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Lessons Learned from Collaborative Development of Research-Based Course Materials

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Introduction

The work reported in this paper begins with the end of a previous research project. Our earlier work investigated student understanding of mechanics of materials[1–3]. After describing how students understand this topic, we wanted to move on to developing course materials to help build on students' existing understanding and address misconceptions. This is not an unusual progression, and, indeed, our initial research in this area showed us that most course materials that are developed from research never achieve broad adoption[4]. Many engineering educators develop their own materials, duplicating researchers' efforts and potentially denying students the benefit of research-based materials with proven effectiveness. The lack of adoption is a complex phenomena, but research shows that many innovations are never adopted because they fail to address the needs, perceptions and contexts of potential adopters[5,6]. Our approach to developing curricular materials that were more likely to be adopted (and therefore more likely to achieve their goals of helping students develop rich conceptual understanding of mechanics of materials) is based on including future adopters as collaborators in the development process. The purpose of this paper is to provide first-hand accounts of this collaboration process including the challenges we faced and our potential solutions. Understanding the challenges in collaborations between researchers and practitioners will help us promote the adoption of effective curricular materials and pedagogies, which will in turn improve engineering education practice.

Overview

This paper will first briefly outline the context of this collaboration by describing: (1) the general approach to adoption that informed the development of the collaboration, and (2) the theoretical framework of the research that inspired the curricular materials. Note that this project is ongoing. For a summary of our previous findings on student understanding (as well as our recommendations for instructors), see[1–3,7,8], and for our research exploring adoption more generally see [7,9,10].

Our collaboration was built on a two-day, in-person workshop involving six researchers and 15 engineering instructors. Participants formed small groups with at least one researcher and three instructors. Each group was assigned a topic area in mechanics of materials and tasked with developing curricular materials that would address student misconceptions our research had identified in that topic area. In one set of materials, for example, students are guided through predictions, measurements and explanations of deformation and strain in an elastic band. These exercises encourage students to carefully construct intuitions about the physical differences between stress, strain and deformation. Other course materials help students investigate the limitations of their measurements and calculations with the elastic band. This is intended to help them develop keener awareness of the relationships between physical and analytical realities.

Each participant also agreed to implement the materials they developed, as well as at least one other group's materials. This inter-accountability formed the core of our collaboration; every participant was engaged as a developer and implementer and therefore interested in both the effectiveness and ease-of-use of the materials. They, in effect, embodied both the developers' and implementers' perspectives as they attempted to make the best use of the research findings presented to them. The authors of this paper include both the researchers and participants involved in this workshop.

Framing of Adoption

A review of previous work investigating student learning in mechanics of materials revealed 78 articles promoting particular curricular materials. None of the materials described in those articles have been broadly adopted. There are multiple theoretical approaches to describing why some innovations are broadly adopted but most are not. It can be seen as a process of diffusion in which knowledge is slowly communicated among individuals[11], as the gradual acclimation of individuals to a new idea[12], or the process of changing an organization[13] or its policies[14]. All of these different approaches similarly find that broad adoption is usually controlled by the degree of fit (or perceived degree of fit) between potential adopters and the innovation. This fit includes various dimensions depending on the framework chosen, but it often includes references to the adopters' core values or basic beliefs about the world. In many cases it is not that the innovation is fundamentally contrary to potential adopters' basic beliefs and values, but that is *perceived* to be so[11,12,15]. In the context of engineering education, "potential adopters" include both the teacher and the students because both groups are closely involved in the implementation and effectiveness of any new course materials or pedagogies[12,16].

Additionally, adoption researchers have noted that many adopters do not actually use innovations as intended by their developers. This is particularly important in the case of curricular materials where the method of implementation can determine their effectiveness. Hall and Hord have developed a way of measuring and managing the different ways in which people can use innovations in educational settings[17]. They suggest that developers of educational innovations define the "configurations" – i.e. the allowable variations in implementation – that would still likely generate the intended benefit. Curricular materials based on an interactive group discussion, for example, could still be effective in an asynchronous online message-board, but might not engage the same type of thinking if replaced with an essay assignment. In this case the message-board would be an acceptable innovation configuration, while the essay assignment would not be considered a true implementation of the materials.

Our workshop incorporated this understanding of adoption in its design. By including the instructors and collaborators, we hoped to develop curricular materials that better matched their core values and beliefs. We additionally asked each group to define a list of acceptable variations (what Hall and Hord would call "innovation configurations") for their materials.

Theoretical Framing of the Research

Our collaboration focused on developing curricular materials based on our previous research on students' conceptual understanding. "Conceptual understanding" is a cognitive science term that refers to a specific type of learning. The conceptual understanding a person has about a topic can be viewed as the mechanism through which they develop explanations or predictions about the topic[18]. Such a mechanism means that new learning is built upon the foundation of preexisting knowledge and beliefs [19]. While these preconceptions may be highly intricate and familiar to the learner, they may also be wildly inaccurate. Any new learning that proceeds through the lens of this faulty understanding will therefore also be subject to misinterpretation. These inaccurate preconceptions are known as "misconceptions"[20].

Students at both the undergraduate and graduate level consistently struggle with differentiating core concepts in physics and engineering such as stress, strain, force, or load. Traditional lecture-based courses are usually ineffective at improving student conceptual understanding of these topics [3,21]. Misconceptions persist because students struggle to re-categorize preexisting knowledge, or "frameworks" [22,23]. In mechanics of materials, students find it difficult to move between "analytical concepts" (eg. Mohr's circle, stress elements, various moduli) and "real" or "physical" concepts (e.g. deformations and failures)[24–26]. Instruction on these topics does not often explicitly indicate the relationships between analyses and physical realities[27].

The participants in our workshop were asked to incorporate a conceptual understanding approach into their course materials. They therefore focused on having students predict or explain observable phenomena, and relate it causally to equations and calculations. The curricular materials developed in our workshop specifically target research-identified misconceptions, and are intended to help students distinguish between similar concepts.

Lessons Learned

We will present three general lessons we've learned through our collaboration and reflection. In presenting these findings we distinguish between researchers and instructors, but note that most engineering educators perform some combination of the two roles. Additionally, we note that many of these lessons refer to commonly held intuitions about the interactions of research and practice in education. We seek here to surface and further develop these intuitions into productive public discourse.

1. *We need to attend to the differences in what we know as researchers and what we know as instructors*

Our experiences in the workshop have reminded us that the difference between learning scientists' and instructors' knowledge of student understanding is one of *kind*, not degree. It is tempting to compare the amounts of knowledge researchers and instructors have, but regardless of which side the comparison favors, it is not productive in guiding our interactions. It is more productive to instead focus on the different ways in which we know about the same things because this leads more directly to collaborations where both parties benefit.

As an example, it took some adjustment and compromise to be able to productively discuss what phenomena students can "see" when using different physical models (e.g. foam pool noodles, rubber bands, or pieces of dowel). We had complementary knowledge-bases: As researchers we had in-depth, interview-based knowledge of how students' mental models interacted with hands-on physical models; As instructors we had broad experience with how students reacted to different kinds of physical models. The difficulty was in coordinating our different knowledge-bases. As researchers our tendency to hedge, clarify, and limit any assertions made our knowledge difficult to apply to classroom experiences. As instructors, our tendency to refer to personal experience for justification made our knowledge difficult to relate to others' classrooms. The key to addressing these differences lay in acknowledging and communicating the different motivations underlying our knowledge. Instructors learned to distinguish between research-informed opinions and empirically confirmed hypotheses, and researchers learned to hear the difference between intuitive expectations and definitive predictions based on previous experience.

2. *We may need to work to collectively define what we consider "fundamental" in a topic area.*
Conceptual understanding is often described as being "foundational" or "fundamental" to other kinds of knowledge and learning, which implies that it should come first. Conceptual understanding theorists and researchers are less sanguine about this assumption however, noting for example that some conceptual teaching serves to generate misconceptions rather than address them[28]. Our group included instructors who teach advanced courses in structural and mechanical engineering, and they often argued that the concepts we were emphasizing in our materials did not always hold true in more complex systems. In other words, we tended to think primarily within the traditional definition of the course's content and unconsciously applied a set of simplifying assumptions. It is unclear to us, however, if the simplifications are more helpful to new students or harmful to advanced students.

For example, our research on student understanding suggests that students significantly over-estimate the local deformations caused by loadings on structural members. We sought, therefore, to develop materials to help students see the relative unimportance of local deformations. Some members of the group were concerned, however, that we were dismissing an important phenomenon that would be significant in later courses. The challenge is differentiating *why* students fixate on local deformations. Naïve students misunderstand the basic interactions that lead to stress and deformation, and therefore predict that local effects will be more important than the more-difficult-to-explain deformations further from the loading. Teaching students to routinely ignore local effects will help develop their understanding of deformation, but will need to be "un-taught" in later courses where students are asked to analyze special cases where local stresses are prevalent. The best solution to this challenge will be informed by cognitive science theory, engineering educators' classroom expertise, and engineering practitioners input on how these concepts are actually applied.

3. *We need to recognize the dilemma of producing complete-yet-flexible research-based curricular materials*
We have experienced a particular dilemma that may illuminate a broader trend in the adoption process. As instructors we want simple and direct contributions to our teaching. The most broadly adopted materials from our workshop (a published workbook [citation removed for review] and a scripted demonstration) were also the most proscriptive and narrow. We designed many demonstrations, and the most successful ones were those linked directly to a particular unit or even lecture. It is much easier to adopt a concrete, defined, and action-oriented "lesson plan" than a new idea that pervades your approach to lecture, homework and assessment. As instructors we want a polished, finished product that we can plug neatly and predictably into the course as a whole.

However, the process of crafting research findings into concrete activities also requires a great deal of interpretation and assumptions. Across our group mechanics of materials courses differed in many ways, from simple logistics (some of us prefer groups of three while others rely on structured groups of four) to more wide-ranging philosophical differences (some of us prefer the precision of demonstrations, while others want students to interact with each other as much as possible). Every decision we make as designers, therefore, has the potential to exclude our collaborators and potential adopters. In our workshops each small group developed a set of shared compromises, and each group was somewhat disappointed by the resulting lack of polish and specificity.

The problem of how to assess students' understanding provides a particularly illuminating example. Researchers and instructors wanted meaningful assessments, and both groups looked to the other to balance ease-of-use with flexibility. The researchers were asked to provide assessments from the research, but felt that it was inappropriate to promote a singular, "best" way to do it, and were unable to cite any "proven" assessments. Similarly, the instructors were asked to use their expertise and design assessments to their preference, but felt that their experiences didn't necessarily apply to the developed activities.

Conclusions

The basic assumption of the workshop was that adoption would succeed with closer communal ties between developers and adopters. That assumption has been somewhat justified, but also complicated through what we have learned.

Trustworthiness and credibility seem to play a similar role in adoption as they are proposed to do for qualitative research[29]. In other words, the discourse of "proving" an innovation could be re-centered to include the importance of trust in the developer or development process. As researcher/instructors we find ourselves most comfortable with highly proscriptive curricular materials from sources we trust. "Evidence" and traditional, pseudo-experimental studies certainly have a role to play in generating that trust, but they become a means rather than an end in themselves.

We designed the workshops with the goal of developing an alignment of values among developers and implementers, but found this goal to be more complex than predicted. In part this is because we tacitly assumed a "banking model [30]" of knowledge whereby researchers and instructors would share interchangeable bits of knowledge. We ignored the significant differences-in-kind between researchers' and instructors' knowledge. Upon reflection it is a small leap from the constructivism we hope to apply in our classrooms to a more collaborative model of curricular innovation and adoption.

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