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Integrating Engineering Science and Design: A Definition and Discussion*

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An important goal of an undergraduate engineering curriculum is to facilitate students' development of an integrated understanding of engineering. Although attempts have been made to integrate engineering science and design curricula, many students are not developing knowledge and skills that synthesize the subjects covered by these two curricula. A few observations of student performance are provided that suggest this lack of integration. A definition of integration is proposed and used to discuss possible reasons why engineering science and design curricula are not well integrated. The definition is based on the observable outcomes and behavior students produce while engaged in learning activities. Mismatched learning objectives, excessive focus on outcomes and inconsistent learning contexts are identified as causes. Finally, suggestions are given for improving engineering curricula based on this discussion.

INTRODUCTION

THE IMPORTANCE of integrating design activities throughout the undergraduate engineering curriculum is well recognized. One need only look at the ongoing activities of ABET and NSF funded coalitions or look through past ASEE publications to see the emphasis design activities are receiving. Like many other engineering departments, our mechanical engineering department has been adding design activities to its engineering science curriculum for some time. The result, however, is that our department now has essentially two curricula occupying one educational program space.

Although attempts have been made to integrate the engineering science and design curricula, they remain largely separate. Students are not developing knowledge and skills that synthesize the subjects covered in the two curricula. After reading numerous reports by others on their efforts to integrate design activities into their curricula, we believe that we are not alone in experiencing this difficulty. Many of these reports describe design activities similar to ours. Although there are reports [1–4 are examples] that address the relationship between design activities and core engineering science activities, most do not.

In this paper, we provide a few observations of our students that indicate a lack of integration. We then propose a definition of integration and use this definition to discuss possible reasons why engineering science and design curricula are not very well integrated. Finally, we give some suggestions for improving the integration of the two curricula.

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OBSERVATIONS

Our students have several opportunities to demonstrate their engineering analysis skills within our design courses. We have observed that students have considerable difficulty applying their analysis skills in the design activities. They have successfully completed considerable numbers of engineering science problems before the senior design course. Yet in this course, many students cannot set up and solve basic engineering analysis problems without help. Others have indicated a similar situation as illustrated by the following statement: 'The difficulties experienced by senior engineering students in applying basic principles was perceived to be an indictment of the existing system . . .' [1]

The existence of these difficulties is supported by studies of our students' estimation skills. For example, students in the senior design course were given five minutes to 'estimate the drag force on a bicycle and rider traveling at 20 mph (9 m/s)'. Their answers covered a range of five orders of magnitude. Several students gave answers that were higher than their own weight. Figure 1 is a relative frequency histogram of the responses ($n = 67$). Other students in this course were given five minutes to write down the units for thirty common engineering quantities. Only 56% of these students gave the correct units for Reynolds number. Only 69% gave the correct units for angular acceleration. 81% gave the correct units for work. See [5] for additional examples.

We do not believe these difficulties are due to lack of effort or competence on the part of the students. They are some of the best students that we could hope to have enrolled in the program.

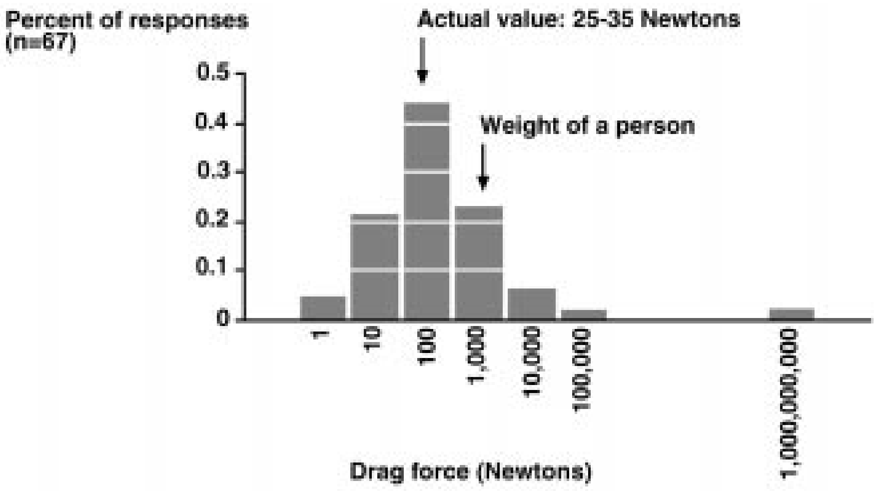

Fig. 1. Student estimates for the drag force on a bicycle and rider traveling at 20 mph (9 m/s). The actual value ranges from 25 to 35 N. Each bin spans an order of magnitude and is labeled with its upper value.

Still, almost all of the students have difficulty addressing analysis problems in their design activities. Thus, the difficulties are more likely due to the nature of our educational program than differences in the demographics of our students.

A DEFINITION OF INTEGRATION

As a simple definition, we can say that some integration exists when students learn knowledge and skills in one activity and use them in another activity. To know that we have integration however, we have to know that students are learning and using the knowledge and skills we are teaching. The only way to do that is to look at what the students produce and the actions they go through during an activity. We will refer to the things that students produce as outcomes and the actions they go through as behaviors. For example, students may be asked to do a homework assignment that involves solving a number of problems. The solutions to these problems are the outcomes of the activity and the steps taken to solve the problems are the behaviors or actions used to obtain the outcomes. We will also refer to the knowledge and skills we are attempting to teach as simply learning objectives.

We are now in a position to give a better definition of integration. Two activities are integrated for a learning objective when students produce behaviors and outcomes in both activities that indicate progress towards that objective. Including behaviors in this definition emphasizes the belief that valid behaviors with invalid outcomes are more important than invalid behaviors with outcomes that appear to be valid. Notice that there are no references to courses in this definition. This is because integration does not necessarily exist when one course contains, say, engineering science homework problems and a design project. Students may still have compartmentalized knowledge and skills despite the juxtaposition of these activities.

This definition helps us formulate useful questions about the reasons engineering science and design activities are not well integrated. Are students having trouble in the design activities because of what they learn in the engineering science activities or the design activities? If so, is it an issue with behaviors or outcomes? Which learning objectives or activities are involved? Should the design activities or engineering science activities or both be changed? The following three sections begin to answer questions like these by giving three reasons that core engineering science and design activities may not be well integrated.

MISMATCHED OBJECTIVES

The simplest reason that any two learning activities are not integrated is that one activity supports a different learning objective than is required by the other activity. In the case of our engineering science and design activities, the engineering science activities support different problem-solving knowledge and skills than those needed by design activities. This is one of the more important differences, but there are other differences. For example, these activities are often focused in different ways on the knowledge and skills associated with physical engineering artifacts.

In an engineering science course, students are introduced to the main concepts of the subject and then given well-defined problems designed to focus on these concepts. When these students take design courses they are confronted with open-ended, ill-defined analysis problems. Unfortunately, the ability to solve such analysis problems is also not developed by the learning activities in the design courses. Also, the issue is too easily avoided by defining design courses that focus on design specific objectives and only require limited amounts of engineering analysis. Where analysis is required, students are provided with analysis support or are directed to carry out informal experiments.

Students will have to solve open-ended,

ill-defined analysis problems in practice, but they are only learning how to solve problems that have already been set up. In neither the engineering science nor the design activities do students have a chance to learn the initial steps of a general problem-solving process for analysis. These steps include exploring and setting up a problem, which are necessary for solving open-ended, ill-defined problems.

EXCESSIVE FOCUS ON OUTCOMES

In the section defining integration, we mentioned that student behaviors and outcomes are both important indicators of progress towards learning objectives. In practice, faculty members primarily use outcomes as a method of assessment. A small number of faculty members can gauge the progress of many students by only considering outcomes. The result is that faculty guide the outcomes students produce but not their behaviors. Students must still choose behaviors or actions to obtain outcomes. Many students, understandably, develop behaviors that are ineffective. They do not yet have enough experience with the subject material to decide which actions to take first or which actions are likely to be effective in a range of situations. Thus, when students cannot produce outcomes in our design activities it may be a result of ineffective behaviors.

Many of the commonly used learning activities afford few opportunities for faculty members to observe students' behaviors and give students feedback on them. Equally important, there are few opportunities for students to learn effective behaviors from the faculty. For example, almost all problems presented in lectures and recitations are pre-solved problems. Students are really seeing an outcome when the 'solution steps' are presented. However, students could ask, 'How did you know to do that step?' The answer to this question is the behavior the instructor exhibited the first time that they solved the problem, which includes all of the ideas tried, reasoning used, and emotions involved in find the 'solution steps'. As a matter of practicality, many of the problems used by instructors were not solved by them, let alone solved by them for the first time in front of students. The same holds for explanations, papers, and other outcomes. Students seldom see an explanation being developed or a paper being written. Instead, they primarily see outcomes.

INCONSISTENT CONTEXTS

The contexts in which students learn knowledge and skills are often different than the contexts in which they apply them. Unfortunately, students often develop knowledge and skills that are dependent upon the context in which they are learned [6]. Thus, when students move to a new context they are unable to use the knowledge or skills effectively.

For example, our students learn to solve engineering analysis problems in the context of a particular chapter of an engineering science textbook and corresponding lectures. This supporting context is absent when they are solving problems in our design activities. In fact, design contexts often include whole stacks of textbooks. The challenge is to develop knowledge and skills in learning contexts consistent with the contexts of their use, or to find ways of merging the contexts.

This problem is exacerbated by our desire to have students be highly accomplished. As we give them more material to cover and more problems to solve, they must find ways to handle this additional work. Given that we are not guiding their behaviors, the students are free to depend on the learning contexts to help them with the extra work. This dependency, in turn, allows us to add additional work, which then causes them to depend even more on the learning contexts.

SUGGESTIONS

There is actually a fair amount of synergy between the techniques that might be used to address the issues of mismatched objectives, excessive focus on outcomes, and inconsistent contexts. Because of this synergy we are presenting a few suggestions for addressing these issues in one discussion. The discussion can be thought of as describing a different 'operating point' for our teaching and learning activities. Please note that we have not yet had a chance to test most of these ideas.

Students need to spend time solving open-ended, ill-defined analysis problems. We know that simply having them solve more problems will not increase their problem-solving skills. We need to teach problem-solving knowledge and skills as well [7, 8]. Several of the steps in a general problem-solving process are very similar to the steps in a general design process, and these steps might be covered together.

We do not mean open-ended problems in the sense of design problems; rather, we mean problems like the bicycle problem mentioned earlier in this paper. There are at least a half-dozen solutions to the bicycle problem—each involving distinctly different subject material. Such problems are lessons in integration by themselves. Basing these problems on specific physical artifacts, such as a bicycle or common catalog components, should also help make the engineering science and design learning contexts more consistent.

Open-ended, ill-defined problems are not as easy to solve by taking recourse to a text, and using them should eliminate some contextual dependency. However, they may not help significantly if they are still asked within the context of course material that can be used to solve the problems. A problem is not very ill-defined if one is given the exact subject material needed to solve it. Thus, it will be necessary to weaken or break the association between the subject material students cover and the problems that they are given. Perhaps we could have a problem-solving course that is concurrent with (or subsequent to) our subject courses. In this way, students could address a variety of problems without directly being given the subject material needed to solve them.

Teaching the problem-solving process will help students make choices between the actions they could take when working analysis problems. In order to learn how to make these choices well they will need opportunities to observe the behaviors exhibited by others and demonstrate their own behaviors. This could be accomplished by placing students in cooperative learning groups [8, 9]. Cooperative learning groups are well suited to open-ended problem-solving activity [8]. Additionally, they make the learning contexts for engineering science and design activities more consistent.

Case studies are meant to capture the actions or behaviors of another person [8]. Why not have small, guided case studies for analysis problems that show in detail the exploration, definition, and solution choices made by a practicing engineer, a professor, or even a student? Case studies naturally include all of the ideas and solution paths considered, even the ineffective ones. These guided case studies would only be interesting for open-ended, ill-defined problems.

CONCLUSIONS

We have suggested that design activities are not well integrated into undergraduate engineering curricula. The main reason appears to be that design throughout the curriculum is being implemented by increasing the number of design activities without making significant changes to the existing learning activities. Nor are the design activities being defined to make them consistent with the existing learning activities.

Introducing more design activities certainly has the benefit of increasing the number of design learning objectives in a curriculum. All of the issues raised here, however, require significant changes to either engineering science or design activities in order for integration to exist. Without making these changes, we are at risk of simply having more design activities that are separate from engineering science activities. For example, if we place a design project within an engineering science course without changing the engineering science activities of the course, we may have only made the course more concrete and found curricular space for more design objectives. Although both of these results are valuable, integration will not have been achieved.

In this paper we have presented a definition of integration that allowed us to enumerate some of the reasons why engineering science and design activities may not be integrated. The related educational issues are not new to the educational community and, as such, there are more thoughtful and in-depth discussions in the references given. We believe that identifying these issues as specific hindrances to the integration of engineering science and design activities is an important step towards achieving integration. There are clearly many more reasons than those discussed and additional mechanisms for addressing the related issues. Addressing these issues by some of the proposed methods should result in a significant amount of integration.

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