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Influence of Engineering Instructors' Teaching and Learning Beliefs on Pedagogies in Engineering Science Courses*

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This study explored how academics' beliefs about teaching and learning influenced their teaching in engineering science courses typically taught in the second or third year of 4-year engineering undergraduate degrees. Data were collected via a national survey of 166 U.S. statics instructors and interviews at two different institutions with 17 instructors of engineering science courses such as thermodynamics, circuits and statics. The study identified a number of common beliefs about how to best support student learning of these topics; each is discussed in relation to the literature about student development and learning. Specific recommendations are given for educational developers to encourage use of research-based instructional strategies in these courses.

Keywords: engineering science; faculty beliefs; research-based instructional strategies; statics

1. Introduction

Numerous national and international reports have called for priorities in engineering education to include: (i) increasing the number of students enrolled in engineering [1], (ii) increasing graduation rates for undergraduate students, (iii) increasing the quality of engineering graduates as described by many different attributes [2–6], and increasing the diversity of engineering graduates [4–6]. Growing attention is being paid to roles of instructional strategies that engineering academics apply in their courses to attain these broader goals and faculty development to help faculty apply these instructional strategies effectively [7]. A committee formed by the National Academies in the United States recommends that "efforts to translate research into practice include . . . deliberate focus on changing faculty conceptions about teaching and learning" [7].

The research-based instructional strategies in question apply learning research to actively engage students in their learning. These include active learning [8, 9] Felder, 2009), think-pair-share [10, 11], concept tests [11], TAPPS [11], cooperative learning [9, 12], collaborative learning [9, 13], problem-based learning [9, 14–16], project-based learning [15], case-based teaching [15], just-in-time teaching [17], peer instruction [18], inquiry learning [15, 19] and service learning [20, 21]. Summaries of research supporting the effectiveness of these specific instructional strategies are provided in [9, 15, 22].

Educational researchers have long considered the question of why, if there is evidence that these instructional strategies help students learn better, there are not more instructors using them. Prior studies have investigated whether instructor characteristics are correlated with use of instructional strategies. For example, it has been hypothesized that more experienced instructors are less willing to change their teaching; however, U.S. studies that have investigated relationships between academic rank and instructional approaches in engineering and physics did not find a significant relationship [23, 24]. Instead, correlations were found between instructor gender and attendance at teaching workshops and presentations [23, 24].

Prior research has also explored the reasons why instructors do not use more of these instructional strategies in their teaching. In survey and interview

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studies, engineering and physics academics have cited several barriers: (a) concerns about preparation time, (b) concerns about ability to cover the syllabus or curriculum, (c) questions about the efficacy of the strategy, (d) concerns about student resistance, (e) reward system and (f) limited resources or facilities [25–34].

However, decisions that academics make about modifying their instructional strategies through incorporating new instructional strategies are also influenced by what they believe about learning and how they think about teaching [35–38]. Many studies in different countries have been conducted into instructor beliefs about learning and teaching, including the United States [39–42], Hong Kong [43, 44], Israel [45], Australia [46–48], the United Kingdom [49, 50], and Canada [37, 51]. Many of these studies employed interviews of academics to develop categories of beliefs, which they may later test using survey methods [49, 52, 53]. Although several studies have developed 4–5 categories of instructor belief types along a continuum ranging from teacher/lecture-centered to students/learning-centered, this literature is not building on itself as well as it could be. Adding to this complexity is the finding among secondary school teachers that beliefs shift over time to mirror those of colleagues, which usually tend toward more traditional views of teaching [46].

Studies have shown that academics' beliefs about teaching influence their decisions about instructional strategies that, in turn, influence the quality of student learning as well as student attitudes toward learning [35, 36, 38]. For example, thinking about teaching as knowledge transmission tended to promote surface learning among students, while conceiving teaching as learning facilitation tended to promote deep learning [36]. However, relationships between teacher beliefs and instructional strategy decisions cannot be described thoroughly through dichotomous simplifications, e.g., if academics believe X, then student learning is poor, and if academics believe Y, the student learning is good. A study into factors influencing adoption of computer-assisted learning found that relationships between faculty beliefs and instructional practices were best described in terms of five belief-practice clusters [54].

However, there are only a few studies of what engineering academics believe about teaching and learning. One study examined engineering academics' concerns about teaching, including concerns about adapting new strategies, by interviewing an instructional consultant who had worked with many engineering faculty members [55]. In another study, interviews with seven mechanical engineering academics revealed differences across several themes: (i) nature of engineering, (ii) applied artistic creation versus analysis of how artifacts work, (iii) synthesis versus analysis, (iv) divergent versus convergent thinking, (v) well-defined versus ill-defined challenges, (vi) modes of instruction, (vii) laboratories versus projects, (viii) roles of project-based learning in curriculum and course design, (ix) lecturers versus facilitators, and (x) student difficulties [56]. Although the breadth of themes is impressive and many themes might resonate with engineering academics worldwide, this is but one study. Given the (a) importance of promoting adaptation of research-based instructional strategies (RBIS)[29] that have been developed, evaluated, and shown to be effective, (b) influences of faculty beliefs in faculty adaptation of new instructional strategies, and (c) scarcity of findings regarding beliefs about teaching and learning held by engineering academics, more studies on engineering instructor beliefs appear to be timely and necessary. Therefore, the present study has been conducted to provide more information about engineering academics' beliefs about teaching. Specifically, the research questions addressed in this study are:

1. What beliefs about teaching and learning do instructors of engineering science courses hold?
2. How are these beliefs about teaching and learning related to use of research-based instructional strategies in engineering science courses?

This study focuses on academics teaching engineering science courses, which are core, required courses, usually taught at the sophomore level (i.e., year 2 of a 4-year curriculum). One reason for this focus is to limit our investigations to one type of course; the results indicate that academics may have different beliefs for different courses or levels of students. Second, these courses are typically the first engineering courses taken by engineering majors in relatively large classes, and retention data consistently show that U.S. engineering students who leave engineering do so in the first two years of their curriculum [57, 58]. Third, these particular courses tend not to have undergone as much change as introductory and capstone-level courses, which are more likely to include design projects that actively engage students in learning [59]. We want to understand why these courses seem particularly resistant to instructional change.

Specifically, we focus on introductory thermodynamics, fluid mechanics, and heat transfer taught in chemical engineering; circuits, electronics, or introductory digital logic or digital design in electrical or computer engineering; and statics taught in any engineering discipline. This is because our prior survey study found that RBIS adoption rates were lowest for electrical, computer and chemical engineering, and that focusing on specific disciplinary networks is likely to increase survey response rates [32]; we added statics later because it is the focus of important conceptual change research [60], although little is known about instructional practices.

2. Methods

The overall study design was embedded mixed methods [61]. The study relies primarily on qualitative interview data, supplemented by some quantitative survey data. Like many other studies on academics' beliefs about teaching and learning, we rely on qualitative interviews to allow themes to emerge, since there are few if any established frameworks for understanding these beliefs. Quantitative survey data allows us to understand how and whether our findings apply to broader populations.

This paper presents selected data from a multi-year study of engineering instructors' use of Research-Based Instructional Strategies (RBIS). In spring 2011, we surveyed electrical, computer and chemical engineering faculty who had recently taught the courses of interest. Based on promising initial results, we obtained additional funding to expand the project to include statics. We conducted interview site visits in fall 2011 and spring 2012. Before conducting the statics survey in spring 2012, we revised the survey to remove some items and add the questions about faculty beliefs reported here. Due to the project expansion, we have interview data from instructors teaching all of the courses of interest, but only survey responses from statics instructors.

2.1 Survey methods

2.1.1 Instrument

The survey instrument and its development are described in more complete detail in our other publications [62]. The instrument was divided into three sections. The first section comprised 7 items about teaching and learning beliefs (listed in Table 3). Wording of these items was based on interviews with the six Metropolitan University faculty and an instrument developed by Trigwell and Prosser [63]. The second section asked faculty to estimate the amount of class time spent on different activities generally associated with RBIS use (significant items listed in Table 4; all items see [62]). The third asked respondents about their level of use and knowledge of specific RBIS (listed in Table 1); detailed descriptions of each RBIS are available elsewhere [62]. The fourth section included demographic information such as gender, rank, and frequency of attendance at teaching workshops. The survey was first administered in 2011; this version had a Cronbach's alpha of 0.8. Some items were removed, and the version administered to statics instructors had a Cronbach's alpha of 0.9208 indicating an acceptable level of reliability [64].

2.1.2 Data collection

Statics instructors were identified by contacting all accredited U.S. mechanical engineering programs (n = 285) as well as 7 civil engineering and 4 aeronautical/aerospace engineering programs at institutions that do not offer mechanical engineering. Initial contacts were made via telephone with email follow-up as necessary. Each instructor was invited to complete the survey via a personalized e-mail signed by Paul Steif and Anna Dollár, established statics professors and researchers. The survey was administered in fall 2012. Responses were screened to ensure respondents had taught statics within the last five years and had completed a majority of the survey items. Any participant who did not meet these characteristics was removed from the analysis, leaving 166 statics faculty with usable responses. The survey was sent to 764 academics; 166 responded, for a response rate of 22%. Of the 166 usable responses, 20% of respondents were female and 62% male (18% did not respond); 13% were lecturers (i.e., not tenure track), 17% assistant professors, 25% associate professors, 17% full professors, and 10% listed their position as other (18% did not respond). The respondents came from a variety of engineering departments or programs: 34% mechanical engineering, 34% civil, 5% aerospace/aeronautical, 2% engineering mechanics, and 7% indicated "other" (18% did not respond).

2.1.3 Data analysis

Descriptive statistics including means and response frequencies are reported for the teaching beliefs items. Spearman correlations were calculated to identify significant relationships between teaching beliefs and the amount of class time spent on specific activities. Spearman correlations were selected over Pearson correlations due to the unknown relationships between the variables. Pearson correlations only truly represent linear relationships, which may not be true for our data. The Spearman correlation will detect both linear and nonlinear relationships [65].

2.2 Interview methods

2.2.1 Site selection, interview participants and data collection

Interviews were conducted during site visits to two institutions selected from among a list of U.S.

institutions with ABET-accredited electrical engineering and chemical engineering programs. One was selected from among 128 institutions with Carnegie classification as research universities (institutions that awarded at least 20 research doctoral degrees in the prior year); the other was selected from among 27 institutions with all other Carnegie classifications (presumably more focused on teaching and undergraduate education). Selection attempted to maximize institutional diversity to the extent possible. We focused on selecting institutions that did not have reputations for being particularly innovative in undergraduate engineering education. Neither was a member of an engineering education coalition.

Metropolitan University (a pseudonym) is the main campus of a state university system, located in a major city. Its engineering programs are nationally ranked, and students are drawn from in state, out of state, and several countries. Rural State University is also part of its state university system. Students are primarily drawn from the local region. (Location information is not given to protect the identities of the participants.)

Local site coordinators were used to assist with IRB approval and appointment scheduling. Metropolitan University was visited in fall 2011, and Rural State University was visited in spring 2012. At each site, we interviewed academics teaching the courses of interest, their department chairs, the engineering dean, the engineering undergraduate academic dean, and directors of STEM and teaching and learning centers. Few instructors declined to participate: 2 statics instructors from Metropolitan University and 1 electronics instructor from Rural State University.

The faculty interview protocol included questions about teaching and learning, including:

1. How do you know that your teaching is working?
2. What do students do during lecture? If I were observing your class, what would I see?
3. Do you receive feedback on your teaching from your students? What kinds of things [criteria, evidence] do students use to evaluate good teaching?
4. How has class size or teacher-student ratio affected your decisions about what activities you could do in class?

For the second half of the interview, we gave participants a table (Table 1) of research-based instructional strategies that included a short (1–2 sentence) definition of each. We asked them to discuss whether they use or have tried any of the strategies on the list and why they think the strategies are not being used more often. As participants talked, we asked clarifying questions to encourage them to give specific details of what they do in their courses and their reasoning behind these decisions.

Table 1. Descriptions of Research-Based Instructional Strategies Shared with Interview Participants

Just-In-Time Teaching	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the plan for the class accordingly.
Active Learning	A very general term describing anything course-related that all students in a class session are called upon to do other than passively watch, listen and take notes.
Think-Pair-Share	Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses.
Concept Tests	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions.
Peer Instruction	The instructor poses a conceptual question in class, asks students to respond individually (possibly using a classroom response system or "clickers"), and then shares the distribution of responses with the class. Students form pairs, discuss their answers, and then vote again.
Thinking Aloud-Paired Problem Solving	Forming pairs in which one student works through a problem while the other questions the problem solver in an attempt to get them to clarify their thinking.
Collaborative Learning	Asking students to work on a common task in small groups.
Cooperative Learning	A structured form of group work in which faculty help students develop team skills, assess both individual learning as well as overall group results, and structure assignments to strengthen interactions between team members.
Inquiry Learning	Presenting students with questions, problems or a set of observations and using this to drive the desired learning.
Problem-Based Learning	Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material.
Service Learning	A form of project-based learning in which significant realistic problems are drawn from community service opportunities to enhance the learning of the core content and to give students broader learning opportunities about themselves and society at large.
Case-Based Teaching	Asking students to analyze case studies of historical or hypothetical situations that involve solving problems and/or making decisions.

Table 2. Characteristics of interview participants

Institution	Course	Position
Rural State University	Circuits	Associate professor
Rural State University	Circuits, Electronics	Full professor
Metropolitan University	Electronics	Full professor
Metropolitan University	Introductory digital logic and/or digital design	Assistant professor
Rural State University	Introductory digital logic and/or digital design	Assistant professor
Rural State University	Introductory digital logic and/or digital design	Associate professor
Metropolitan University	Digital signal processing	Full professor
Metropolitan University	Digital signal processing	Full professor
Rural State University	Fluid mechanics	Full professor
Rural State University	Heat transfer	Assistant professor
Metropolitan University	Heat transfer	Full professor
Rural State University	Thermodynamics	Associate professor
Metropolitan University	Thermodynamics	Assistant professor
Rural State University	Statics	Associate professor
Rural State University	Statics	Associate professor
Rural State University	Statics	Instructor (not tenure track)
Rural State University	Statics	Full professor

All interviews were transcribed verbatim. Based on a careful reading of the transcripts, we determined that administrators' interviews were not detailed enough to support this analysis, so only instructor interviews were used. Interviews with administrators tended to focus on the resources available to academics rather than any specific instructional practices or the underlying rationale for them. One department chair also taught one of the courses of interest, and the portion of that interview dealing with the course was included.

Selected characteristics of the instructor participants are presented in Table 2. The courses of interest were: thermodynamics and heat transfer in chemical engineering; circuits, electronics, digital logic/design and digital signal processing in electrical engineering; and statics in various departments (not listed, to protect identities of participants). Based on the interviewers' observations (i.e., not reported by participants), the faculty interviewed included two women and one person of Hispanic/Latino descent. All others were males of European/Caucasian or Asian descent (e.g., from India or China).

2.2.2 Interview data analysis

First, we identified the portions of the transcripts that directly addressed beliefs about learning and rationale for pedagogical practices. Since interviewees frequently circled back to previous topics, relevant responses were parsed into units ranging from a few paragraphs to a sentence, which dealt with a single topic or explanation. These units were then iteratively and open coded into categories created to fully describe the range of activities, concerns and rationales offered by the faculty participants related to their teaching [66]. The subheadings of the interview results sections below represent the final categories.

2.3 Limitations

Since there have been few investigations of engineering instructor beliefs about teaching, this study is exploratory. The results are not generalizable to the larger population of engineering science faculty because 1) generalizability is typically not a goal of qualitative interview studies and 2) the survey likely includes a response bias favoring statics instructors who are interested in quality teaching. Nonetheless, the study identifies important factors and findings that can be examined further in future work.

3. Results

Surveys and interviews were analyzed separately before the results were combined to answer the research questions. Although surveys and interviews were analyzed concurrently, survey results are presented first because they give an overview of what is happening in engineering science courses. These are followed by interview findings, which provide more insight into why instructors are making these decisions.

3.1 Survey results

Survey responses are presented in Tables 3 and 4. Table 3 presents the distribution of responses to all 7 teaching beliefs items. Table 4 displays the significant relationships between these items and classroom activities (The complete list of classroom activities is included in our other publications [62].).

The teaching beliefs items can be divided into two sets: problem-solving and lecture. Highest agreement is related to the problem-solving items (Table 3). These items focus on how learning happens, not necessarily on practical decisions about how to use class time. Nonetheless, there is a high correlation among instructors who believe that problem-sol-

Table 3. Distribution of responses to teaching beliefs survey items. N = 166. The percentage of participants who did not respond to each item ranges from 0.6% to 1.8%

Teaching Beliefs Item	Mean	Strongly Agree (5)	Agree (4)	Neither Agree nor Disagree (3)	Disagree (2)	Strongly Disagree (1)
Problem-Solving Items						
The most effective learning in statics happens when students solve problems.	4.47	57%	36%	4.8%	0%	1.8%
Students learn statics better when an instructor or teaching assistant is available while they are working on problems.	4.13	32%	51%	12%	2.4%	0.6%
Students learn statics better when they work on problems together than when they work on problems alone.	3.76	25%	37%	26%	7.8%	2.4%
Lecture Items						
A formal lecture is necessary before students can effectively solve statics problems.	3.64	18%	43%	25%	11%	1.8%
Lecturing is the best use of limited statics class time.	3.30	12%	34%	31%	16%	6.0%
The most effective learning in statics happens when students listen to a well-prepared lecture.	3.06	11%	18%	38%	28%	3.6%
When students talk to each other during statics class, it distracts them from learning.	2.99	14%	18%	30%	30%	8.4%

ving is the key to learning statics and use of class time for students to work in problems, often in pairs or groups (Table 4).

The highest and most positive responses were to the statement, "The most effective learning in statics happens when students solve problems." The overwhelming majority, (93%, Table 3) of respondents strongly agreed or agreed with this statement; only 3 respondents (1.8%) disagreed. There was nearly as high agreement that students should solve problems when an instructor or teaching assistant is available (83% agree or strongly agree), or with other students (62% agree or strongly agree).

As shown in Table 4, there are also correlations between beliefs about problem solving and student activities during class time. Respondents who believe students learn better when an instructor is available when they solve problems were more likely to have their students discuss problems in pairs or groups (correlation coefficient = 0.224, p = 0.004). Those who felt students learn better when they solve problems with other students were more likely to both have students discuss problems (coefficient = 0.333, p = 0.000) and work on problems (coefficient = 0.299, p = 0.000) in pairs or groups. There were no significant relationships with the one item about relating problem solving to learning (first item in Tables 3 and 4), although this might be expected given the small variation in responses to this item.

There is less agreement on the items related to the

Table 4. Spearman correlations between teaching beliefs and classroom activities (only significant relationships shown). The response scale for student activities as a percentage of class time was: "Never 0%" (1), "Rarely 1–25%" (2), "Sometimes 26–50%" (3), "Often 51–75%" (4), "Nearly Every Class 76–100%" (5)

	Watch, listen and/or take notes on a lecture		Discuss a problem in pairs or groups		Work on problem sets or projects in pairs or small groups	
Teaching Beliefs Item	**correl.**	**p**	**correl.**	**P**	**correl.**	**p**
The most effective learning in statics happens when students solve problems.						
Students learn statics better when an instructor or teaching assistant is available while they are working on problems.			0.224	0.004		
Students learn statics better when they work on problems together than when they work on problems alone.			0.333	0.000	0.299	0.000
A formal lecture is necessary before students can effectively solve statics problems.	0.285	0.000				
Lecturing is the best use of limited statics class time.	0.358	0.000			–0.228	0.003
The most effective learning in statics happens when students listen to a well-prepared lecture.	0.388	0.000				
When students talk to each other during statics class, it distracts them from learning.			–0.309	0.000	–0.229	0.003

importance of lecture. Among these items, there was most agreement with the statement that, ''A formal lecture is necessary before students can effectively solve statics problems,'' (18% + 43% = 61%, Table 3) although 25% responded neutrally. It may be possible to use resources such as recorded lectures or online resources created by other statics instructors to fulfill this requirement without using class time. However, 34% of respondents agreed and an additional 12% strongly agreed that ''Lecturing is the best use of limited statics class time.'' Again, nearly as many (31%) responded neutrally. The average was just barely in agreement (mean = 3.06) with the statement regarding the importance of well-prepared lectures, although the majority of responses were neutral (38%). Finally, the average was essentially neutral (mean = 2.99) regarding students talking in class. The majority disagreed (30%) or responded neutrally (30%).

These responses are to at least some extent contradicted by the literature. Inductive teaching methods (for which there is strong evidence of improved student learning [15]) encourage instructors to start with real-world questions or problems to motivate learning before lecturing on relevant material. In problem-based learning, a specific case of using problems to motivate learning, lectures are minimized or abandoned altogether [16, 67]. If statics instructors are uncomfortable with ceasing lectures, resources such as recorded lectures and other online resources created by other statics instructors can fulfill this requirement [68]. This allows class time to be used on other activities that actively engage students in their own learning in the presence of a knowledgeable facilitator [9].

Again, there were a number of statistically significant correlations between these beliefs and students discussing or working together on problems during class time, as listed in Table 4. Respondents who spent the highest percentage of class time lecturing were most likely to agree with the statements about the need for formal lectures (correlation coefficient = 0.285, p = 0.000), using limited class time for lecture (coefficient = 0.358, p = 0.000), and well-prepared lectures (coefficient = 0.388, p = 0.000). This may be the first empirical data to demonstrate that some engineering academics chose to lecture because they believe it is the best way to support student learning. It can be applied directly by faculty development professionals and developers of research-based instructional strategies to address the concerns of engineering academics. A number of previous studies have demonstrated that awareness of new strategies is high and that the largest gap is between awareness and use [23, 24]. This finding suggests that deep-seated beliefs about how different pedagogies best support student learning must be addressed. The type of shift is more affective and attitudinal than is likely to be addressed by assessment evidence that a particular new method increases student learning.

There are also a number of negative correlations because instructors who believe in the value of lecture and spend a significant majority of their class time lecturing are less likely to engage students in other activities. Statics instructors who believe that talking in class distracts from learning, as might have been expected, are less likely to have their students discuss (correlation coefficient = –0.309, p = 0.000) or work on (coefficient = –0.229, p = 0.003) problems in pairs or groups during class time. Similarly, instructors who believe lecturing is the best use of class time are less likely to use class time for group work (coefficient = –0.228, p = 0.003).

In sum, there is clear empirical evidence that statics instructors' beliefs about teaching influence how they use their limited class time. There was extremely high agreement among statics instructors that students learn best when they solve problems, frequently in collaboration with other students or when an instructor is available. There was less agreement on the importance of lecture; many instructors responded neutrally to these items. Instructors who agreed with the importance of working with other students were most likely to have their students discuss or work on problems together during class time. Similarly, instructors who felt strongly about the value of lecturing were most likely to spend their class time lecturing rather than engaging students in group work. This quantitative data demonstrates a weak to moderate relationship between beliefs about teaching and learning and classroom activities, but it does not provide much insight into the details of these beliefs or how they are translated into instructional decisions. This is provided by the interview data.

3.2 Interview findings

Overall, the academics we interviewed appeared to be conscientious teachers. They displayed thoughtfulness about teaching and learning and carefully described pedagogical content knowledge that they had developed over many iterations of teaching these and other courses. It was clear to us that their teaching is informed by their own beliefs about how to best support student learning and development. Accompanying each quotation is information about the course and academic rank of the participant. This is provided for additional context and so that future research can build upon our findings.

3.2.1 Difference from upper division courses

One important finding from the interview data is that instructors held different beliefs about teaching, learning and student development for courses at different levels. Most of the academics we interviewed also taught upper division undergraduate or graduate courses, and they contrasted their teaching practices and beliefs with those other courses. An instructor explained that statics is the only course in which he quizzes students and structures the syllabus so tightly because it is "a basic concept course." A circuits full professor said, "I used to do a lot more derivations in class, . . . but if you're teaching undergraduate, especially sophomore-level classes, you should not—, I feel like I shouldn't do too many derivations." An associate professor contrasted hydraulics, hydrology and water resources with statics, saying "those are quite different. There it's more, the conceptual nature is broader." This instructor went on to explain that statics is "just these three equations you solve, . . . forces, moments, they all sum up to zero equilibrium," but in hydraulics, "there are lots of different equations. There are lots of physical complexities, so I spend a lot more time showing examples, doing hands-on."

These quotations demonstrate that decisions about teaching aren't dictated solely by general beliefs about teaching and learning, but there are specific considerations for engineering science courses. This finding that beliefs about teaching are course specific is consistent with prior work [69].

One important distinction that some interview participants made between engineering science and upper division courses was that at lower levels, it is important for students to demonstrate they can do the work on their own. Academics described teamwork, division of labor and specialization as modes of real engineering work acceptable in upper division courses, including laboratories, but not appropriate to engineering science:

> In this [statics course], they're not doing so much teamwork . . . I want to make sure each and every individual can really do, say, all these individual things I want them to learn. I want them to be totally independent in this particular course because that's what the employers expect in this one. But in other courses I can see it would be important. [statics, assoc prof]

Others struggled with encouraging students to work on their assignments together while ensuring that they each learn the material: "Sometimes they work a little too closely together . . . somebody's doing it, and somebody else is just rote copying." [circuits, full prof]

> I do tell the students that it's okay with me if you work together to solve a problem, it does not bother me, because you learn that way, and which it's up to you to learn. If you just want to copy someone else's work, that doesn't help, and you take the consequences. But if you discuss among yourselves how to go about solving it, why this is the way to solve the problem, that's fine, because you learn that way. [statics, assoc prof]

These instructors are essentially viewing group work as incompatible with individual accountability, but this is not necessarily the case. The cooperative learning literature emphasizes some level of individual accountability as a best practice for promoting student learning [12, 70, 71]. Further, a vast body of literature, including a number of meta-analyses of individual studies demonstrates the individual learning benefits of allowing students to collaborate [12, 70, 71]. Clearly, those who work with engineering academics have more work to do in increasing understanding and awareness of individual accountability aspects of cooperative learning.

We note that there were a few exceptions who valued group work. For example, a thermodynamics associate professor clearly explained that requiring group work during class time results in more learning and better grades than relying on students to organize group work on their own time.

3.2.2 Developmentally appropriate pedagogies

The second important finding is that engineering science instructors hold a number of beliefs related to the developmental maturity of students, including study habits, which are necessary to cultivate among students in these courses in addition to learning dense, conceptually challenging content. In the following subsections, we describe four beliefs related to developmentally appropriate pedagogies:

1. Students need to be broken of the habit of mindlessly solving problems without learning underlying concepts.
2. Students need structure, including deadlines, to pace their academic work.
3. Students need examples to motivate and sustain their interest in engineering science content.
4. Students need to be treated like human beings to help them through difficult transitions.

We note that these academics are correct in viewing engineering students with different developmental needs at different points in college, as documented by a number of student development theories [e.g., 72]. These statements are not particularly new, but we document them here to assist the engineering education community and faculty developers in furthering the discussion of academics' beliefs and their implications for teaching decisions.

3.2.2.1 Students are in the habit of mindlessly solving problems, which prevents them from learning underlying concepts

A statics associate professor explained that, ". . . these kids, unfortunately they're still kids now, they're still hung up on math . . . all they want to do is get an equation and plug and chug. They don't want to think, and it's hard to beat that out of them, most of them." Similarly, a fluid mechanics full professor said, "a significant number of students become confused by not having to do rote work . . . if I'm giving four homework problems a week, that's why I make three of them routine number-pluggers, because they're very reassured." Unfortunately, this translates to discomfort with active learning pedagogies, as described by this statics instructor:

> I do use active learning in the upper-level courses where I'm trying to develop critical thinking skills, but I am not trying to develop critical thinking skills with my statics students. They're still overwhelmed by solving problems. It's the mechanics of solving a problem . . . they're just not ready, in my opinion, for these types of teaching methods. [statics, instructor]

These academics' beliefs are consistent with the literature in the sense that simply solving many problems, as students typically do in engineering courses, does not lead to significant gains in student learning, particularly of important concepts [73, 74]. However, the literature also presents a great deal of evidence that research-based instructional strategies are in fact successful in introductory STEM courses [e.g., 75, 76]. Increasing awareness of this literature would be another important task for faculty developers.

3.2.2.2 Students need structure, including deadlines, to pace their academic work

These engineering science academics gave detailed descriptions of how they ensure that their students are practicing and learning throughout the course, as opposed to cramming just before exams. The most frequently cited strategy was a combination of collecting homework and/or quizzes for a small percentage of students' grades. A circuits full professor explained that he collects and grades homework to ensure students practice throughout the term and do not blame him for poor exam performance. A circuits associate professor (also from RSU) explained that he uses pop quizzes "to enforce to the students don't try to absorb this as drinking a gallon at one time, but take it in small sips and make sure you're understanding it along the way." Multiple statics instructors at RSU described a similar rationale for giving frequent quizzes.

Two statics instructors explained that they include in the syllabus a detailed schedule of topics and assignments. However, it appears that this only works in conjunction with graded assignments:

> I've always [given] them on day one a day-by-day schedule of everything we're going to do, every section we're going to cover, every homework problem that's assigned, although not required to be submitted, every date of the test, and I think that's one reason I don't get good attendance in class. [statics, full prof]

A circuits full professor goes so far as to require specific layouts: "I have them do everything on green engineering graph paper. This is obsessive, compulsive, I'm sure . . . the headings have to be a certain way, so then I expect them to lay the problem solution out in a very systematic manner." Two others asserted that this structured practice is necessary to learn engineering sciences: "Go through the steps and learn. That's the process of learning . . . the purpose of homework is to learn." [digital signal processing, full prof]

> Bottom line in the statics thing is it's practice, practice, practice. That's what I tell them. It's such a type of a course it's like maybe like a math course where the more you practice, the better you get at it with the numbers and the concepts. No matter how well you think you understood it by reading the book, I want to see you do it. You're not going to be able to be really good master of it, the subject. [statics, assoc prof]

This type of structure forces students into guided practice and feedback on problem-solving, which the literature strongly supports as important for learning [77–79]. It is not clear, though, whether these instructors are advocating the type of thoughtful, reflective feedback that is supported by research studies. If repeated practice is too rote, then students will not be able to develop the critical thinking skills needed in their later coursework. The structure described by these instructors also provides extrinsic (external) motivation to students who are more interested in passing the course than in learning the material [80]. Helping students build intrinsic (internal) motivation for learning is better addressed through relevant examples, as described below.

3.2.2.3. Students need examples to motivate and sustain their interest in engineering science content

Instructors from each discipline described specific applications and demonstrations they bring to their classes. A fluid mechanics full professor said, "I constantly try to find examples that will make it more real to them," because most of his students end with bachelor's and go into industry. A statics instructor from the same institution (RSU) explained, "I come from a practice background rather than an academic background, and so as I introduce each new topic I try to introduce it from a practical perspective. This is how you would use this as a practicing engineer . . . by using the application part of this, I think it kind of motivates some of them."

> [Y]ou want to give them that assurance that, you know, after all of this struggle with the theory, this actually leads you somewhere. So a lot of what, you know, is,

> I'm always looking for better examples that people can connect with . . . you try to bring in more things that they can get excited about. And once they do, you have their attention now, you give them the boring stuff. [digital signal processing, full prof]

In the few cases where the instructors explained why they work so hard to find examples, it is to motivate students to learn the material. This belief is consistent with a broad and deep literature supporting relevance as a primary motivator of adult learning [81–83].

3.2.2.4 Students need to be treated like human beings to help them through difficult transitions

Many of the academics interviewed explained that they try to learn students' names. A thermodynamics associate professor explained that he takes attendance in class for this purpose. By handing back students' papers individually, a circuits full professor explained, "I'm trying to imbue the attitude that, you know, I'm glad you're here, and it's good to see you, and here's your paper, and, you know, so that they don't feel like 'well, this guy's like the gatekeeper' or something. 'He's really here to help me.'" A circuits associate professor from the same institution (RSU) described the benefit as: "in a class where you know everybody's name you can call on a student and say, you know, well, 'Bill, what did you think about it?' . . . so it does change the dynamic of the class a little bit." A statics associate professor asserted, "Well, one thing I don't do is belittle them, because I had that happen to me enough and I didn't like it. So, no matter what they tell me, I'll find something correct about it."

In sum, in moving from high school to college, students enrolled in engineering science courses are going through difficult transitions that require them to develop organizational and time management skills that will enable them to take responsibility for learning the material at a conceptual level. These are difficult transitions, and engineering science instructors try to support students' interest through use of examples and developing personal connections. Left to their own devices, students might not complete assigned practice problems, or they may complete them in groups without learning the material themselves. This leads to a high level of structure in these courses that is at odds with engaging students in group work.

3.2.3 Rationale for limiting active student engagement

The interview protocol included giving participants a list of research-based instructional strategies (with definitions) and asking whether participants use any of these in their courses and why. In addition to the concerns described above, participants gave three primary arguments for their inability to actively engage students in engineering science courses. (We note that we specifically asked about large class sizes and dense curricula, and participants agreed these were factors.)

3.2.3.1 Not wanting to embarrass or intimidate students

Across all three departments at RSU and in electrical engineering at MU, academics were very hesitant to require students to work together on the basis that some students are shy or do not have friends in the class. For example, a digital signal processing full professor (MU) said,

> . . . unfortunately, for some students that does not seem to be an option. I have no idea why. I have people who come to class and you know that person's by themselves, and if, you know, it almost would be an embarrassment for them to say, you know, talk to your colleague [and students do not have a friend in the class they can work with]. . ..if I have a barrier, part of that barrier for me is that I don't want to force the issue [of working in groups].

A circuits and electronics full professor (RSU) explained, "I've toyed around with the idea of asking individuals directly . . . You know, there's a lot of people that would be intimidated by that, and so I'm not looking to do that."

These academics and others expressed concern for asking students to risk giving an incorrect answer and potentially embarrassing themselves. This is a legitimate concern, particularly in the first few years of engineering, when many students change their majors due to self-efficacy concerns [e.g., 84]. Fortunately, there are many ways that academics can help students find others to work with and test their answers with peers before sharing them with the entire class. This is typically done by assigning students to work in groups or pairs, and it need not take a significant amount of class time. For example, think-pair-share, as the name implies, gives students time to discuss their ideas in small groups before reporting to the rest of the class [11]. A digital signal processing full professor thought that clickers or other personal response systems that could elicit anonymous feedback from students would be a desirable solution. This would be another method of allowing students to see their response in relation to others before explaining their reasoning. Similar concerns were expressed in several sections below, including respecting individual differences.

3.2.3.2 Assuming equal participation is required

Several responses suggested that instructors assumed that all students must participate in class at the same level. When discussing various active learning techniques, an electronics full professor who is a proponent said, "making these activities is always a challenge, and, you know, obviously everybody cannot participate in a large class." A digital logic/design associate professor explained how he tries to ask students questions during class, but expressed frustration at feeling like each student should participate at least once during a class period:

> I tried that and increase its frequency as I teach the class more and more, find more opportunities to ask questions to the students, and attending conferences and feeling that portions of that, some instructors they really say that we have to ask every one of them in every class, but for a big class size would be too much. I guess I'm amazed that at a conference one of the presenters said that you have to pick on each of them twice every class. That also requires, say, a class maximum size of 10. If I, I use the volunteer approach, just because of the class size, who knows, who volunteers to come to the board and present what they did, just because of the size. And because of that structure, some might fall asleep, so I cannot pick on everybody, every class, twice.

A counterargument would be that even during a formal lecture, students do not all engage at the same level. Some students are asking questions, while others are not paying attention. Equality is not a particularly useful goal if all students are equally bored and disengaged from learning. When active learning methods are used properly, they better engage all students in thinking about the material [9]. This is enabled at a large scale through use of technology and peer interaction among students. These methods have been shown to result in learning gains in very large classes of 800 students [75, 76].

3.2.3.3 Respecting individual differences

Individual differences among students (and sometimes among academics) were cited often to rationalize instructional decisions. However, the argument was not always consistent. For example, this explanation combines students' differences and faculty differences in the same argument:

> I mean, people have different ways that they think things should be done. I don't think that they don't use [instructional strategies] because they think they're bad or they don't use them because they can't do them. I think it's more just people having the way that they like to do things. You know, not every student is responsive to these types of strategies. Some of them think it's a waste of time and they would prefer something a bit more direct. So, I think in the end it's useful for the students, too, to have diversity of different types of instruction. [thermodynamics, asst prof]

This instructor is focusing on a minority of students who may not participate in active learning approaches, rather than the majority that is likely to benefit from it [11]. (This instructor primarily lectures with some practice problems when he erases the board. Recitation is very active, but most RBIS he dismissed as impractical given the size of the class. As described above, these methods have been shown to work in very large classes of hundreds of students [75, 76].)

Similarly, a digital signal processing full professor gave examples of student differences that are tolerated: writing lecture notes or just listening, running simulations or not:

> I always think the best way to learn is write down the notes as the teacher goes along. I think that's the best way to learn, but I am constantly told by students that they cannot learn that way, and that's okay. I recognize that, and this, so that they cannot simultaneously write down lecture notes and understand . . . So they can do one or the other, and that doesn't matter to me. I am here to help them learn in any way that they can learn. If they learn by doing the programming and not, they don't want to bother about math, that's fine with me. That's fine. You know, there are engineers working in a company, somebody does all the programming, somebody else, a colleague, figures out all the math and details of why it works, that's fine, too. So we are here to teach. We are here to teach students to the best of their abilities.

This instructor leaves it up to students to know what works best for them and adapt their mode of work to the course.

Finally, we note that these individual differences were a barrier to active learning pedagogies:

> they may be much more willing to share an idea with their colleague if they have confidence than, you know, kind of saying it flat-out, you know, in front of the class. I know that that should work. And when we get to the design, if I had the time, I would do it that way. But I explained earlier why the barriers that I think they exist in a potentially larger class. You have the grad students, undergrad students. We have BME students that are coming from different departments. So I don't have, I don't know if I can guarantee if the students are homogenous enough to—[digital signal processing, full prof]

A counterargument would be that activities that actively engage students in discussing problems are actually a better way to work with a diverse group. A lecture makes assumptions about the audience's level of understanding and experience, confusing students below that level and boring students above it. When students discuss the material in small groups, the level of discussion adjusts appropriately [15].

3.2.4 Lectures, labs and recitations

Although the interview questions focused on course meetings labeled "lecture," several respondents contrasted activities in lecture from other formal and informal course meetings. For example, the two MU academics who inspired the survey item about talking in class distracting from learning ("We don't want them to work together. We just want them to listen to me. I don't want them to talk to each other and to figure things out" [digital signal processing, full prof]) were both more open to students working together during laboratories and design activities. A chemical engineering professor explained that in recitation,

> . . . the students recite, and by that I mean they answer questions, and I go around the room, as a rule, in order, so they know when the question is coming. And I try and match the question to the ability of the student. In other words, I want them, I want four out of five questions right . . . the recitations in particular are completely active learning. Interestingly, students really like that. I was initially reticent to kind of nail students and potentially shame them in front of the class. But I think by, they're not bothered by that at all. Some of the international students, especially those with problems with English, have trouble there. [heat transfer, full]

4. Discussion

This research sought to understand faculty beliefs about teaching and learning in engineering science courses and how these beliefs influence instructional decisions. A survey of statics instructors at U.S. institutions demonstrated a strong belief that students learn statics best by solving problems, particularly when faculty or peers are able to provide assistance. There was more variation in beliefs about the value of lecture; however, a majority of respondents felt that formal lecture was necessary before students can solve problems. Nearly half also felt that lecturing was the best use of class time.

The survey also found that the beliefs academics reported about how students learn are correlated with the teaching practices that academics report engaging in. Academics who have stronger beliefs in the importance of problem solving in learning tend to report that students spend more class time discussing problems or working on problems in small groups. Academics who have stronger beliefs in the importance of lecture tend to report that students spend more class time watching, listening, and taking notes.

Beliefs about teaching and learning, though, are only one consideration that shape instructional decisions. Despite the strong endorsement of the importance of problem solving indicated by the survey results, during interviews, engineering science academics cited a number of reasons for not engaging students in problem solving and other active learning strategies during class time (beyond and more specific than class size and time constraints). Academics do not want to embarrass shy students by calling on them or by asking them to find a partner. They struggle with the assumption that all students must engage equally, for example, by all answering a question over the course of one class session. They cited individual differences and learning preferences as reasons to rely primarily on lecture. Instructors also felt that group work was incompatible with individual accountability. According to the survey data, all of the respondents spent some percentage of class time having students watch/listen to a lecture; however, only 35% reported spending more than 76% of class time on lecture leaving 65% who spent part of their class time on other activities[1]. Other activities include having students discuss a problem in pairs or groups (with 91% of respondents spending some class time on this activity) and students working on problem sets/projects in pairs/small groups (with 81% of respondents spending some class time on this activity).

A very important finding of this research is that most academics believe that students learn best by solving problems and that interactions with instructors and other students are the most productive way that students can learn from solving problems. This belief is validated through educational research. Most academics, though, are also reluctant to increase the amount of class time that is allocated for students to work together to solve problems.

Similar to prior research [41], interview results suggest that academics are essentially caught in two conflicts that they are not able to resolve. The first conflict is that they believe students learn best by being actively engaged, yet academics do not know how to structure courses to successfully employ active engagement and they are also not sure whether it is appropriate for them to force students to work in particular ways. The research literature has suggestions for how to structure a class to employ active learning strategies in ways that are fair to students and that most students find acceptable.

The second conflict is that academics realize that their introductory students solve problems by rote and want students to become reflective problem solvers, yet academics do not know how to structure courses to accomplish this. Thus, they tend to focus on having students solve many basic problems, which they realize leads to unsatisfying results for many students. Again, the research literature has suggestions for how to help students develop meaningful problem solving skills through appropriate scaffolding.

To summarize, academics have many beliefs about *learning* that are consistent with the educational research literature. It is very promising that

[1] The possible response options for this multiple choice item were 0%, 1% to 25%, 26 to 50%, 51% to 75%, and 76% to 100%.

most of the core beliefs (e.g., how students learn best) are quite strongly aligned with the educational research literature. The beliefs about *teaching* and reported teaching practices are less strongly aligned with the educational research literature. Conflicts between beliefs about learning and teaching practices arise from primarily logistical concerns about how to structure classes: how can a class be structured to have students learn by working together to solve problems (e.g., how to assess students in group work, not feeling that it is the instructor's job to force students to work together)? Fortunately, the educational research literature provides much advice and examples about how to structure classes to be successful. This literature is cited in the appropriate sections of the Results to address our primary audience of engineering academics.

A secondary audience for this work is educational development professionals. This group can use the academics' existing belief in the importance of problem solving to motivate deeper thinking about how to structure their classes effectively. Often professional development providers assume that academics are highly committed to the lecture method of teaching and so spend a lot of time attacking the lecture method. The results here, and similar results in physics [41] suggest that attacking the lecture method is unnecessary and could, perhaps, be insulting to academics. A more successful professional development strategy might be to expose academics to this internal conflict between beliefs about how students learn and the structure of classes that academics likely have (cognitive disequilibrium) and providing a way to resolve the conflict may be a productive approach for professional development. Of course, as with any type of "teaching," it is probably most effective not to tell academics, but to engage them in professional development that involves active learning focused on changing their beliefs about teaching and the role of the teacher (e.g., [85]) to match their primarily accurate views about how students learn.

It is also important for professional development providers to keep in mind that academics hold differing beliefs about learning and that professional development will be best focused on addressing particular beliefs. For example, although most statics instructors believe that students learn best when they are solving problems, nearly one third (29%) feel that students learn most effectively by listening to well-prepared lectures. Different professional development approaches addressing these different beliefs are likely to be more effective than singular approaches based on an assumption that all academics share the same beliefs about teaching and learning.

5. Conclusion

This study explored how academics' beliefs about learning influenced their teaching in engineering science courses such as statics, thermodynamics and circuits. Survey data established a direct link between instructor beliefs and classroom activities specific to engineering courses which rely heavily on problem-solving. Interview data provided much more detail about teaching and learning beliefs specific to second year engineering students. Instructors demonstrated deep understanding of the content (including important conceptual difficulties students frequently encounter) and the developmental needs of their students. They were also aware of some of the shortcomings of lecture-based modes of instruction and rote problem-solving. However, they struggled with their role in making changes to engage students more actively in learning during formal class time. Where relevant, we offered explanations and citations to the literature to help engineering academics understand how engineering education research can offer solutions. A secondary audience for this work is educational development professionals, who also need to understand the beliefs of engineering academics in order to help them improve their teaching. This work provides important empirical evidence and specific detail about the teaching beliefs of engineering instructors in courses which appear to be particularly resistant to instructional change. Future work should seek to validate and extend these findings to a larger group of academics in other engineering disciplines, courses and countries.

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