120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013
ATLANTA

Paper ID #7438

Using Writing to Link Procedures and Concepts in Statics

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Using Writing to Link Procedures and Concepts in Statics

This mixed-methods study explores the use of short writing assignments to enhance conceptual knowledge in an engineering mechanics course. In prior work, the authors presented quantitative findings from analysis of scores on the Statics Concept Inventory, which indicated a positive difference in conceptual understanding among students who completed the written problems (experimental group) versus those who did not (control group). However, course grades on common exams were similar, suggesting that while conceptual understanding improved, levels of procedural knowledge between the two groups were undifferentiated. This paper explores the interview data collected during the same semester from selected students in both the control and experimental groups. The results of this qualitative analysis suggest that while many students focus mainly on developing procedural knowledge, the written problems may be effective in developing conceptual knowledge by promoting reflection and self-explanation of the mathematical procedures.

Introduction

Statics, the study of objects and systems in equilibrium and the forces that act upon them, is a foundational subject present in most engineering curricula, but many students struggle to learn and succeed in statics courses. Statics is a "threshold concept" in engineering in that mastery of this area can serve as a "conceptual gateway" that opens up "previously inaccessible way(s) of thinking about something" [1]. However, many statics courses have a high failure rate, and many students who pass still have difficulty conceptualizing important topics and may have trouble in follow-up courses [2-4]. As students develop from novices to experts in threshold topics such as statics, they must engage in both procedural and conceptual learning of problem solving. Novices, for example, often struggle with basic procedural tasks [5] while experts can perform tasks efficiently and with minimal effort. Conceptually, novices demonstrate fragmented knowledge with relatively few connections [6] while experts have highly structured knowledge rich in meaningful connections. In statics, many students who struggle may be focusing only on procedure and rote learning [7]. Metacognition [8] and self-regulation may play an important role in promoting adaptive expertise, and approaches such as writing-out problem solution processes may promote metacognition [9].

We report on a structured experimental study that tests a writing-to-learn intervention in statics courses, with the goal of better understanding how writing may be used as a pedagogical tool to promote metacognition and conceptual learning of statics concepts. Basing our intervention on previous studies by Hanson and Williams [10], we have created written "process problems" that require students to explain their solution processes to statics problems. To that end, we address the following research questions:

1. How do process problems affect the ways that students learn statics content?
2. What are students' attitudes toward the process problems? And how do these attitudes affect learning through the process problems?

Theoretical Framework

The theoretical framework for this study draws upon three major research threads within cognitive learning theory: expertise, conceptual and procedural knowledge development, and conceptual change. Linked together, these threads help to frame the current problems with statics identified in the research literature. The framework then incorporates research in writing-to-learn as a potential solution.

For cognitivists in particular, an expert is someone with considerable domain knowledge that is highly structured around key concepts [11]. This means that experts not only possess a large quantity of knowledge, but that their knowledge is rich in meaningful connections and organized into large related chunks, or concepts. Thus, they possess high levels of quality *conceptual knowledge*, i.e., knowledge about interconnected pieces of information and how they relate to each other. Their well-developed knowledge structure facilitates quick retrieval of pertinent information from long-term memory and allows them to process the information in working memory more efficiently [8]. In addition to conceptual knowledge, experts also possess a large amount of *procedural knowledge*, i.e., knowledge about how to do things, gained from their years of practice and experience. In fact, many experts have performed procedures that are common in their field so often that they reach a level of automaticity in which they can perform the task quickly with little cognitive effort [12].

As noted above, expertise is dependent on the quantity and quality of *both* conceptual and procedural knowledge, yet it is not clear which type of knowledge develops first in novices and hence which should be emphasized in instruction. Dialogue regarding the primacy and relative importance of conceptual and procedural knowledge in learning has been underway for some time, particularly in the context of mathematics education. Both theoretical arguments and empirical findings have been used to advance positions supporting a procedures-first or concepts-first approach to instruction [see 13 for a review]. However, there has not been widespread consensus supporting any position, and the result has been an ongoing debate dubbed the “math wars” [14] (e.g. [15-20]).

Rather than advocating solely for conceptual or procedural knowledge as the basis for the other, some researchers have recently embraced a less dichotomous view. Rittle-Johnson and Alibali [13] view the two types of knowledge as located on different ends of a continuum and not always separable. In their model, either procedural or conceptual knowledge may be learned first, after which the other type is often learned as well. Thus, they suggest that the two types of knowledge are interlocked and must develop together for effective learning. Yet while the exact interplay between procedural and conceptual knowledge is not yet fully understood, most researchers agree that the two are at least in some sense different, yet both required, for meaningful learning.

Many students who struggle to successfully complete statics tend to focus on procedure and rote learning [7]. If students are not building conceptual knowledge alongside procedural knowledge, the learning process may be frustrating and difficult for students, as many have indicated, simply because their procedural knowledge cannot develop without it. Thus, the lack of conceptual knowledge indicated by others may not only be a problem in itself but also a contributor to the other problems associated with the course. A focus on developing ways of improving conceptual knowledge may be particularly important.

As novices transition from naïve understandings to more robust conceptions, their conceptual knowledge is altered though a process called conceptual change. This change may be in the form of enrichment, in which new conceptual knowledge is added to existing knowledge structures, or it may be in the form of revision, in which the structure of existing conceptual knowledge is altered [21]. What novice to expert transition looks like and how knowledge structures change during transition (conceptual change) have not yet been investigated in engineering subjects like statics [22]. However, writing-to-learn may be a potentially fruitful area to explore.

Writing as a means of learning is not a new idea. Klein [23] mentions two time periods in which the notion of including writing across the school curriculum has been popular, first in the 1930s-50s and more recently beginning in the 1970s. Following Janet Emig's [24] classical argument for the explicit connection between writing and learning, many teachers in the 80s and 90s began incorporating writing into their classrooms. During this time, two major movements emerged, arguably with somewhat different views regarding writing in the classroom: Writing Across the Curriculum (WAC) and Writing in the Disciplines (WID) [25].

Writing Across the Curriculum is the older of the two writing movements; it is also the one traditionally associated with supporters of the writing-to-learn (WTL) approach. WAC proponents argue for the use of writing assignments as a way to improve content learning among students in a wide range of courses including mathematics, history, science, and others. Most of the learning theory supporting their approach comes from cognitive views of psychology, specifically information-processing models of memory, the conceptual structure of long term memory, and metacognition [24, 26]. Writing in the Disciplines, in contrast, advocates for exposing students to the specific ways that writing is used by experienced practitioners in their area of study, thus learning about the discipline itself. Thus, the movement has been nicknamed the learning-to-write movement, in part to highlight the difference in their approach from the WAC group. Theoretical backing for WID usually comes from situated views of learning, specifically the ideas of socially-mediated knowledge, apprenticeship models of learning, and legitimate peripheral participation [27, 28].

Despite the strong theoretical ties made between cognitive learning theory and WTL approaches, there has been little in the way of empirical research evidence to strongly support these claims. Klein [23] notes this in his review, where he describes four cognitive hypotheses common in WTL literature, but concludes that only one had received more than "modest to indirect" empirical evidence specifically linking learning to writing. Bangert-Drowns, et al. later conducted a meta-analysis of writing-to-learn studies to search for common factors that showed evidence of promoting learning through writing assignments. From analyzing the reported results from 48 treatment-control studies representing a wide range of treatment designs, student grade levels, and subject areas among other variables, they concluded that WTL interventions had a generally positive, yet small effect on measures of traditional academic performance. Moreover, they found some evidence that shorter writing assignments and metacognitive prompts each showed a relatively strong positive correlation with effect size [26]. Still, both reviews highlight that WTL research, while promising, can benefit from more experimental evidence that specifically links writing processes to improved learning.

In summary, conceptual knowledge development in novices is an essential component of progress toward expertise. Deficiencies in conceptual knowledge may not only result in poor understanding of course content, but may also inhibit the development of more advanced procedural knowledge that supports successful problem solving. Writing-to-learn methods might provide an effective way of having students build conceptual knowledge through reflection, a key component of metacognition. In particular, the process problems used in this study encourage students to reflect on their existing procedural knowledge as a starting point for the development of related conceptual knowledge.

Methods

Implementation of the Intervention

The qualitative results presented in this paper are derived from data collected in a previous mixed methods study (see [9] for an analysis of the quantitative data). The following quoted text from that study describes the participants, setting, intervention and mode of implementation:

> The pilot study was conducted at a large public technical university in the southeast during Spring 2011 in the form of a pseudo-experimental mixed methods design implemented in a single statics course. The course was offered in three sections, each having a maximum capacity of 155 students, with an initial total enrollment of approximately 400 students. Two of the sections were experimental sections receiving the intervention; the single remaining section was used as a control. One of the experimental sections (EX1) and the control section (C1) were both taught by the same instructor, a professor who had taught the course for many years; the second experimental section (EX2) was taught by a member of the research team.
>
> The statics course at the institution was taught in a traditional lecture style format. Tests were given four times throughout the semester with roughly equal spacing between tests, and a comprehensive final exam was given at the end of the semester. Homework sets consisting of approximately six problems were assigned and collected twice weekly through an online course system that accompanied the course text.
>
> For the pilot study, section C1 was taught as usual under the discretion of the instructor; EX1, taught by the same instructor, was conducted in a similar manner with the exception of homework assignments. In addition to the usual problems assigned to the control group, EX1 was also assigned one homework problem nearly each week (13 total) throughout the semester designed to elicit written explanations of course content; these were referred to as “process problems”. These problems were adaptations of those created by Hanson and Williams (2008) in their study of writing in statics. Students in EX1 were given explicit

instruction on how the written responses should be completed, including an example solution and the grading criteria that was used to evaluate their responses. In an effort to keep time requirements for students in the experimental section roughly comparable to those in the control group, students were asked to complete the process problem only for an existing homework problem that they normally completed anyway. Section EX2, although taught by a different instructor and thus having different lectures, homework problems, and test questions, had the same process problems as EX1 and was given the same instruction on how to complete the writing problems.

The instructions given to the students directed them to explain in words the objective of the problem and the steps that they used to complete the objective. Thus, equations were to be described without using mathematic symbols and students were to focus on what the mathematical elements actually refer to in a physical sense. For example, rather than simply writing $M_A=F*d$, students might have said, "To solve for the magnitude of the moment produced at point A by the force **F**, I multiplied the magnitude of the force, F, by the perpendicular distance measured from point A to the line of action of **F**." Students were told that they would be graded based on the detail and clarity of their responses, which should be written as to be understandable by another beginning statics student. More specifically, students were given the four grading criteria used on the grading rubric but were not given the rubric itself. The individual instructors decided how much to weight the process problem assignments, which made up some fraction of the 15% of the total grade assigned to homework.

The typed process problems were collected via an online course management system and graded using a rubric by a team of two teaching assistants (TAs), each assigned to one of the experimental sections. The instructor of EX2, Venters, led the teaching assistants through a training and norming process to ensure consistency in grading of the assignments. [9]

Qualitative Data Collection

Toward the end of the semester, all students enrolled in both the experimental and control sections were emailed a short, optional survey about their experiences in the course; among the survey questions was an invitation to participate in an interview. Out of the total pool of forty-one students who indicated their willingness to participate, interview participants were purposively selected based on their current course section with the intent of having roughly equal numbers of students from each section. Interviews lasting approximately 30-40 minutes were scheduled and conducted toward the end of the semester with students in sections EX1 and C1 by Venters; another Ph.D. student outside of the research team conducted interviews during the same time with students from section EX2. All interviews took place in a quiet, semi-private space on campus and were audio-recorded with the consent of the participants.

The interview protocol was semi-structured and featured open-ended questions related to areas including:

- experiences and perceptions about the course
- what topic(s) they found most difficult and why
- perceptions of the process problems (students in the control section were told about the process problems if they had not heard of them previously and were asked similar questions).

All interviews also contained a think-aloud portion where students were given the statics problem shown in Figure 1 and asked to share their thoughts as they viewed and attempted to complete the problem; follow-up questions meant to probe explanations of their thought processes were asked after the think-aloud was complete. See Appendix A for the actual interview protocols.

The wing of the jet aircraft is subjected to a thrust of T = 8 kN from its engine and the resultant lift force L = 45 kN. If the mass of the wing is 2100 kg and the mass center is at G, determine the x, y, z components of the reaction where the wing is fixed to the fuselage at A.

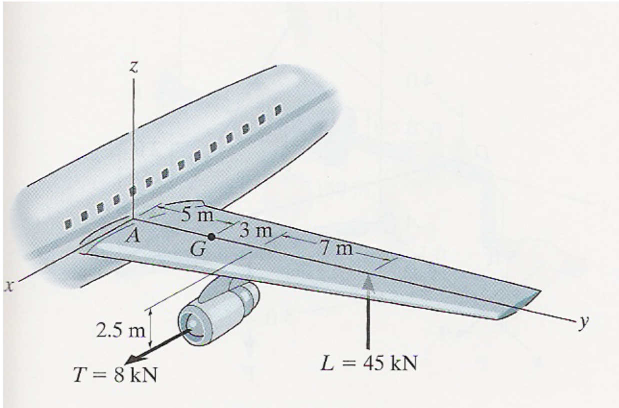

Figure 1. Interview Problem (Taken from Hibbeler [29]).

Qualitative Data Analysis

The audio-recorded interviews were fully transcribed and then analyzed using a three-stage process depicted in Figure 2 below. Each of these stages is described in more detail in the subsequent sections. Though the qualitative data analysis detailed here was performed after the quantitative data analysis reported in prior work, it was treated as an independent data set for which conclusions and answers to the research questions could be made without any knowledge of the previous quantitative results. However, the potential for bias from having previously conducted the quantitative analysis is acknowledged; data analysis from the next iteration of this study will be conducted in the opposite fashion to help control for bias in the overall study.

Figure 2. Interview Data Analysis Process.

Initial Coding Pass

The initial coding pass attempted to identify areas in the transcripts where students demonstrated conceptual and/or procedural knowledge, as these were hypothesized to be potential products of the process problem intervention as stated in the research questions. As coding began, however, the frequency of these two codes was low, likely because of the types of questions that were asked in the interview. However, there did appear to be clear differences in the ways that students discussed learning in the course. Thus, the two codes were expanded to include not only instances in which students demonstrated each knowledge type, but also statements in which they discussed a desire and/or preference for learning that type of knowledge. The two codes, described in detail in Table 1 below, were then used to code all of the interviews. To help establish credibility and minimize bias, an additional coder outside of the research team used the same code descriptions to code a subset of the interviews with high agreeability.

Table 1. Code Descriptions for Initial Coding Pass.

Code	**Description of Code**	**Possible Evidence of Code**
Conceptual Knowledge (CK)	Statement provides evidence of possessing conceptual knowledge and/or a conceptual approach to learning content (do not tag solely based on the usage of the word "concept" or similar). May also be used to tag incomplete or incorrect conceptual knowledge.	Making connections among different ideas, facts, problems, etc. Emphasis on meaningful understanding of course content; possibly links procedure to theory (understands why a particular solution works). Approaches problem solving using fundamental scientific truths, laws, theories, etc.
Procedural Knowledge (PK)	Statement provides evidence of possessing procedural knowledge and/or a procedural approach to learning content. May also be used to tag incorrect or incomplete procedural knowledge.	How to perform a problem solution and/or the "steps" needed. Emphasis on process and how a problem is done. Approaches problem solving algorithmically (uses series of steps that guarantees a correct solution) and/or heuristically (a structured, yet not predetermined approach that may provide a correct or near-correct solution, e.g. trial and error, rule of thumb, working backward, looking at examples, solving a more general problem first, etc.)

In addition to the codes described in Table 1, the researchers also highlighted interview passages that seemed particularly important or significant with respect to the study goals as consistent with an open-coding process [30]. This was aimed at helping prevent potential bias arising from conducting the literature review and/or previous quantitative analyses.

Participant Profiles / Vignettes

After the initial coding pass was completed, each interview transcript was condensed into passages summarizing each participant's responses to the four major parts of the interview:

- learning approach/beliefs about the course, especially they way they tended to approach learning (conceptually/procedurally)
- what topic(s) they found most difficult and why

- perceptions of the process problems, especially how they felt they used them, did or did not benefit from them, and how they think other students would or would not benefit from them
- how they completed the think-aloud problem, especially if they were successful with the problem, the way they talked about starting and working through the problem (evidence of conceptual backing or just rote procedural steps), and how they responded to probing questions regarding free-body diagrams, reactions, etc.

When crafting these participant profiles, full interview transcripts were reread, paying particular attention to lines that were coded and highlighted during the initial coding pass. Participant quotes were used throughout the profiles to illustrate appropriate context and to provide supporting evidence for the summary.

As mentioned previously, a Ph.D. student outside of the research team conducted interviews for the students enrolled in Venters' statics course in accordance with IRB guidelines. It should be noted that this interviewer tended to follow a narrower interpretation of the semi-structured protocol, asking fewer follow-up questions of participants. Thus, the interviews tended to be shorter, and in some cases the participant profiles were not as rich as for the rest of the participant pool.

Theme Development

Once the participant profiles were created, they were reviewed and analyzed for themes common across participants for each part of the interview. For example, the summaries of how each student perceived the process problems were read and investigated for patterns. Additionally, themes were also searched for across two or more interview sections, looking for potential interactions between them.

Results

In total, thirteen participants ultimately completed an interview. Ten were from the experimental sections receiving the process problem intervention (five each from EX1 and EX2); the remaining three were from section C1. The table below summarizes the sample using the pseudonym of each participant. Asterisks indicate the seven students who had been enrolled in the class during a previous semester and had either dropped, withdrawn, or completed the course but did not meet the minimum grade requirements set by their major.

Table 2. Interview Participant List.

Section	Interview Participants
EX1	Alex, Amy*, Charles, Matt*, Steve
C1	Beth*, Melissa*, Scott*
EX2	Alan, Andrew, Kelly*, Ralph, Randall*

Part 1: Learning Approach

Nearly all students felt that working through problems was instrumental in learning the course content; however, students differed in the extent to which they sought out and developed conceptual knowledge, which was highlighted in the way that they went about solving problems.

Throughout all of the interviews, students commented on the importance of working problems as a way of learning statics. "It's really just when you do it yourself; that's when you know it," explains Alex. Scott concurs, "In order to know the material, just actually doing it is very helpful." All students seemed to place value both in developing procedural knowledge as a means of learning and correctly using procedural knowledge as an indicator of successful learning. However, the degree to which students additionally sought out and developed conceptual knowledge varied considerably. The range of student learning approaches might be visualized along a continuum as shown below, with those exhibiting a preference toward developing mostly procedural knowledge on the left and mostly conceptual knowledge on the right. It was difficult to summarize the learning approaches for two students, Ralph and Randall, based on their limited responses to the interview questions, so they are not included.

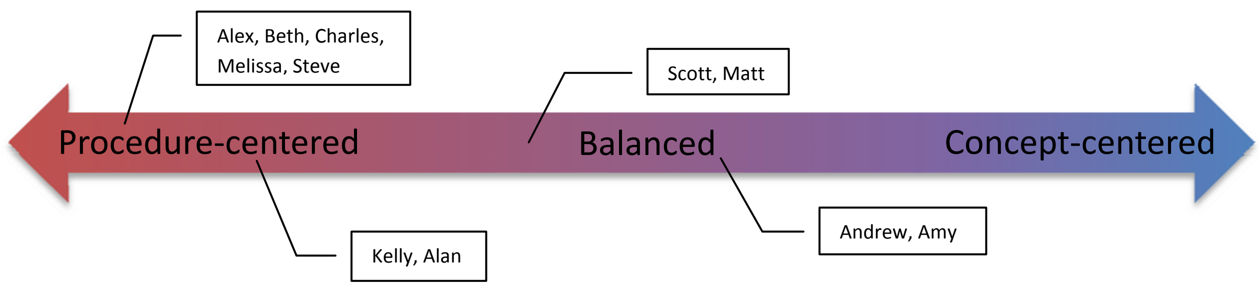

Figure 3. Learning Approaches of Interviewed Students.

Alex, Beth, Charles, Melissa, and Steve all discussed what might be described as a procedure-centered view of learning statics. To procedure-centered students, procedural knowledge is paramount, and whether aware of it or not, these students act in ways that seek to develop that type of knowledge almost exclusively. In general, they use their course resources only as a means of solving problems. Alex talks about how he uses his class notes to "see how the problem is done" rather than focusing on the concepts. Beth similarly uses her book to find formulas and example problems "rather than read[ing] about [the content]". The result of focusing on worked-out examples is often a guess-and-check approach to solving new problems by trying to mimic procedures used in the examples, possibly without giving much thought as to the reasonableness of the approach. Kelly, who showed many of the same characteristics of the procedure-centered students, exemplified this when she said, "I usually go through a process even if I don't know if it's right or not, and I'll just go through the whole entire thing." Melissa also admits, "It takes me a couple of times to mess up and realize [what I need to do]". As a result, procedure-centered students tend to study for tests by spending considerable amounts of time working problems beyond those assigned for homework. However, they are often focused on simply getting to a correct final answer and may spend little to no time trying to understand why a particular solution process worked.

Students in the procedure-centered group generally fail to make conceptual connections among similar problems. Kelly seems to at least recognize this of herself when she mentions that students like her "can't just understand the broad aspect of why [a particular solution process is used]". Some procedure-centered students, though, may not even be aware of the need to think about the big ideas covered in the course, something to which Alex admits, "It's something that I haven't really thought about too much." This lack of conceptual knowledge can be frustrating for students, causing them to struggle knowing when or how to use their procedural knowledge. Beth, taking the course for the second time, reflects, "This time I know how to break down the problem; I know what formulas to use. I just – I don't know; there's some breakdown…" Charles also seems to share this frustration when he describes test problems as "entirely new" compared to those he has worked previously for homework. This problem, if not addressed, is likely to resurface in subsequent courses that build upon the statics foundation.

In contrast to the procedure-centered students, other students discussed a view of learning statics that emphasizes both conceptual and procedural knowledge. While Amy and Andrew both still work problems as a way of learning, they also seem to be actively searching for and creating connections among related problems and course content. For example, when discussing his strategy for studying, Andrew talks about choosing more difficult problems that contain "tricky part[s]" and thus require a deeper understanding of statics concepts to solve: "If I can do the hard problems then I would be able to do the easier one[s]." Amy echoes this when asked what is most helpful for her with regard to studying for the course, to which she responds, "I think just grasping the concepts and not just how to do one problem, but how to do them all." This seems to be an important difference between students who focus mostly on procedure and students with a more balanced approach to learning. Matt also seems to be making conceptual connections, although it is difficult to tell from his interview if he is as deliberate about it as Amy and Andrew. He puts it like this: "I feel like a lot of people…look at it as a bunch of different math word problems that they've never seen before when in fact, everything that we do in [statics] is completely related."

For students focusing on conceptual and procedural knowledge, working through a problem involves more than just getting the correct answer; they also use the problems as a way to seek deeper understanding of the course content. In the case of Andrew, he looks to understand the underlying assumptions made in setting up a problem. According to him, "You have to know your assumption, and it's based on [a] scientific approach. Usually when I [make] bad assumptions I don't get the right answer, but when I try to understand the problem… [it] helps in solving the problem." Many of the students in this group look to the content areas of the textbook for help when stuck on problems in addition to worked out examples. Amy in particular also works with a tutor to discuss course content, often reviewing notes and worked out problems to make sure that she understands why certain procedures are used.

Interestingly, three of the four students identified as taking a more balanced approach to learning, i.e., developing conceptual knowledge in addition to procedural knowledge, were students who had been enrolled in the course previously. When asked what changed from their first attempt to their current one, all of them at least partially credit their conceptual knowledge. Amy mentions that during her first time in the course she would "just try and learn the homework" and "figure out the math part of it" rather than trying to understand the concepts, a practice that she feels most students do. Scott explicitly recalls the feelings of frustration similar to those reported by students in the procedure-centered group during his previous attempt when he says:

> "I mean, each problem was kind of different, and I didn't seem to make as many connections as I think I've been able to make since retaking the course. And with each problem seeming unique, you get to the test and you're just confused

> because all of a sudden that thing is round and you have no idea what to do when it's round."

Part 2: Most Difficult Topic

Students clustered around 3-D equilibrium and trusses as their most-difficult topics, and these choices may connect with their learning approach.

Five students list 3-D equilibrium as their most difficult topic; three of them are students who approached learning both conceptually and procedurally, and the remaining two are the students whose learning approach could not be determined. The four students who identified trusses as their most difficult topic all approached learning procedurally. At this time, we cannot make a definite link between troublesome topics and learning approach although the pattern observed here may be plausible given the problem-solving tendencies that characterize each group, particularly in the case of the procedure-centered students. For these students, who tend to use more guess-and-check approaches, truss problems might be especially difficult because they typically involve consideration of many possible solution paths. In fact, many of these students discussed having problems knowing where to start, choosing appropriate sections to isolate, and selecting advantageous points to sum moments about. Making such decisions without first evaluating their effects may lead to more complicated and less time-efficient solution paths. The reasons why students with a balanced approach found more difficulty in 3-D equilibrium problems is perhaps less easily explained, but most of them cited issues with visualization of the figures. With analysis of data collected in subsequent semesters, we hope to explore this topic area more thoroughly.

Part 3: Perceptions of the Process Problems

Despite dissatisfaction with the process problems, many students reported that the problems prompted them to reflect about their solution procedures in ways that they normally would not.

Many students expressed some level of dissatisfaction with the process problems. Particularly in the beginning of the semester, some students reported difficulty understanding the requirements of the problems and were not sure why they were losing points on graded assignments. Though these issues were generally resolved as the semester progressed, many of the students were frustrated and felt that the problems simply hurt their grade. In addition, some students felt that the problems were not useful and/or were redundant given the requirement to complete the mathematical solution first.

Regardless of their perception of the problems, many students discussed reflecting on their solution process as a result of completing them. For procedure-centered students in particular, self-explanation seemed to be an important outcome of working on the process problems. Kelly talked about how she would try to explain why she was performing certain procedures when writing. Alex said that the problems would sometimes make him "slow down and think, …I've got to explain this to someone else; how else can I explain it?". Randall elaborated on these thoughts even further; according to him, the process problems:

> "kind of force you to really think through what you were doing, because on the homeworks I'd be kind of guilty of just looking at an example and just swapping out numbers or just punching it into my calculator until I got the right answer whereas when you're writing, you can't really do that. It kind of made me focus more."

This self-explaining may be particularly helpful for procedure-centered students since it may provide them with a way to revisit their problem-solving procedures and understand more fully why those particular procedures work, thus building conceptual knowledge.

For students who are already more knowledge-balanced, the process problems may additionally provide a way to utilize conceptual links to further build procedural knowledge. Both Amy and Matt seem to use the problems as a way to generalize their solution process for specific problem types. According to Matt, "I feel like the point was you can take the [process problem] and just look at it and be able to apply it to every kind of problem that it covers for the chapter to a certain extent." Amy similarly comments, "Usually, like, the steps, you could just manipulate them for all other problems for that type, so I like to put it into words." In both of these instances, Matt and Amy seem to conceptually link similar problems together and use the process problems as a way to generate higher level procedural knowledge that would likely facilitate future problem solving.

Interestingly, the students in the control group, when told about the process problem assignment, seemed to follow similar patterns in thinking about the potential benefit of doing the process problems. Beth, a procedure-centered student, said, "It would just make me think about, you know, why am I doing this, why I need this number, how do I get it?" Scott, a student with a more balanced approach in the control group, said that he thought writing out the process problems would "help you to understand the concept that links different problems together of a similar nature, or even problems that build off of the kind of problem you're explaining".

Part 4: Think-aloud Problem

The think-aloud problems were difficult to analyze, primarily since they inherently focused so much on procedure; consequently, it was difficult to determine whether students who were not directly asked to talk about conceptual topics did not possess that knowledge or merely did not communicate it spontaneously. To complicate matters, the two interviewers took different approaches in conducting the think-aloud, causing difficulty in making comparisons across cases. The interview protocol for this section has since been modified to include more direct questions that should elicit further explanation from students.

Conclusions

The results from this qualitative analysis indicate that many students in statics tend to act in ways that develop procedural knowledge often without accompanying conceptual knowledge. This finding is potentially not surprising, given the focus by most statics curricula on demonstrating and assessing the ability to carry out appropriate procedures. Unfortunately, this focus on procedural knowledge leads to difficulties for students both while they are enrolled in the course as well as in subsequent courses that require statics knowledge. Certainly procedural knowledge is important and should be taught, developed through practice, and assessed. However, if we are to believe that procedural knowledge must be supported by conceptual knowledge and vice-versa [13], then statics instructors must be more deliberate in the development of instructional tools that also promote the development of relevant conceptual knowledge.

The findings presented indicate that the process problems used this study are a potentially effective way of promoting the development of conceptual knowledge in students, particularly for those who might not seek it out on their own. By eliciting reflection and self-explanation, the problems provide a way for students to connect their problem solving procedure to relevant content knowledge, allowing for a deeper understanding of why particular procedures work. As students build more conceptual knowledge, the problems may also serve as a way of further developing procedural knowledge as students make connections among similar problems and generalize their solution process. Thus, the process problems appear to benefit a wide range of students in ways that are not necessarily provided by traditional statics problems alone.

Acknowledgements

The authors would like to thank Jim Hanson and Julia Williams for their assistance and advice throughout the duration of this ongoing study. The authors would also like to thank the course instructors, TAs, and students for their participation.

This material is based upon work supported by the National Science Foundation under Grant No. NSF EEC-1129338. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Appendix A1. Interview Protocol for Students in Experimental Sections (EX1 and EX2)

1. Tell me about your experience in Statics this semester.
   - Anything else?
   - Tell me more about…
   - Elaborate on that some…
2. What do you do to try to learn statics beyond going to class?
   - Thinking about the things you mentioned, along with the actual lecture, which do you feel is most helpful in learning the material?
   - Why?
3. Next I'd like you to think about the way that you usually go about doing your homework. If you have a normal routine, describe what it is like. If you don't have a normal routine, what varies from assignment to assignment?
4. What do you feel is the most difficult concept that is covered in statics? Why?
5. Some people describe statics as being a "critical concept" course, or a "lightbulb" course. Why might you think people refer to it as such?
   - What do most students say about the course?

Next, I would like to talk to you some about the process problems that you had as part of your homework this semester.

6. Tell me about your experience with the process problems this semester.
7. Describe how you usually go about completing a process problem.
8. If I were to tell you that the process problems actually improved the amount that you and your classmates learned during the semester, what would you say?
   - Are there any reasons that you can think of why that might be true?
9. What if I were to tell you that the process problems had no effect on your learning this semester?
   - Are there any reasons that you can think of why that might be true?
10. If the statics instructors decided to use the process problem assignments again, what if anything do you think should be changed?
    - Can you go into any more detail about that?
    - What are some of the features if any that you liked?

Next, I want you to take a look at this problem. Read over the problem statement and the given figure, and give me your initial thoughts about them.

Next, go through and begin to solve the problem. You do not need to actually solve it, but at least set it up. As you work through it, say out loud any thoughts that pass through your mind, no matter how trivial. In essence, I want you to continuously let me know what is going on in your mind as you work through the problem.

(be sure to remind them to say what they are thinking if they are not doing so)

11. Follow-up questions:
    - Why did you…? (probe them about the decisions they made, especially if they were incorrect or seemed like guesses)
    - Is there a method or process that you are using to solve this problem?
    - To you, what is a free-body diagram?
    - What are reactions?
    - If moments calculated by inspection:
      - Why could you simply look at the figure and calculate the resulting moment at point A for each force?
      - How would this problem be different if the forces were not directed along the coordinate directions?
    - If moments calculated by cross product:
      - Why did you choose to use the cross product to find the moments at A?
      - Was it completely necessary in this case? In what case would it be?
    - Would you call this a difficult statics problem? Why or why not? How could it have been made easier? Harder?

Appendix A2. Interview Protocol for Students in the Control Section (C1)

1. Tell me about your experience in Statics this semester.
    - Anything else?
    - Tell me more about…
    - Elaborate on that some…
2. What do you do to try to learn statics beyond going to class?
    - Thinking about the things you mentioned, along with the actual lecture, which do you feel is most helpful in learning the material?
    - Why?
3. Next I'd like you to think about the way that you usually go about doing your homework. If you have a normal routine, describe what it is like. If you don't have a normal routine, what varies from assignment to assignment?
4. What do you feel is the most difficult concept that is covered in statics? Why?
5. Some people describe statics as being a "critical concept" course, or a "lightbulb" course. Why might you think people refer to it as such?
    - What do most students say about the course?

This semester, some sections of statics participated in an experimental study that involved completing "process problems" for homework. Have you heard about these problems?

6. If yes, tell me what you have heard about them. If no, the problems were typed, essay-style problems in which students explained their process for solving a particular homework problem. The description was required to be words only, no equations or numbers.
7. What are your thoughts about these types of problems if they had been assigned to you?
    - Do you think you would have had trouble completing this type of problem? Why or why not?
    - Why do you think they might be helpful for students in statics?
    - Why might they not be helpful?

Next, I want you to take a look at this problem. Read over the problem statement and the given figure, and give me your initial thoughts about them.

Next, go through and begin to solve the problem. You do not need to actually solve it, but at least set it up. As you work through it, say out loud any thoughts that pass through your mind, no matter how trivial. In essence, I want you to continuously let me know what is going on in your mind as you work through the problem.

(be sure to remind them to say what they are thinking if they are not doing so)

8. Follow-up questions:
    - Why did you…? (probe them about the decisions they made, especially if they were incorrect or seemed like guesses)
    - Is there a method or process that you are using to solve this problem?
    - To you, what is a free-body diagram?
    - What are reactions?
    - If moments calculated by inspection:
        - Why could you simply look at the figure and calculate the resulting moment at point A for each force?
        - How would this problem be different if the forces were not directed along the coordinate directions?
    - If moments calculated by cross product:
        - Why did you choose to use the cross product to find the moments at A?
        - Was it completely necessary in this case? In what case would it be?
    - Would you call this a difficult statics problem? Why or why not? How could it have been made easier? Harder?