide "buy-in," time, and money, all of which may be difficult to obtain. While working within the

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* Accepted 4 March 2012.

existing curricular framework, the second approach requires less drastic changes in course requirements, but might result in uneven implementation of design instruction by faculty in their courses.

Impromptu design exercises represent the second approach described above, i.e., they offer a valuable way to integrate design into existing engineering science courses [15–18]. In a typical impromptu design exercise, students are given a simple design task capable of being completed in a short amount of time. In addition to a needs statement, description of the problem, and scoring metric, students may receive a bag of materials to use in solving the problem. Working in teams, students approach the problem as they best see fit with minimal assistance from the professor. After the allotted time has transpired, the professor and students evaluate the designs according to a predetermined metric.

The study described in this paper presents one of the first systematic studies focused on using impromptu design in engineering science classes. The current research in this area has focused on the ability of impromptu design exercises to foster creative thinking and team building [15]. A study performed in classrooms across the College of Engineering at Villanova University (VU) is presented and results are discussed. This study examined the process of implementing impromptu design exercises into engineering science classes and sought to identify the potential benefits and challenges for both students and instructors. To this end, we found that, while implementation of impromptu design exercises may be more challenging for professors than straightforward lectures, students see them as contributing to their design understanding.

The remainder of the paper is organized as follows: In Section 2, background regarding impromptu design exercises and how they fit into the current research on design pedagogy are discussed. In Section 3, details of the study are discussed. In Section 4 and 5, results of the study and a discussion of these results are presented. Finally, in Section 6, conclusions are drawn and future directions for the work are identified.

2. Background

As discussed in the introduction, there have been significant efforts over the past years to integrate engineering design throughout the engineering curriculum. However, it is difficult to emphasize pure design education in engineering science courses, while at the same time covering all the important content expected of an engineering program. This "time-crunch" provides a niche for impromptu design exercises.

2.1 Impromptu design exercises

Impromptu design exercises require students to solve a simple design task in a limited amount of time (15 to 30 minutes). Working in teams, students approach the problem as they best see fit with minimal assistance from the professor, e.g. students may employ methods such as trial and error or design-build-test-redesign. Unlike typical hands-on exercises (such as laboratories), students are not given a set of procedures to follow, but rather must develop the steps themselves. After the allotted amount of time, students evaluate the designs according to a predetermined metric to identify a "winner."

An example impromptu design exercise problem statement used in a construction materials class (VU course CEE 2106) is shown in Figure 1. For this exercise, the supplied materials included equal amounts of cement, water, fine aggregate (sand) and coarse aggregate (gravel). Using these four basic concrete constituents, students were asked to proportion and mix materials together to obtain a mixture that could be poured and placed into a cubic mold (2 × 2 × 2 inches). Once students completed the proportioning steps and poured the mixture, they were asked to provide the amount of each material used and the mixing sequence they followed. This impromptu design exercise was then directly followed by a lecture on how to properly design a concrete mixture using the ACI design method. During the next class meeting, their cubes were tested under compression and the strength of

Need Statement: A new high-rise building is being constructed in Philadelphia. Concrete compressive strength requirements need to be met for the material to be accepted.

Problem: Design a concrete mixture that will maximize strength while minimizing cost.

Scoring Metric: The design will be judged based on the maximum compressive strength (f'_c) and minimum cost of the mixture, following the final score formula:

$$Score = 75\frac{f'_c}{f'_{c,\max}} - 25\frac{P}{P_{\min}}$$

Fig. 1. Example impromptu design exercise used in a construction materials class.

Fig. 2. Students test a concrete beam fabricated using the winning mixture from the impromptu design exercise.

the concrete designs was determined. A class discussion comparing different results ensued. The winning design was then used to design a large concrete batch and cast a full-scale concrete beam that was tested in three-point bending, as seen in Fig. 2. This allowed students to see how their initial design decisions related to real-life applications.

Impromptu design exercises differ from other types of problem-based learning or cooperative strategies in at least two ways. First, the "impromptu" nature of the exercises means that students do not have an opportunity to gather information on the problem in advance. Students encounter the dilemma for the first time when their professors give them the bag of materials and problem statement. They must quickly jump into action, using only the knowledge and skills they have available to them at that moment (which may include knowledge of engineering science content they have learned in previous lectures). Second, unlike large-scale, long-term projects, impromptu design activities are "exercises," not extensive undertakings. Since they are purposely intended to be brief, impromptu design exercises do not offer students the time to procrastinate regarding the task or lose interest in the project. In a short amount of time, students witness an idea's transformation from a bag of deliverables to a final product. Consequently, they instantly see the effects of their design decisions.

2.2 Design education and impromptu design exercises

In ABET's 2010-2011 Criteria for Accrediting Engineering Programs engineering design is defined as:

> . . . the *process* of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the *basic sciences, mathematics, and the engineering sciences are applied* to convert resources optimally to meet these stated needs [emphasis added].

The emphasized words in this definition point towards key ideas involved in engineering design—first that design is a *process* and second that technical material is *applied*. Traditional engineering curricula fail to adequately address these two key components of the ABET definition. Specifically, the use of cornerstone (freshman) and capstone (senior) projects does not give students the opportunity to adequately practice the design process and does not sufficiently foster the transfer or application of technical knowledge to the solution of a problem. Research on how students learn engineering design most effectively call for repeated opportunities to engage in hands-on, open-ended problems [1, 4, 25].

Impromptu design exercises reflect this type of pedagogy because they give students a chance to examine real-life scenarios (such as the concrete design problem in Fig. 1) and rehearse the behaviors, skills, and mindsets of professional engineers. The rehearsal aspect of impromptu design exercises is significant for several reasons. First, students have a first-hand opportunity to approximate the work of engineers. Clearly, practicing professional engineers activate a different knowledge and experiential base [13] and have a larger range of resources and time at their disposal. However, through impromptu design exercises, students get a glimpse at what engineers actually do, i.e., they are given a real life problem and asked to progress through the engineering design process to develop a solution. Second, this experience can be exhilarating and motivating for students, helping students identify more closely with their chosen profession [15], possibly leading to greater retention and student satisfaction [26].

These small-scale activities also help address two other weaknesses in the pedagogy currently used to teach design. First, they have the potential to cultivate the iterative divergent-convergent thinking and questioning process identified as central to design thinking [4]. As students progress through the impromptu design exercise, they inevitably go through several revisions of the design albeit on a smaller scale than in professional practice. Second, these exercises promote cognitive transfer, that is, the ability to apply information learned in one context (e.g. an engineering science course) to another, different context (e.g. an impromptu design task). In these ways, impromptu design exercises reflect current thinking about what constitutes engineering design and how it can best be learned.

2.3 Hands-on design pedagogies and impromptu design exercises

In order to put impromptu design exercises in the larger context of design education and hands-on instructional tools, they are compared with two of the most common approaches: 1) Long-term design projects and 2) Laboratory experiments. A summary of this comparison can be found in Table 1.

Long-term design projects: Perhaps the most commonly used design educational tools are long-term design projects [3], e.g., senior design and semester-long design projects. Impromptu design exercises significantly differ from long-term projects in a number of ways. First, impromptu design exercises are small-scale tasks that are expected to be completed in one class period as compared to the long-term nature of typical design projects. This enables students to get immediate feedback regarding their understanding of a particular concept (even if the concept has not been discussed in class) and provides them with a hands-on experience that they can relate to past and/or future course content.

Second, the short nature of the impromptu design project necessitates that the problem formulation (e.g. need, constraints, and evaluation metrics) and materials to be used are given by the instructor. This differs from a typical long-term design projects (especially senior design projects) where students have input on problem statement and materials to be used. This is perhaps an advantage of long-term projects as impromptu design exercises (as they are presented in this paper) are unable to engage students in problem formulation.

Finally, the pedagogical goals of impromptu design and long-term projects, while both focused on design, differ in that impromptu design exercises focus on the application of one or two particular class concepts (possible design or engineering science content related), while long-term projects are typically focused on synthesis of a larger amount of material (for example, senior design projects require synthesis of all information learned during the student's course of study). This allows impromptu design exercises to serve a variety of assessment objectives (diagnostic, formative, sum-

Table 1. Comparison between impromptu design exercises and two of the most common hands-on pedagogies, laboratory exercises and long-term design projects.

	Impromptu design exercises	**Laboratory experiments**	**Semester-long design projects**
Role of the student	To solve the given problem using any design or engineering science methods the student group perceives as appropriate	To test a given hypothesis or measure properties of interest using standard predetermined procedures (typically not a design exercise)	To develop and complete all components of a design project, including problem statement, procedures, test, results, analysis, and conclusions
Role of the instructor	Provide need statement, problem, and scoring metric; Prepare needed materials; Clarify problem statement; Lead de-briefing discussion of problem and students' proposed solutions	Prepare lab instructions and materials; Monitor students during the lab; Connect lab to course content.	Provide parameters of project; Monitor student progress
Learning objective	To integrate concepts related to design into an engineering science course	To reinforce course content through direct application; To introduce students to appropriate equipment and procedures	To assess students' ability to synthesize and apply knowledge and skills learned over an entire course or degree program
Degree of explicit design instruction	Students learn about design while also learning and/or reinforcing scientific content; Lectures and discussions on design concepts should follow the exercises	Depends on the nature of laboratory component, but typically does not leave much room for design	Design instruction throughout
Assessment provided	May be used as a diagnostic, formative, or summative assessment	Typically formative	Typically summative
Group work?	Yes—Required	Typically	Depends on the project
Instructional time needed	15 to 50 minutes	1–3 hours	1 week to 1 year
Advantages	Small-scale way for students to work with design concepts in an engineering science class; connection between design and engineering science is clear	Labs allow students to *apply* learned content	Provides students an opportunity to complete *all phases* of an engineering project from conception to completion
Challenges	Students may not be accustomed to the type of active engagement required by these exercises	Often requires a significant amount of setup time	Team management may be difficult

mative—this is elaborated upon in Section 5), while semester-long projects typically serve exclusively as a summative assessment.

Despite their differences, a number of similarities exist between impromptu design exercises and long-term design projects. First, it is perhaps obvious that both types of projects focus on design education. Second, both pedagogies typically employ the use of groups. Third, the course instructor has limited involvement in the implementation and completion of the task.

It is important to note that the authors do not view the use of impromptu design exercises and semester-long projects as mutually exclusive. In fact, the use of both types of instruction in a course or curriculum would be recommended as the impromptu design exercise is less "overwhelming" to a student than a long-term project, giving them smaller challenges that build their confidence for longer-term projects.

Laboratory experiments: Perhaps the most common hands-on pedagogy is laboratory experimentation. The primary difference between typical laboratory experiments and impromptu design exercises are that laboratory experiments are hypothesis driven processes, where students are led through the experimental procedure, are used to provide hands-on experience with laboratory equipment and are used to reinforce course content. Impromptu design exercises, on the other hand, have little structure and are used to introduce, reinforce, or test student understanding of course content. In the case where laboratory experiments are more open-ended and design oriented, the difference is more subtle. These types of design-based laboratory experiments quite often involve, for example, the tuning of parameters, choice of component, or similar decision, thus putting the focus of the laboratory on analysis in order to identify a "best" choice. While design concepts may need to be applied (e.g. optimization to choose parameters), the design space is relatively limited when compared to impromptu design exercises, so students do not have to engage in all steps of the design process (e.g. brainstorming may not be necessary).

Again, it is important to note that, while the authors believe that impromptu design exercises offer some advantages to professors (as discussed above), we also advocate the use of a variety of different instructional approaches including laboratories. In addition, the impromptu design format can be augmented to replace the standard laboratory format by providing students with an impromptu design exercise problem statement (as in Fig. 1) as well as other pertinent information about the laboratory (e.g., information on the equipment/materials to be used). With some instructor guidance, students could then design and carry out their own experimental procedure.

3. Details of the study

This paper presents the results of a study completed in the VU College of Engineering that provided a preliminary assessment of the benefits and challenges of introducing impromptu design exercises into engineering science courses.

3.1 Courses and topics

The study was carried out in three classes, as presented in Table 2. These classes included approximately 100 students, ranging in level from sophomore to senior, and included the departments of Mechanical, Civil and Environmental, and Chemical Engineering. The exact focus of each of the projects (shown in the Table) was chosen by the course instructor and reflected what they saw as important subjects in their course.

3.2 Assessment instruments

In order to identify the potential benefits and drawbacks of using impromptu design exercises, data was collected from both students and professors. Several types of data provided information regarding students' perceptions of impromptu design exercises relative to their learning. First, surveys distributed at the beginning and end of the course assessed the contribution of the impromptu design exercise to their design knowledge. Second, immediately before and after each impromptu design exercise, students filled out brief questionnaires assessing the perceived difficulty of the task and determining what students believed to be the main concept at hand in the exercise (note that these surveys provided some significant insights and, are

Table 2. Details of the courses included in this study.

Course #	# Students	Impromptu Design Project	Level	Type
ME 5411	23	Windshield Wiper Control—Logic Design Roller Coaster —Sensor Selection	Senior	Elective
CHE 5534	25	Bone Fixation on Remote Island	Senior	Elective
CEE 2106	60 (2 sections)	Aggregate Choice Concrete Mixture Design	Sophomore	Required

thus, shown in Fig. 3). Third, information concerning students' behavior during the impromptu design exercises was gleaned from the observations of the instructors and an educational evaluator who attended selected classes in which impromptu design exercises were used. Regarding the faculty, data about the process of implementing impromptu design exercises was obtained via pre- and post-course surveys (focused on determining how the instructors perceive the value of impromptu design exercises) and interviews conducted by the education evaluator both after each impromptu design exercise (focused on the instructors' perception of how well the exercise went) as well as at the end of the semester.

3.3 Example projects

As seen in Table 2, this study used impromptu design exercises in a wide range of courses. In this section, some of the projects used in this study are presented as examples. Note that these are in addition to the project discussed in Section 2.1 and shown in Figs. 1 and 2.

The impromptu design exercise shown in Fig. 4 was given in a Chemical Engineering Biomaterials class (CHE 5534).

Materials provided for the students included a model of the broken femur (a broken piece of 2 inch $\times$ 2 inch wood), flowers (live), grasses (live), soap (bar), bubble gum, water, plastic trash bag, twist ties, rubber bands, plastic utensils, and corks. This exercise was given after lectures on basic material properties (strength of materials, human body's affect on material), and in the midst of lectures on the affect of materials on the human body. Therefore, some concepts involved with the project (such as sterilization issues) were new to the students.

After examining the materials provided for this project, but BEFORE actually doing the exercise, please answer the following questions individually and submit to your professor.

1. Rate the degree of difficulty of this project on a scale of 1 to 10 with "1" being "easy" and "10" denoting "extremely difficult".

   1 2 3 4 5 6 7 8 9 10

2. What do I think that we need to do? How should we proceed?

3. What do I think will be the central problem that we will need to think about?

(a) Pre-exercise survey

After examining the materials provided for this project, but BEFORE actually doing the exercise, please answer the following questions individually and submit to your professor.

1. Rate the degree of difficulty of this project on a scale of 1 to 10 with "1" being "easy" and "10" denoting "extremely difficult".

   1 2 3 4 5 6 7 8 9 10

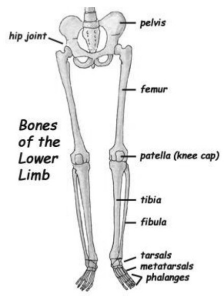
2. What do I think that we need to do? How should we proceed?

3. What do I think will be the central problem that we will need to think about?

(b) Post-exercise survey

Fig. 3. (a) Pre- and (b) post-exercise surveys used in the presented study.

The Dilemma [Need]: A class field trip to visit a remote lab with novel biomaterial research has gone very wrong. The airplane taking the entire class to the remote lab has broken down and everyone is now stuck on the island. Unfortunately, in trying to fix the engine, Dr. *** has fallen off the wing and broken her leg. Her right fibula is now not only exposed through the skin, but has lost a piece and needs immediate attention. Simply stabilizing the leg would still leave a hole in her leg's support (see picture).



Your Team's Challenge: *Dr. *** has faith that her class can successful fix the bone back together!* Using only the provided materials, each group must design a way to repair the weight bearing function of Dr. *** leg. Keep in mind this must be completed quickly! (35 minutes) Dr. *** also hopes her students remember what she has just taught them about material bulk AND surface properties to determine their best choice for their design.

Requirements of your design: Using two pieces of wood as the model "bone" you will have to affix them and prove it can support the weights during testing. Only the materials provided can be used. Things to consider include: corrosion/degradation of the material, fouling of the surface, cleanliness of the material (what do you propose you could do to clean it?), strength, wear, etc.

The Ultimate Test: (Rubric)

Can you design hold a load? **Weights will be placed on each design starting at 10:05 AM** to determine which design can best support weight.

Explanation: of how you will clean/why you used each material- will be orally presented to the class prior to your "test".

Fig. 4. Example impromptu design exercise used in a biomaterials class.

Students were allowed to divide into teams of 4 and were given the project statement to read over, before being provided their supplies. Not all groups were given the same supplies, but were allowed to trade their "limited resources" with another group. The teams had time to affix their two pieces of "bone" and then all groups tested how much weight their repaired "bone" could hold and explained their design choices to the class. The exercise allowed students to reinforce concepts on material science, and provided the instructor a chance to see what they knew already about sterilization.

The impromptu design exercise shown in Fig. 5 was given in a Mechanical Engineering Mechatronics class (ME 5411). The goal of this exercise was to familiarize students with the use of product specification sheets when designing mechatronic systems, as well as an opportunity to assess understanding of data acquisition principles.

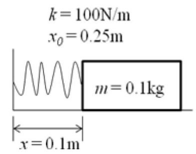
Materials provided for this exercise were a number of accelerometer specification sheets. This exercise was given directly following a lecture discussing sensor nomenclature, classifications, and characteristics, so the students were able to read and understand the specification sheets and determine an adequate sensor. When all teams had chosen a sensor, each team was asked to explain its choice, followed by questions and comments by other groups and the instructor. Aside from the technical aspects of this exercise, when the problem statement was given, a discussion of human factors engineering, specifically with regard to acceleration limitations, was led by the instructor to put the problem in context—this integration of a design concept into an engineering science course highlights one of the advantages of impromptu design exercises.

4. Results

This study assessed the benefits and challenges associated with introducing impromptu design exercises into engineering science courses as one of

Need Statement: Acceleration can be dangerous! A new roller coaster is being designed and a determination of approximate acceleration needs to be made. [A YouTube video of the roller coaster "Superman: The Escape" was shown].

Problem: Given a working model of the roller coasters' drive system (modeled as a spring and mass), you need to choose an accelerometer to integrate into the model.



The model shown includes a data acquisition system – A/D has a voltage range 0 to +5V and an 8 bit resolution.

First team to give me a reasonable thorough choice wins!

Fig. 5. Example impromptu design exercise used in a mechatronics class.

the means of moving towards a design-centric curriculum. In this section, we organize the results according to impact on instructors and students.

4.1 Effects on instructors

Despite the label, "impromptu," design exercises of this nature require substantial planning before implementation in the classroom. Faculty in this study had to address several significant issues before introducing the impromptu design exercises to students. First, instructors had to determine which topics in their courses offered the most promise for being taught or reinforced through this type of pedagogy. Referring to concept inventories in the engineering sciences can be helpful in aligning the impromptu design task with relevant course content [27]. Professors have a variety of instructional approaches at their disposal, e.g. direct instruction, demonstration, and cooperative learning. Course instructors must therefore consider whether using an impromptu design exercise would be appropriate for teaching this particular concept. One faculty member in this study noted that the impromptu design exercise (Fig. 4) allowed her students to understand physical concepts that are not as easy to teach with traditional lectures (e.g., the difference between shear and tensile stress, fixation of different materials in a design, and the mobility of different joints in the human body). She found that having students work with the concepts through an impromptu design exercise allowed them to understand feasibility issues with their designs. On the other hand, another course instructor reported that an impromptu design exercise focused on digital logic design (see Table 2), was not well received, possibly because the problem was not posed correctly, or perhaps more likely, because it was not an appropriate way to teach the subject.

Once the instructor has selected the content and decided to use an impromptu design exercise, he or she must then begin drafting the need and problem statements. An essential consideration to keep in mind when writing the exercise is the learning objective or outcome—e.g. what do I want students to get out of this activity? While writing the impromptu design exercise might appear to be a trivial task, our data indicate that the specificity and clarity of the need and problem statements greatly affect students' ability to uncover the instructor's expectations of them. In a post-class interview, one of the instructors, after reading the pre-exercise surveys (Fig. 3a) commented on the importance of appropriate wording in her impromptu design exercise on concrete aggregates (Fig. 1).

> Based on the students' pre-activity questionnaires, I see that the formulation of the problem needs to be reworded. I don't need to mention how the voids will be measured. Using the word 'water' is confusing for them, as it implies that water will be used as one of the four main concrete components. The students figured it out as they started working on the problem, but some of their first thoughts were off because my wording wasn't accurate . . .

To the instructor, the problem statement was straightforward, but the students found it confusing. Before they could begin work, they needed to ask follow-up questions to clarify precisely what they were supposed to do. Another faculty member in the study likewise noted that one of her problem statements might have been too open-ended and vague. Instructors must expend time in carefully crafting the wording for impromptu design tasks. Otherwise, students may focus their efforts on something that is not germane to the curricular topic.

Several other considerations must be taken into account in writing an impromptu design exercise.

Educational research indicates that students are most motivated to complete tasks that are challenging, but within their grasp [28, 29]. If the task is too simple, students may not take it seriously and may not put forth their best effort. If the task is too difficult, they may become easily frustrated and give up. Therefore, instructors must align the complexity of the task with the students' ability levels and degree of background knowledge. In addition, when drafting the problem statement, instructors should attempt to pique student curiosity by making the problem interesting and relevant to real life.

Another aspect of impromptu design exercises for instructors to consider before using them in the classroom is the anticipated length of time that the task will take to complete. This characteristic is perhaps the most difficult one to gauge. The task should be long enough to engage students and keep them on task, but short enough to allow sufficient time for debriefing afterwards. Impromptu design tasks are not long-term projects. They are intended to be completed in one class period or less. Therefore, they should not require students to search for background information or complete additional research.

After students complete the task, it is essential that the instructor dedicate some time to whole class discussion regarding the students' experiences. This discussion is critical for several reasons. First, asking students questions about their thought processes provides a means for the professor to assess whether or not students achieved the intended learning outcomes. It supplies the professor with valuable feedback concerning aspects of the concept that students understood well and facets that will require additional explanation. Second, a whole class discussion encourages students to reflect on their decision-making processes. This opportunity for metacognition provides useful feedback for students as they learn the design process. The post-task discussion also gives instructors a chance to connect the concept of the impromptu design task with previously learned material or with information to be taught in the future. Ideally, such a discussion would take place immediately upon completion of the impromptu design task; however, if this is not possible, then it should happen during the next class meeting or via an online discussion. Follow-up to the impromptu design task is critical if students are to see a connection between the design problem addressed in their small groups and the engineering science content taught in the course.

Once instructors have written the need and problem statements, they must now turn their planning efforts towards implementation in the classroom. Professors should decide how they will introduce the task to students and how much background information or context they will present. Once again, a delicate balance must be reached between providing too much guidance, thus stifling student creativity, and providing not enough structure, thus leaving students at a loss for how to proceed. Planning for implementation also involves preparing the exercise materials and deciding on the number of students per group.

Despite the difficulties encountered in writing the problem statements and estimating how much time to allot to the task, the professors in this study shared positive results associated with using impromptu design exercises in class. They valued the benefit of providing students a hands-on activity to help them engage not only the course material, but the design process as well:

> [Improptu Design Exercises] makes them [the students] question each other more and discuss more than a simple word problem does.
>
> It is rewarding to see how excited the students get as they complete this exercise. It is even more rewarding when you see them using material from the class in a new context.

Based on the study results, a summary of the characteristics of an effective impromptu design exercise are as follows:

The impromptu design exercise should . . .

- . . . address a critical concept in the course
- . . . contain clear and precise wording
- . . . be cognitively demanding, yet doable
- . . . be completed within one class period
- . . . pique student interest and connect to real-life

4.2 *Effects on students*

This pilot study obtained student feedback concerning the use of impromptu design exercises through the use of pre- and post-activity questionnaires (Fig. 3) distributed every time that an impromptu design exercise was used in class. Surveys given at the beginning and end of each course provided additional information on how the exercises impacted students.

While this study did not assess student knowledge of design before and after the impromptu design tasks, we are able to share student responses on surveys which imply that students believe they are valuable as tools in learning design. The following is a sampling of student responses to the post-course survey question, "Do you think that you learned engineering design in this course?":

> I also enjoyed the many activities we did with Dr. *** where we mixed aggregates in cups in groups. This gave us *hands on experience* to think about what makes the most sense and *it really made the information stick in my mind* [emphasis added].
>
> In addition, I *especially learned more about engineering design when we did hands-on activities* like trying to see

> which fine aggregate and coarse aggregate mixture held the most amount of water, or whenever we worked with concrete in the structural engineering lab [emphasis added].
>
> Yes. The open-ended exercises are unique *(I've never done them before in other classes)*. The projects allow for *creative* endeavors [emphasis added].

This data indicates that students perceive impromptu design exercises as helpful in learning design. The responses above highlight the "hands-on" nature of the exercise as facilitating their learning and retention (e.g. "it really made the information stick in my mind"). It should be noted that the survey question was open-ended. Students voluntarily cited impromptu design exercises as beneficial to learning design. In addition, it is notable that students mentioned the impromptu design exercises because the survey was administrated at the end of the semester, several weeks after the exercises were completed in class.

One of the greatest challenges with introducing impromptu design exercises in engineering science classes is that students are not accustomed to the type of work that they require. Most students encounter direct instruction as the primary method of instruction. As a result, they internalize a passive role for themselves in which they simply record what is transmitted to them. Students expect the teacher to tell them "all the answers." The pedagogy of impromptu design tasks is very different. Impromptu design exercises require students to actively engage in the hands-on use of the design process. Since this type of interaction might not be familiar to students, professors should explicitly communicate to students their expectations, e.g. that every member of the group participate in the conversation.

5. Discussion

This pilot study provides preliminary data supporting the incorporation of impromptu design exercises into engineering science courses. However, as noted above, professors must consider a number of significant issues as they attempt to introduce impromptu design exercises into their teaching repertoire. We believe that these challenges can be overcome and that impromptu design exercises can make a positive contribution towards design-centric education. In this section, we highlight a few of the reasons why impromptu design exercises hold promise as a means of integrating design across the engineering curriculum.

Finding a balance between teaching engineering science content and providing design opportunities is one of the most difficult curricular tasks faced by engineering faculty members—in practice the balance almost always tips towards engineering science content. Impromptu design exercises address this issue, as these exercises can be seamlessly integrated into engineering science courses, providing opportunities for students to develop design capacity without missing out on engineering science content. In fact, impromptu design exercises can be used to reinforce course content because professors can create or select design exercises which match the content of the course. Through such exercises, engineering design education may be integrated into any engineering class without loss of significant class time. The incorporation of these small-scale exercises is thus feasible, even in engineering science classes where course schedules leave little time for design education.

Impromptu design exercises also address a troublesome issue noted by faculty who teach engineering science courses. Students in their courses are often unmotivated to learn course material because they do not see its relevance or applicability to "real life." Framed as problems to be solved, impromptu design exercises hold the capacity to arouse student interest in course material and foster motivation. Particularly when utilized at the beginning of class, these exercises serve as outstanding "hooks" to draw students into the lesson. Rather than being told that the concepts they are presented in class will be useful at some unknown point in the future, students realize first-hand the value of learning content material by applying it in impromptu design exercises.

Lastly, impromptu design exercises can serve as versatile assessment tools. Their versatility allows faculty the flexibility to use them to meet their needs. For example, the following three methods illustrate how impromptu design exercises may be employed in various ways.

Method 1—True Impromptu Design: This delivery method follows the original concept of impromptu design exercises as implemented at student conferences, where there is no assumption of *a priori* knowledge. In this method, impromptu design exercises are given in class without discussion of the engineering science content to be used and without the provision of any background information. In this way, the impromptu design exercise serves as a valuable form of diagnostic assessment. Without prior knowledge of the engineering science content, students are forced to test their preconceptions of the concepts addressed in the exercise. This will identify, both to instructor and student, which preconceptions are indeed misconceptions, and which preconceptions are correct, pointing to student aptitude in a particular subject. In addition, giving students a hands-on experience with a course concept before it is taught allows them to build upon this example, especially if the instructor uses these exercises as examples when the concept is taught more formally.

Method 2—Impromptu design with pre-lecture: This delivery method breaks from the typical impromptu design exercise as students are given a lecture covering the engineering science concepts before the exercise is undertaken. This approach allows the instructor and students to determine how well a concept has been mastered following some instruction (application requires a higher level of understanding). This delivery method may also prove to be less time intensive because students will not require as much time to find direction. Used in this way, impromptu design exercises comprise formative assessments because they provide feedback on student progress towards a given learning outcome.

Method 3—End-of-unit impromptu design: This delivery method is similar to Method 2, but the impromptu design exercise is given at the end of a particular unit. If used at the conclusion of a series of lessons centered on a given topic, then the impromptu design exercises serve as summative assessments, evaluating the degree to which students met the learning objectives.

6. Conclusions

Through this study, the authors learned that impromptu design exercises offer instructors a valuable instructional approach for teaching design. Students' positive feedback indicates that the hands-on nature of the exercises was appealing to them. Impromptu design exercises offer students a means of taking an active role in their own learning. In "learning by doing," students apply knowledge and develop skills and dispositions important for a career in engineering, including creativity and the ability to work successfully in a group. Impromptu design exercises also provide a practical way for instructors to bridge the theory-practice gap in engineering education. Despite the challenges named above, the authors believe that impromptu design exercises offer instructors a worthwhile means of integrating design education across the engineering curriculum and moving toward a more design-centric engineering curriculum. Beyond their use at student competitions, impromptu design exercises present instructors with a way to diversify their instruction while meeting important course objectives.

Acknowledgments—The authors gratefully acknowledge the Villanova Institute for Teaching and Learning (VITAL) for supporting this project.

References

1. A. J. Dutson, R. H. Todd, S. P. Magleby and C. D. Sorenson, A review of literature on teaching engineering design through project oriented capstone courses. *Journal of Engineering Education*, **86**, 1997, pp. 17–28.
2. C. Dym, Teaching design to freshmen: style and content. *Journal of Engineering Education*, **83**, 1994, pp. 303–10.
3. J. Turns, M. Cardella, C. J. Atman, J. Martin, J. Newman and R. S. Adams, Tackling the Research-to-Teaching Challenge in Engineering Design Education: Making the Invisible Visible, *International Journal of Engineering Education,* **22**(3), 2006, pp. 598–608.
4. C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey and L. J. Leifer, Engineering design thinking, teaching, and learning, *Journal of Engineering Education*, **94**, 2005, pp. 103–20.
5. C. J. Atman, D. Kilgore and A. McKenna, Characterizing Design Learning: A Mixed Methods Study of Engineering Designers' Use of Language. *Journal of Engineering Education*, **97**, 2008, pp. 309–326.
6. D. Dinehart, S. Gross, J. Yost and A. Radlinska, The Role of Structural Engineering in Multi-Disciplinary Freshman Projects, *ASEE Annual Conference and Exhibition*, 2010.
7. N. Comolli, Q. Wu and W. Kelly, The Artificial Kidney: Investigating Current Dialysis Methods as a Freshman Design Project. *ASEE Conference and Exhibition*, 2010.
8. S. Campbell and C. L. Colbeck. Teaching and assessing engineering design: a review of the research, *ASEE Annual Conference & Exposition*, 1998.
9. P. H. Gregson and T. A. Little, Design contests for teaching electrical engineering design, *International Journal of Engineering Education*, 14, 1998, pp. 367–74.
10. B. M. Olds, B. M. Moskal and R. L. Miller, Assessment in Engineering Education: Evolution, Approaches and Future Collaborations, *Journal of Engineering Education*, **94**, 2005.
11. D. Dunn-Rankin, J. E. Bobrow, K. E. Mease and J. M. McCarthy, Engineering design in industry: teaching students and faculty to apply engineering science in design, *Journal of Engineering Education*, **87**, 1998, pp. 219–22.
12. E. Koehn, Preparing students for engineering design and practice, *Journal of Engineering Education*, **88**, 1999, pp. 163–7.
13. C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg and J. Saleem, Engineering design processes: a comparison of students and expert practitioners, *Journal of Engineering Education*, **95**, 2007, pp. 359–79.
14. J. W. Prados, Engineering Education in the United States: Past Present and Future, *1998 International Conference on Engineering Education.*
15. C. Reidsema, S. Wilson and C. Netherton, Impromptu Design as a Vehicle for Developing Team Work and Problem Solving Skills in Design Engineering, *International Conference on Engineering Education*, 2004.
16. G. M. Clayton, Introducing engineering design using impromptu design projects, *ASEE Congress and Exposition*, 2010.
17. G. M. Clayton, A. Radlinska, N. K. Comolli and T. G. Wojcik, Integrating design education across the curriculum using impromptu design projects, *Fall 2010 Mid-Atlantic ASEE Conference*.
18. T. G. Wojcik, G. M. Clayton, A. Radlinska and N. K. Comolli, The Promise of Impromptu Design Exercises as a Pedagogical Tool in Engineering Design Education, *2011 ASEE Congress and Exposition.*
19. P. Little and M. Cardenas, Use of 'Studio' Methods in the Introductory Engineering Design Curriculum, *ASEE Journal of Engineering Education*, **90**, 2001, pp. 309–318.
20. J. S. Lamancusa, J. E. Jorgensen and J. L. Zayas-Castro, The Learning Factory—A New Approach to Integrating Design and Manufacturing into the Engineering Curriculum, *ASEE Journal of Engineering Edcuation*, **86**, 1997, pp. 103–112.
21. J. Kadlowec, K. Bhatia, T. R. Chadrupatia, J. C. Chen, E. Constans, H. Hartman, A. J. Marchese, P. von Lockette and H. Zhang, Design Integrated in the Mechanical Engineering Curriculum: Assessment of the Engineering Clinics. *Transactions of the ASME*, **129**, 2007, pp. 682–691.
22. F. G. Splitt, The Challenge to Change: On Realizing the New

paradigm for Engineering Educaiton, *ASEE Journal of Engineering Education*, **92**, 2003, pp. 181–187.
23. V. Wilczynski and S. M. Douglas, Integrating design across the engineering curriculum: a report from the trenches, *Journal of Engineering Education*, **83**, 1995, pp. 235–40.
24. K. W. Chau, Incorporation of Sustainability Concepts into a Civil Engineering Curriculum, *Journal of Professional Issues in Engineering Education and Practice,* **133**(3), 2007, pp. 188–191.
25. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education*, **93**, 2004, pp. 223–31.
26. W. M. Clark, D. DiBiasio and A. G. Dixon, A Project-Based, Spiral Curriculum for Chemical Engineering, Seattle Conference of the American Society for Engineering Education, 1998.
27. P. S. Steif and M. A. Hansen, New Practices for Administering and Analyzing the Results of Concept Inventories. *Journal of Engineering Education*, **96**, 2007, pp. 205–221.
28. A. Wigfield and J. Eccles, Expectancy-value theory of achievement motivation, *Contemporary Educational Psychologist*, **25**(1), 2000, pp. 68–81.
29. J. Brophy, Toward a model of the value aspects of motivation in education: Developing appreciation for particular learning domains and activities, *Educational Psychologist*, **34**(2), 1999, pp. 75–85.

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