Indispensable Resource? A Phenomenological Study of Textbook Use in Engineering Problem Solving

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Abstract

Background Textbooks play an important role in engineering education, influencing instructors' pedagogical approaches and providing much of the information students learn. Research has explored students' recollections of the roles that textbooks played in their educational experiences, but how students actually use textbooks remains largely unexplored.

Purpose This phenomenological study describes engineering students' textbook use during problem-solving activities. This study directly examined how students employed a textbook in order to generate detailed descriptions of students' behaviors, approaches, and reflections regarding their actual problem-solving experiences.

Method Ten senior materials engineering students (8 males and 2 females) were asked to think aloud while solving engineering problems. Follow-up retrospective interviews regarding the think aloud session were conducted to gain in-depth information on students' textbook use during the problem-solving activities.

Results Students used the textbook primarily to find information related to problem constraints that were explicitly stated in the problem. Furthermore, textbook example problems exerted a strong influence on students' problem-solving processes. Students also reported limitations of the textbook, contrasting it to the diversity of resources available via the Internet.

Conclusions This study provides insight into students' textbook use during engineering problem-solving activities. Students' limited application of the textbook during problem solving suggests that textbooks may not be serving their intended purposes.

Keywords textbook; problem solving; phenomenology

Introduction

Textbooks are ubiquitous in higher education. Instructors use them as off-the-shelf compilations of material to structure their courses, and textbooks are students' primary learning resource outside of the classroom (Besser, Nan, & Stone, 1999; Connors, 1986; Issitt, 2004). Students frequently use textbooks during a wide range of learning activities, such as supplementing lecture notes, practicing problems, and locating specific

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information (Smith & Jacobs, 2003; Taraban, Hayes, Anderson, & Sharma, 2004). In these ways, textbooks play a significant role in determining what students learn about specific content and how instructors structure and implement their pedagogical practices. Although student recollections of textbook use in higher education have been investigated (e.g., Lynch & Bogen, 1997; Stambaugh & Trank, 2010; Taraban, 2011), little is known about how students actively engage with the information presented in their textbooks, especially in engineering courses.

In engineering, students often use textbooks to model their approaches to problem solving. Learning to solve problems is a fundamental objective of engineering education (Dym, Agogino, Eris, Frey, & Leifer, 2005; Sheppard, Macatangay, Colby, & Sullivan, 2008; Widmann & Shollenberger, 2006), and as result, it is expected that students will graduate with strong problem-solving skills (ABET, 2011; Woods et al., 1997). Most problems engineering students encounter are derived from the textbooks required in their courses (Widmann & Shollenberger, 2006). Textbooks also provide many of the homework problems assigned to students and contain practice problems to be solved in preparation for exams (Smith & Jacobs, 2003; Taraban et al., 2004).

Although textbooks are widely employed in engineering courses, few studies have analyzed the effects of textbooks on student learning and development of problem-solving skills in engineering. Research pursuing these lines of inquiry is needed to better understand student learning and problem-solving experiences outside the classroom, which commonly involve the use of the course textbook. This phenomenological study addresses this gap in the literature by gathering information from engineering students' reported experiences of using a textbook while solving engineering problems.

Phenomenology is used to describe the essence of how a particular phenomenon is experienced (Creswell, 2003). In this study, phenomenological analysis was used to develop comprehensive descriptions of the shared structures underlying a set of student experiences during problem-solving activities (Moustakas, 1994; Starks & Trinidad, 2007; Worthen & McNeill, 1996). We studied engineering students' textbook use during problem solving in order to answer the following research question: How do students describe the phenomenon of textbook use while solving engineering problems?

Definition and Contents of Engineering Textbooks

Textbooks have been in use for so long that a common definition is often taken for granted. However, defining a textbook can be problematic (Issitt, 2004), as not every book used in an educational setting is a textbook (Connors, 1986). For example, many books used in literature or history courses are novels, biographies, or historical accounts – books that were not written specifically for use in a formal educational setting. Further complicating the definition of a textbook are advances in technology. The print textbook is no longer the norm. Many textbooks are now available in electronic form, and some teachers substitute multimedia modules and wiki resources for traditional textbooks (Hohne, Fu, Barkel, & Woolf, 2007; Lindsley & Burrows, 2007; Reid & Cooney, 2001). Most studies of textbooks lack a clear definition and instead loosely define textbooks as the required texts in the courses the researchers are studying.

Textbooks designed for courses in the sciences are typically densely filled with content and are often distinguished by the large number of problems they contain, both example problems that illustrate the steps and solution of a problem, and practice problems that students are required to solve on their own (Smith & Jacobs, 2003). Since problem solving is an integral part of the engineering profession (Dym et al., 2005; Sheppard et al., 2008; Widmann & Shollenberger, 2006), the large number of problems in engineering textbooks seems logical.

Student-Reported Uses of Textbooks

Studies show that students generally do not read their textbooks for a better understanding of content related to their field. Podolefsky and Finkelstein (2006) found that less than half the students in a physics course read their textbooks regularly. They also found that college students primarily used their textbooks to look up properties and formulae or to solve practice problems. For example, Smith and Jacobs (2003) surveyed 3,200 first-year general chemistry and second-year organic chemistry students regarding the amount of time they spent using textbooks as well as the quality and degree of helpfulness of specific textbook features. Both groups rated in-chapter example problems and end-of-chapter practice problems as the most important features of their textbooks and those to which they devoted the most time. Similarly, students in an introductory mathematics course used their textbooks primarily for example and practice problems (Weinberg, Wiesner, Benesh, & Boester, 2012). Taraban et al. (2004) examined 211 student uses of learning resources in an introductory thermodynamics course. Using self-reported weekly activity logs, students reported spending an average of 1.94 hours attending class each week, 2.17 hours working on problems from the textbook, and 0.61 hours reading the textbook. This breakdown suggests that students used the textbook not to read new content, but mainly to complete textbook practice problems either to fulfill homework assignments or to prepare for exams. Besser et al. (1999) surveyed student perceptions of the writing style and features of textbooks and found that students believed that the relevant problems in their textbooks are the most helpful features, followed by clear writing that contains cues (e.g., boldfaced or italicized key words) that highlight expected goals and help to interpret the content.

Overall, research shows that students generally use only a small portion of the information and features available in textbooks; they focus primarily on reference information (e.g., tables, charts, material properties) or textbook problems. Most of students' time spent with textbooks involves solving problems and much less time is spent reading for content. These findings contrast with many instructors' expectations and beliefs, for they often instruct their students to read the textbook, advising that reading it will lead to better course performance (Podolefsky & Finkelstein, 2006). Although this conventional wisdom is widely accepted, studies show that students engage in superficial reading for understanding and instead take a more utilitarian approach; students generally use the textbook as a place to the find the problem assigned by the teacher or to look up specific reference information.

The Role of Textbooks in Engineering Problem Solving

Engineering education programs strive to teach students the knowledge and problem-solving skills they will need in professional practice. In the workplace, engineers must keep up-to-date on engineering principles and practices that are changing rapidly due to advances in technology and growing global marketplace (National Academy of Engineering, 2004; Wise, Kosky, Balmer, & Keat, 2006).

Relatively few studies have investigated textbook use in science, technology, engineering, and mathematics (STEM) fields. Chi et al. (1981, 1989) used think-aloud protocols to analyze the approaches that 10 students took to solving mechanics problems. Participants were of various majors, and none had previously taken a college-level physics course. They found that "poor" students relied heavily on textbook example problems during the think-aloud sessions. In contrast, "good" students exhibited greater self-awareness and transferred their knowledge to new contexts. Another think-aloud study that investigated problem-solving among engineering students showed that throughout a materials engineering problem-solving task, students spent a significantly greater portion of their time on textbook use than on other activities such as writing, reflecting on their work, and conducting calculations to solve the problems (Douglas et al., 2011).

Although research indicates that students are not spending much time reading their textbooks, the literature shows that reading pertinent textbook passages has positive benefits for student problem-solving abilities. In a study with 10 first- and second-year engineering students, Atman and Bursic (1996) found that students who had read a related passage of text from an engineering design textbook prior to solving three design problems used more sophisticated strategies to solve the problems. In a study examining text-processing skills and beliefs among undergraduate engineer majors, Taraban (2011) concludes that "by far, the predominant source of written information for engineering students is a textbook, and the primary functions of text are to answer homework questions, prepare for quizzes and exams, and to fill in information that was not covered fully in lecture" (p. 409). It appears that, as with students in other science disciplines, engineering students spend very little time critically reading their textbooks but, rather, use them as a source of information to memorize and solve problems in preparation for examinations.

Previous studies have mainly used self-report measures to gather information on student perceptions and uses of textbooks, and little is known regarding the specific ways students approach information in textbooks during engineering problem solving. Addressing this gap in the literature is needed because of the important role that textbooks have for instructors' pedagogical approaches and on student learning. Specifically in the context of engineering education, assigned textbooks often serve as a resource for learning and practicing problem-solving skills that are critical for future professional engineers.

Method

We adopted a think-aloud method to explore how engineering students used a textbook during problem solving. We videotaped students thinking aloud as they used a textbook to solve engineering problems then conducted follow-up interviews for more detailed data regarding the problem-solving activity on the basis of the students' think-aloud data. By gathering detailed information of student beliefs, reflections, and evaluations of the problem-solving experience when assisted by a textbook, we aim to shed light on how students interact with a traditional textbook during complex problem-solving activities outside the classroom.

Participants and Data Collection

Ten senior materials engineering students (eight male, two female; nine Caucasian and one African American) from a large southeastern university participated in this study during the fall semester of 2010. The participants ranged from 18 to 28 years of age ($M = 22.5$ years, $SD = 1.86$). The study reported in this article is part of a larger mixed methods study examining problem solving among materials engineering students (Douglas et al., 2011). The broad aim of the larger study was to explore how advanced engineering students, who were entering the workforce in the near future, approached real-world, open-ended problems. In the larger study, 30 senior materials engineering students completed two working memory tasks (symmetry span and reading span task), a thirty-question multiple-choice materials concept inventory, and a measure of epistemic beliefs (reasoning about current issues test; RCI). These four measures assessed the students' cognitive abilities in spatial and verbal domains, domain knowledge in materials engineering, and beliefs regarding the nature of knowledge, respectively. On the basis of the results from these quantitative measures, 10 students were selected to participate in the present study to represent the greatest range of ability with respect to working memory and epistemic belief scores. These quantitative measures were only used for selecting participants. The students participated in an individual think-aloud problem-solving session, followed by semi-structured interviews. Approval from the university's Institutional Review Board was received prior to recruiting students and collecting data. Pseudonyms are used for participants.

During the think-aloud sessions, students were instructed to verbalize any thoughts that came to mind (Ericsson & Simon, 1993) as they solved four materials engineering problems. The problems related to the mechanical behavior of materials and included tasks such as calculating stresses and strains and selecting materials on the basis of given constraints. The goal of the think-aloud method is to gain insight into participants' thought processes in real time (Ericsson & Simon, 1993). Therefore, participants were asked to talk aloud throughout the entire problem-solving process, regardless of how task-relevant (or irrelevant) their thoughts were. At the beginning of the think-aloud session, a researcher first modeled the think-aloud procedures and the participants also practiced thinking aloud for two minutes. If the participants fell silent during the problem-solving process, the researchers prompted the participant to continue talking by asking statements such as "What are you thinking now?" A calculator and the textbook *Materials Science and Engineering* by William Callister and David Rethwisch (2009), commonly used in introductory materials engineering courses, were provided. All students reported having used an edition of this textbook in their previous course. The think-aloud sessions were video recorded and transcribed verbatim. Members from the research team collectively viewed the think-aloud videos to develop an individualized retrospective interview protocol for each student, which aimed to probe deeper into the student's problem-solving processes. Each interview was scheduled about two days after the student's think-aloud session, so that the student could recall the think-aloud experience accurately during the interview. The follow-up interviews were also audio recorded and transcribed verbatim. Students were each compensated with a \$30 and two \$60 gift cards to a retail store after each of the three parts of the study (i.e., 30-minute session to complete the quantitative measures, one to two hours for the think-aloud session, and approximately one hour for the interview session), receiving a total of \$150 for their participation.

The development and application of the follow-up interviews were guided by a constructivist perspective, focused on enabling the construction of situated, participant-generated knowledge (Koro-Ljungberg, Douglas, McNeill, Therriault, & Malcolm, 2011). The interviews served to gain insight into students' "inner voices," including their beliefs, reflections, and evaluations of the problem-solving experience. In the interviews, students were asked to reflect on and explain their problem-solving steps, use of strategies, difficulties encountered, and prior knowledge used for the problem-solving activities. The interviews also served to clarify gaps and inconsistencies in student-produced knowledge from the think-aloud portion of the study. For example, general comments such as "Oh! I see . . ." and "Hm . . . I'm not sure." as well as periods of silence or incoherent speech that occurred during the think aloud were explored further in the interview by having participants review their think-aloud recordings and provide additional insight. At the beginning of the interviews, students were asked to use as little technical language (e.g., step-by-step math process descriptions, terms specific to materials engineering) as possible. This request was made in order to encourage students to engage in psychological and conceptual reflections about their problem-solving experience. Two researchers were present for each interview. During the interview, students were provided with their written solutions as well as the video clips from the think-aloud session, if needed. Examples of interview questions regarding textbook use included "How would you have done without the Callister [textbook]?" and "You started off early on looking through the appendices in the book . . . I'm wondering if you remember what you were looking for." The follow-up interviews typically lasted one hour; however, up to two hours were allocated for the interviews in order to avoid constraining interviewees with an imposed time limit.

Analysis

A phenomenological analysis was conducted to describe the essence of textbook use among senior materials engineering students during a problem-solving activity. The goal of the analysis was to develop comprehensive descriptions (rather than explanations or interpretations) of the shared structures underlying a set of individuals' experiences within the context of a particular situation (Moustakas, 1994; Starks & Trinidad, 2007; Worthen & McNeill, 1996). Only the participants' accounts of their experiences with the phenomenon were considered; any historical, political, or other influences that may account for the meanings of the experiences were left out of the analysis (Moustakas, 1994). A phenomenological analysis of each student's interview protocol was first conducted to explore the depth and intricacies of the phenomenon of using a textbook while solving materials engineering problems. Individual descriptions of the phenomenon were then combined to develop a description of the essence and structures of the common experience of using a textbook for engineering problem solving under the conditions imposed during this study.

Prior to analyzing the data, the first author gained awareness of preconceptions associated with the particular phenomenon under study (Logue, Hutchens, & Hector, 2005; Patton, 1990). By "bracketing" the textbook as the object of the experience, the researcher makes a conscientious attempt to systematically separate and suspend any past knowledge or experiences associated with textbooks, a process consistent with the philosophy of phenomenological study (Moustakas, 1994). The outcome of bracketing was a full description of the structures associated with the researcher's experiences using the textbook. A list of the researcher's personal knowledge, experiences, and values associated with the textbook was created and returned to during the analysis process in order to maintain a distinction between the researcher's preconceptions of textbooks and the data generated by the participants. The researcher also maintained an ongoing record of ideas and impressions related to the textbook that emerged throughout the data analysis process.

Following bracketing, the semi-structured interview transcripts from the 10 students were analyzed using Moustakas' (1994) modification of the Van Kaam and Stevick-Colaizzi-Keen method of analysis. The first author served as the primary analyst. Following the preliminary analysis, the analysis processes and preliminary findings, including the textural and structural descriptions, were shared with the rest of the research team to solicit feedback and additional perspectives. Our phenomenological analysis process involved the following phases (examples of each phase of analysis are presented in the Results section).

Horizontalization All expressions (or "horizons") considered relevant to the experience of textbook use were marked on each transcript. In this phase, each horizon is considered to have equal value and is separated by a slash on the interview transcript.

Delimiting invariant constituents Each nonrepetitive, nonoverlapping horizon from the first step was documented. To determine invariant constituents, the researcher assessed whether the horizon contained a moment of experience necessary and sufficient to the experience, and if it was possible to abstract and label the horizon. All other irrelevant horizons were eliminated from further analysis.

Clustering and thematicizing The invariant constituents were clustered and thematicized. For each participant, the nonoverlapping constituents that made up the core experience of textbook use were grouped together, and themes were developed for each group.

Imaginative variation The researcher engaged in imaginative variation, developing various possible meanings and perspectives from the themes of each participant.

Textural descriptions Textural descriptions were developed for each participant. Textural descriptions consisted of integrated descriptions of the invariant constituents and themes from the previous two stages, and included verbatim examples from participants' interview transcripts. The textural descriptions were constructed in a first-person narrative retelling of the experience of textbook use.

Structural descriptions Individual structural descriptions, abstracted from the individual experiences, were constructed. The textural descriptions were examined to understand the expressed and implied meanings, and described in more direct psychological language from a third-person perspective (Worthen & McNeill, 1996). This phase involved alternating between the concrete data (i.e., interview transcripts) and the abstracted meanings.

Textural–structural synthesis Finally, the textural and structural descriptions were integrated into a unified statement of the essences that capture the experience of the phenomenon as a whole. From the textural–structural descriptions, a composite description is developed, which represents the essence of the experience of the group as a whole.

Results

In the following section, two individual examples of engineering student textural and structural descriptions are presented (horizons are indicated by italics). Examples from these two individuals were selected to illustrate common horizons that emerged among the participants' interviews regarding their experience using a textbook during the problem-solving activity. The results from the analysis of individual textural and structural descriptions precede the final step of the phenomenological analysis, textural–structural synthesis. The experiences of Daniel and Robert below reveal both similarities and differences in using the textbook during a problem-solving activity. The analyses from these two individuals were intentionally selected to highlight the structures that were part of the final essence of the phenomenon of textbook use: the search for equations and dependence on example problems in Daniel's description, and the listing of constraints in Robert's description. In line with the goal of the phenomenological approach, the final results that follow the textural and structural descriptions refer to the essence of the shared experience of using the textbook for problem solving. The similarities in their experiences are elaborated upon in this Results section, in which we describe the structures that underlie the essence of the phenomenon under study.

Daniel: Equations and Example Problems

In Daniel's individual textural description, he describes focusing on looking for equations and example problems to structure his problem-solving steps:

> After I read the problem and identify as many of the important terms as I can, I use the textbook to *find equations* that will allow me to relate all of the problem variables together. For example, I'll go "to the book to try to *find equations* on what would help me out with stress and strain because I thought that might be what was needed to solve the problem." Most of the time, I'll find a *few separate equations* that relate to some of the problem variables, but then I run into the trouble of figuring out "how they tied together to the problem." *Sometimes, after I find "the equations that I was looking for*... they didn't quite help me out in terms of what I was trying to figure out. I still couldn't figure out what variables I was trying to isolate and how I would get to ... solving the problem. I knew I was *looking for stress and strain equations* and the relationships between them, but then when I tried to come up with a combined equation ... I was coming up with too many unknown variables, so I wasn't able to solve it." When *I can't find the equations* I need to solve the problem in the textbook, "I kind of just kept *looking for more equations*," hoping to find "a key term ... that pops out at you." Finally, textbooks are helpful because they have example problems that can guarantee me being able to solve the problem. I was unsure about how to solve one of the problems, "but since *they had the schematic in the book*, I knew I would eventually be able to figure it out." (Daniel)

We can express Daniel's individual structural description as follows:

> *The textbook provides equations and example problems that help clarify ambiguity during the problem-solving process. The structural description of Daniel's experience with the textbook during the problem-solving process is predominantly related to retrieving equations and referring to example problems. The equations were often necessary to solve the problem and the example problems provided guidance when he was uncertain of how to approach a problem. Most of Daniel's comments about using the textbook described the uncertainty that he experienced at the beginning of his problem-solving process. He recalled struggling with constructing a clear problem-solving plan. During these times of uncertainty, Daniel turned to the textbook primarily to locate equations that he hoped would aid him in better conceptualizing the problem. His search was guided by concrete information (e.g., variables, numbers) provided in the problem statement. He used the textbook as a reference tool to identify specific information (e.g., equations) that he hoped would integrate all of the variables in a given problem statement. Daniel also described positive experiences associated with finding example problems in the textbook. Daniel referred to example problems as "schematics" that scaffolded his problem-solving steps and supported his ability to successfully solve a problem.*

Robert: Material Properties and Definitions

In Robert's individual textural description, he emphasized using the textbook to find specific information such as material properties and definitions after determining his problem-solving plan:

> As I read the problem, I gather as much information as I can from the problem statement in order to determine what type of problem I will be solving. Next, I look in the

> textbook for the appropriate information that relates to the problem. For example, I realized that "this was a materials selection problem . . . so first *I wanted to select a proper material*. So I looked in the Callister handbook [Callister & Rethwisch, 2009] and selected some *materials that would give me appropriate properties*." Another problem emphasized a specific factor, cost, so "*I approached it from the cost perspective using Callister to determine the cheapest material* because they gave you a reference sheet of cost." I also use the textbook to read more about definitions that I'm not sure of. For example, "If you didn't understand what a safety factor was, then you'd obviously have to look that up." Overall, I would say that *the textbook is a good reference source*. "I know that *Callister is definitely a good resource* and I have used it before a lot extensively." However, the *textbook is less efficient than other sources like the Internet*. When I use the textbook, I "have to sometimes look a little bit deeper." (Robert)

We can express Robert's individual structural description as follows:

> *The textbook serves as a comprehensive reference during the problem-solving process; however, the Internet is a preferred source of reference. The structural description of Robert's experience with the textbook is characterized by an organized search through the textbook content, trust that it has all the information needed, and an awareness of the limitations of the textbook. Robert describes a well-planned search in the textbook for a wide range of information including equations, materials, material properties, and definitions. Before looking in the textbook for information, he first identifies the reason for employing the textbook, including the variables, constraints, and considerations that he identifies, as well as the important considerations needed to solve a given problem. Robert describes the textbook as a helpful resource that he has used extensively in the past. However, he also describes drawbacks of using a textbook, stating that he experienced frustration with the inability to locate the desired information in the index or table of contents. While Robert acknowledged that the textbook was a helpful resource, he also described the limitations of using a textbook by contrast to more efficient online resources.*

Essence of Using the Textbook as a Reference Source

In order to extract the essence of student experience using the textbook, the composite textural and structural descriptions developed for each student were integrated and synthesized. The essence underlying the experiences of materials engineering students using the textbook during the problem-solving activity was characterized by a search for specific information that would structure, guide, and/or confirm the students' problem-solving steps, as well as an uncritical application of textbook information to the problem at hand. Students described the textbook as a reference source necessary for successfully solving the open and closed-ended problems in the problem-solving activity.

In the following, three composite structural descriptions of student experiences using the textbook while solving engineering problems are discussed in more depth: (1) the search: finding equations, materials, and material properties, (2) working backwards: using example problems to determine problem-solving steps, and (3) constraint listing: commenting upon the static nature of textbook.

The search: Finding equations, materials, and material properties Throughout the problem-solving process, all 10 students utilized the textbook as a reference source in order to extract specific pieces of information, including equations, materials, and material properties (e.g., conversions, yield strength of materials, Poisson's ratio) from the index or table of contents. They emphasized the necessity of this information for problem solving, and many reported that without the textbook, some or all of the problem components would have been impossible to solve. For example, the following student describes how material properties and equations listed in the textbook were critical for completing problems that involved choosing materials to build a truss bridge and to calculate stress:

> Without Callister? This one would have been impossible. For the material selection problems I needed Callister for determining moduli of the material. And for the first problem I needed to look up that equation for the critical resolved shear stress, so using it as a reference material is pretty necessary as far as this assessment was concerned. (Andrew)

Furthermore, students believed that if they are given a problem that requires specific equations, materials, or material properties, an appropriate textbook would contain this information. The following quote illustrates a student's expectation to find information regarding the limit for testing crack sizes, based on the knowledge that this information is required to determine whether or not the given problem could be solved:

> I think it's reasonable that it could've been in the book . . . If you're solving for these small crack sizes you need to know whether they can be tested or not so I thought it was pretty reasonable. I think it might be in the book we have for that class. (Nick)

Students varied in the amount of time spent searching for equations, materials, and material properties from the textbook, ranging from a brief scan through the appendixes to prolonged searches through different chapters in the textbook. Some described depending extensively on the textbook as a guide throughout most of their problem-solving process, whereas others utilized the textbook to find relevant information at specific points in their problem solving. Despite these variations, every student described using the textbook information related to equations, materials, and material properties for guidance during times of uncertainty. Students consulted the textbook when they had no clear direction towards a solution:

> I remember doing this, but I don't remember how. And so I started looking through the book, and I thought there was a formula, something to do with a dot product or something . . . The thought process wasn't too extravagant on this one; the problem was just kind of confusing, so I was searching through the book. (James)

In some cases, once a student decided to search in the textbook for a specific piece of information (such as an equation), attempts to draw that information from their own knowledge bank were either abandoned or put on hold. One student describes how searching in the textbook hindered his ability to remember a formula he may have been able to retrieve from memory on his own:

> The angle formula – I assumed that I'd be able to find it in the Callister book. And once I had my mind set on me being able to find it, it kind of . . . sometimes when your mind is in a mode to look up something, it triggers it to not to be in the mode to remember something . . . gives me a less likely chance of me being able to remember the formula myself. (Ryan)

In other cases, the textbook was used to confirm information students recalled from memory but were uncertain of. Similarly, the reference material in the textbook provided confirmation for decisions or assumptions made during the problem-solving process, as well as validation for a final answer to a problem. For example, one student looked up information from the textbook regarding the material properties of concrete to support his selection and application of this material:

> I know from previous classes and real-world experience that concrete, as far as an engineering material, is fairly cheap and the use of reinforced concrete is common in many different applications … As far as what Callister has taught us, this is a very viable option for the particular application … From Callister I was able to read about reinforced concrete. (Andrew)

In addition, having equations and material properties given in the reference section in the textbook made problem-solving easier. For example, a student describes how solving one of the closed-ended problems simply involved extracting the appropriate formula from the textbook:

> This problem wasn't too bad because I knew there was a formula that you can look up for the critical resolved shear stress. (Sarah)

Altogether, students said the textbook was necessary for locating critical pieces of information, including equations, materials, and material properties, during their problem-solving process.

Working backwards: Using example problems to determine problem-solving steps The students described the example problems in the textbook as valuable information that helped them successfully solve a problem. Regardless of whether the example problems were sought out intentionally or stumbled upon while flipping through the textbook, all the students took time to read and compare information presented in the example problem (e.g., concepts, formulas, steps) to the problem at hand. The information gathered from example problems significantly influenced the students' solution paths – especially at the beginning of the problem-solving process when students referred to an example problem corresponding to the problem they were attempting to solve. Additionally, the steps in the example problem scaffolded the students' overall problem-solving plan. As described by one student:

> Couldn't remember exactly how to do it, but I found it in the book. And then, when I was trying to go through it, I couldn't remember how to get one of the numbers I needed. But there was an example in the book, and so I was able to match up what I was doing with what was in the example to figure out the right way to do it … Using the example in the book, I got the numbers. (Alex)

A common approach taken when consulting the textbook example problems was directly applying the solution pathway in the example problem to the problem at hand without critical reflection. This use of example problems was frequently cited, particularly in cases where students were unsure of how to solve a problem. Students often described applying the steps in an example problem to their own problem-solving activity without much consideration for why these steps were being taken:

> I don't really remember how I started … I just looked in the book and there was an example problem that was similar. So I took the same approach they did and solved it. (Megan)

Furthermore, students described making substantial effort to find ways to make steps in the example problem correspond to the problem at hand. Rather than developing an understanding for the shared principles underlying the example problem and the problem given to solve, students described maneuvering various components of their problem to fit the example problem. Often, these changes involved restructuring superficial features of the problem without having a sound explanation or justification to support the changes. For example, one student attempted to manipulate equations to make the steps in her problem similar to those in the example problem:

> There was a drawing in the book that had this cylinder that was being fractured across a slip plane also, so I guess that related my drawing to this drawing. So I started the same way they started, but when I got to the part where they would be solving for the force, I changed the equation around so I'd be solving for the stress. (Megan)

When they identified an example problem that was similar to the problem at hand, students adapted all, or significant components of the example problem to their problem-solving plan. Unfortunately, on some occasions, this direct application of the example problem steps misled the students, particularly in cases where the example problem did not align exactly with the problem at hand:

> I remembered there was a problem in the book that was similar to this problem and I tried to kind of reverse engineer that problem . . . It was different but similar and that kind of probably got me off track a little bit because the way they went through it was a little bit different on how I went through solving the problem. (Daniel)

Regardless of whether following the example problem steps required students to abandon their initial problem-solving plan, or to uncritically plug values into an equation, the example problems served as the ultimate problem-solving guide, trumping students' own problem-solving processes or ideas. Most students described problem-solving decisions that seemed to be influenced by a belief that example problems provided the correct values for, and superior methods of, solving any given problem:

> So at this point I wasn't sure if I needed to do the safety factor first or if there was some other place I needed to put it. But there is an example problem in the book that just kind of divided it, so I just did that. I used the same equation they used, so then I decided that was okay. (Nick)

Students described feeling more confident about their problem solving and solutions when they could compare their problem-solving steps or answers with those presented in a similar example problem. One student described how the example problems served not only as a guide to solve the problem, but also as a standard to determine whether or not a problem was solved correctly.

> Basically [I] did the example and got what they got, so then I knew I could do it for this using the dot product. So I had something to check against to make sure I was doing the right method, and then I applied it to this problem to get the answer. (Alex)

Altogether, the degree to which students depended on and applied the components of the example problem varied, but all students were drawn to the example problems during their use of the textbook. The example problems were employed as a scaffold that guided students' problem-solving steps during points of uncertainty. When the components of the example problem did not coincide with the problem at hand, students expended significant effort to make direct links between the example problem components and the problem at hand, treating the methods used in the example problems as the ultimate standard for solving the problem.

Constraint listing: Commenting upon the constraints of the textbook All students described the textbook as a useful resource for the problem-solving activity; however, they also described experiencing the limitations of the textbook. They implicitly or explicitly commented on the inefficiency of using it as a reference source. Several students were also acutely aware of the static nature of the textbook (i.e., being a collection of information that does not change its scope or update its data) compared with the Internet. One student expresses how the restriction of reference materials to a single textbook limited his problem-solving ability:

> [If] I were to approach this problem without being restricted, I would have a lot more resources: other books that are more focused and concentrate on this material, and the Internet of course. So as far as this situation, compared to where I would normally otherwise be able to solve the problem, I would say I was limited. But obviously the book helped more than not having it, you know. (Alex)

Students reported the limited range of information available in the textbook, comparing it with not only a more efficient but also more dynamic resource: the Internet. Many students reported being accustomed to having immediate access to a wider range of the latest information available via the Internet that the textbook could not provide:

> If you typed in Google like "Poisson's ratio of polycarbonate" . . . it would give you, you know, 20 resources and then you could go find it in a paper and then find the resource . . . I mean, some people might argue that Wikipedia's not a reliable resource; but as long as it's sourced properly and you can back-check that source, I don't really have a problem with it and it's much more convenient to look up materials constants. Yeah, it's just purely efficiency instead of spending, you know, five minutes looking up in the book, it'll take me 15 seconds. (Robert)

Another student describes outdated information as one of the drawbacks of using a textbook, stating that he could have arrived at a more accurate solution if other resources were available:

> I would have been able to look up the density of various different types of concrete and then get a . . . because the book was from 1998 . . . much more accurate cost estimate based on just online resources typically and possibly some other newer resources. (Alex)

Students felt impeded in their problem solving by minor inconveniences in using a textbook, such as flipping through pages to search for a formula. As one student put it:

> Because I didn't know exactly where in the book it would appear and it wasn't in the index, so instead of me going page by page in like the first couple chapters, I just kind of gave up. (Nick)

Students did not consider the textbook obsolete as a reference; however, they experienced a sense of primitiveness about being limited to a single textbook for their problem-solving activity. Although students were familiar with various strategies for searching for information within the textbook, they were also aware of alternative, more efficient methods of retrieving the same information. Students cited the Internet as a preferred reference that they employ in their daily learning and problem-solving activities, and stated that they would have used it during the problem-solving activity if it had been available to them.

Discussion

This study describes the essence and major structures underlying student experiences of using a textbook during a materials engineering problem-solving activity. The problems used in this study were developed to assess a range of knowledge and skills related to materials engineering, including the selection of appropriate materials under given constraints and accuracy in calculating stresses and strains based on material properties. Results from our phenomenological analysis reveal that students employ the textbook resources narrowly (e.g., as a reference for material properties) when solving problems. Specifically, three major structures common to the student experiences were identified: (1) the search: finding formulas, materials, and material properties; (2) working backwards: using example problems to determine problem-solving steps; and (3) constraint listing: commenting on the static nature of the textbook. Student problem-solving processes using a textbook that exemplify these structures and the implications of our findings for engineering education are discussed below.

The Search

Classic problem-solving studies show that problem solving involves complex, purposive applications of learned mental operations that are applied in flexible and intentional ways (Newell & Simon, 1972; Tolman, 1932). Common to problem-solving theories is the modeling of knowledge embedded in a problem-solving space (Simon, 1980). Knowledge is often categorized as declarative or procedural, the former consisting of factual information and the latter consisting of how-to information (Runco & Chand, 1995; Schunn & Anderson, 1999). A person's knowledge broadly influences various aspects of problem solving, including how problems are constructed, interpreted, and defined, the processes that are supported or inhibited, and the evaluation of solutions or ideas.

The first stage of problem solving often involves the recall of declarative information that is relevant to the problem. This search through one's existing knowledge provides conceptual tools that allow an individual to make deeper relational associations among the problem elements (Stein, 1989). This study found that during this recursive memory search, many students adopted information that related to their problem-solving activity from the textbook to supplement gaps in their knowledge. Throughout the activity, many students frequently used the textbook to retrieve declarative knowledge in the form of equations and material properties located in the table of contents, index, or appendixes of the textbook.

Working Backwards

Students in this study tended to begin solving problems by determining the unknowns from which they would work backwards to meet the constraints of a problem. Students moved through the problem in a bottom-up direction, in which they used the problem constraints (e.g., a maximum weight restriction) to determine the subsequent stages of their problem solving. This approach contrasts to moving in a top-down direction, in which information is drawn from preexisting knowledge and guided by higher mental processes to make inferences and develop solution paths towards a goal. Text passages, which make up a large portion of the textbook, were rarely consulted during problem solving, and students spent minimal time seeking knowledge regarding the theories and underlying principles related to the problems at hand. These findings support earlier studies in which students reported spending little time reading their textbooks (e.g., Podolefsky & Finkelstein, 2006; Smith & Jacobs, 2003). In this study, students' descriptions of their experience with the textbook illustrated a constrained hunt within a narrowly defined search space in which they sought concrete, declarative information related to the problem constraints. We note that since the present study investigated textbook use only in the domain of materials engineering, the ways students in this study used a textbook while problem solving could be unique to this field. However, given the technical nature of engineering, we expect similar findings in other engineering disciplines.

Problem-solving theorists propose that when faced with a problem for which individuals cannot generate adequate steps toward a solution, problem solvers search for similar problem-solving situations or examples that they can use to form associations (i.e., find links to related ideas) or analogies (Anderson, 1993). In the present study, students did not describe engaging in a mental search for problem-solving situations or examples they had previously experienced. Rather, they spent a significant amount of time searching for, and referring to, example problems in the textbook and formed links between example and practice problems and the problems at hand. This finding supports previous research that shows that most of the time spent by students engaging with a textbook is focused on example problems (Smith & Jacobs, 2003; Taraban et al., 2004; Weinberg et al., 2012). Student descriptions of the ways they used example problems highlighted the important role example problems play in students' problem-solving decisions. The present study found that students' choice of problem-solving steps was largely influenced by those used in the example problems in the textbook they were using.

Students also relied greatly on example problems to scaffold their problem-solving processes. In his sociocultural theory of learning, Lev Vygotsky (1978, 1986) defined scaffolding to be the structuring of student learning by providing supports (or scaffolds) to aid a student through a given task. Research on textbooks using this theoretical framework supports the role of textbooks as supporting artifacts of curriculum, content, and instruction (Rezat, 2006). This study shows that textbooks also serve as significant supports for problem solving. However, students' use of textbook example problems as scaffolds succeeded only where the problem-solving steps in an example problem were directly applicable to the problem at hand. In many cases, the students' ability to successfully apply an example problem to the problem they were solving depended on the degree of similarity between the two problems.

Students in the present study displayed behaviors of novice problem solvers cited in previous studies, characterized by uncritical application of textbook example problems. This textbook-dependent behavior includes a focus on directly translating numbers and relational terms into mathematical operations, rather than seeking to understand the underlying concepts behind such problems (Chi et al., 1981, 1989; Schoenfeld, 1987; Schunn & Anderson, 1999). When example problem solution steps did not map onto the steps required to solve the given problem, students described having difficulty identifying the conceptual differences between the two problems and identifying more appropriate steps to reach a workable solution.

In summary, student skills, abilities, and approaches to solving engineering problems seemed to be heavily influenced by the textbook's example problems. Students reported difficulty determining alternative problem-solving approaches based on the principles and theories of materials engineering when steps were not explicitly presented in a textbook example problem. This study shows that textbook example problems often determine and may also limit how students go about solving a particular problem at hand.

Listing Constraints

Finally, students experienced the static nature of the textbook and described its limitations as a reference source for problem solving. Students frequently described a desire to access online sources as a supplement or alternative to the textbook. Several students contrasted the textbook to the Internet, describing advantages of using online resources, including the efficiency in finding information and the vast range of up-to-date information available. These findings confirm the increasing use of the Internet by students and educators (Hohne et al., 2007; Lindsley & Burrows, 2007; Reid & Cooney, 2001). This study also suggests that students are transitioning from using textbooks to using the Internet as their primary reference source.

Implications for Engineering Education

Textbooks serve several important roles in science and engineering education. Instructors often use the information contained in textbooks to structure the material and topics in a course, and provide students homework and practice problems to solve in preparation for exams (Lynch & Bogen, 1997; Stambaugh & Trank, 2010; Taraban, 2011). Textbooks are one of the most important learning resources available to students, and instructors often encourage students to read the textbook chapters corresponding to lecture material in order to develop a conceptual understanding that will support homework and exam problem solving (Podolefsky & Finkelstein, 2006).

In our study, many of the students did not demonstrate the conceptual understanding required to solve the problems. They often depended heavily on the textbook during their problem solving rather than using it as a resource to complement their knowledge. This study examined the use of a traditional textbook in the context of a problem-solving activity; our findings are consistent with results in the literature that show that students spend most of their time with textbooks solving practice problems as homework assignments or preparation for exams (Podolefsky & Finkelstein, 2006; Smith & Jacobs, 2003; Taraban et al., 2004; Weinberg et al., 2012). These previous studies were in basic math and science courses, and the extent to which our findings hold true across engineering remains to be determined. Still, our findings and others show that students primarily use textbooks for example and practice problems.

The significant influence of textbook example problems on shaping the problem-solving processes of engineering students has important implications for engineering educators. The ability to think in complex, abstract, and creative ways while problem solving is an important attribute of engineers (ABET, 2011; Marra & Palmer, 2004; NAE, 2004; Charyton & Merrill, 2009; Taraban, 2011). However, many of the senior materials engineering students in our study took an uncritical approach to the textbook, demonstrating weakness in applying principles to solving complex engineering problems.

The structural components of textbook use among the students in our study are characterized by a search for equations that relate to specific parts of the problem at hand. This search often lacks the conceptual understanding that should accompany finding and applying facts and formulae during the problem-solving activity. Students also frequently reported being unable to develop a clear problem-solving strategy, including defining the goals for an open-ended problem and the logical series of steps to achieving those goals. Instead, students frequently searched for and relied on an analogous example problem for structuring their problem solving. Our results suggest that during a problem-solving activity – rather than serving as a reference source to complement their knowledge – students use the textbook in lieu of their knowledge. In other words, information or example problems from the textbook often trumped or replaced students' autonomous problem-solving decisions.

Information in the classroom obtained from lectures, textbooks, and other sources should be presented as knowledge to be used and not simply as facts to be learned. Several education researchers emphasize the critical importance of contextualizing the classroom acquisition of information and skills within real-life situations in which this knowledge and skill will be applied (Anderson, 1993; Cognition and Technology Group at Vanderbilt, 1997; Newell & Simon, 1972). Moreover, training engineering students to become critical readers and users of information requires training how to use the different resources they are introduced to in school. Engineering education may need to increase the emphasis on, and demonstration of the relationships among, theories and principles, facts and techniques, and practices and applications of engineering found in various reference sources. Our study suggests that students compartmentalize the theory and academic knowledge learned in school from the practice aspect of engineering. They view problem solving as looking up a series of equations in the textbook without taking into account real-world constraints and considerations that are critical in industry. They also view the textbook as a means to an immediate objective (i.e., source of example problems that show how to get an answer) rather than a step towards greater understanding of engineering content, skills, and practices. Taraban (2011) proposes that textbook example problems should be ill-defined and purposefully designed in ways that create a context of ambiguity and open-endedness more characteristic of the problem-solving contexts students will face in professional practice. Future research is needed to examine the content and types of textbook example problems, as well as the role that different types of example problems have on students' problem-solving processes. Future research can also explore how to encourage students to make more meaningful, critical, and comprehensive uses of their textbooks.

Finally, students in the present study reported that being limited to a single textbook as their reference source was not representative of their real-life problem-solving experiences. Several students stated that the Internet is their primary reference source outside the classroom. The limitation that this study's design enforced on the students revealed their desire to move beyond traditional textbooks as their primary information source. Future research on the ways electronic resources affect student approaches to information gathering and problem solving is needed.

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