EMBEDDED TRANSPORTATION ENGINEERING KNOWLEDGE: COMPARING PRACTICING ENGINEERS' AND UNIVERSITY INSTRUCTORS' CONTEXT FOR UNDERSTANDING SIGHT DISTANCE AND STOPPING SIGHT DISTANCE

By

SHANNON DAVIS

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE IN CIVIL ENGINEERING

WASHINGTON STATE UNIVERSITIY
Department of Civil and Environmental Engineering

DECEMBER 2011

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of SHANNON DOW DAVIS find it satisfactory and recommend that it be accepted.

Shane A. Brown, Ph.D., Chair

Haifang Wen, Ph.D.

David McLean, Ph.D.

ACKNOWLEDGMENT

I would like to acknowledge the National Institute for Advanced Transportation Technology (NIATT) Grant DTRT07G0056, and the University of Idaho for their funding and support on this project. I would also like to thank Dr. Brown for all his encouragement and guidance and my family for all of their love and support.

EMBEDDED TRANSPORTATION ENGINEERING KNOWLEDGE: COMPARING PRACTICING ENGINEERS' AND UNIVERSITY INSTRUCTORS' CONTEXT FOR UNDERSTANDING SIGHT DISTANCE AND STOPPING SIGHT DISTANCE

Abstract

by Shannon Dow Davis
Washington State University
December 2011

Chair: Shane A. Brown

Educational theories of situated cognition suggest that knowledge is embedded in practice and tied to the ways in which it is applied. Substantial research in a diversity of fields suggests that being successful in a skilled profession requires ways of knowing and doing that are unique to the context of that profession, and present in practitioners. Similar research has not been conducted in transportation engineering. The purpose of this study is to characterize embedded knowledge of sight distance and stopping sight distance in instructors and engineers and similarly examine course materials. Individual interviews were conducted with 29 engineering practitioners and with 19 transportation engineering instructors. Course notes from a selection of instructors as well as three commonly used textbooks were analyzed. Although instructors and practitioners expressed similar content knowledge, there were significant differences in the context in which it was embedded. The engineering practitioners used and referred to a variety of resources, including software, local and state manuals, and specific experiences, while the instructors primarily spoke in a more abstract context, or referred to textbooks. Finally, engineers discussed methods of mitigating for the inability to meet minimum sight distance design criteria, but this was not found in course notes or textbooks. This research strongly suggests that context-dependent embedded knowledge exists in transportation engineering and that efforts are necessary to integrate this knowledge in the curriculum. Recommendations are made to encourage the development of embedded knowledge, including direction of future research required to better understand how practicing engineers use their knowledge.

TABEL OF CONTENTS

LIST OF TABLES

INTRODUCTION

Numerous studies have evaluated the conceptual understanding of students within engineering and science disciplines and found that students can perform simple calculations but lack fundamental understandings of core concepts (*1,2*). Compounding this problem, engineering education researchers and engineering practitioners have been concerned about the lack of embedded and practical knowledge present in graduating engineering students. Engineering firms commonly have to train students when they enter the workforce, particularly in the areas of engineering design and how to be a functioning practitioner. This has led to substantial efforts attempting to reform engineering education and to more functionally define the skills and capabilities required of the modern engineer. (*3,4*).

Educational researchers have long recognized the importance of context in determining how concepts are learned, and therefore how they can be applied in engineering. For example, researchers talk about "embedded knowledge," which refers to not only the knowledge that relates to engineering, but also the ways of thinking and knowing that are characteristic of engineers (*5*). The embedded knowledge of engineers (their knowledge as well as the context in which they use and think about that knowledge) needs to be well understood in order to best prepare students to be practicing engineers. This is an important focus of this paper, which investigates how knowledge about geometric design is embedded for practicing engineers and in the engineering classroom.

Embedded Conceptual Situated Knowledge

Learning theorists in situated cognition suggest that knowledge exists as an interaction between the knower and the contexts in which it is applied, and not solely in the mind (*6-8*). If knowledge is situated or embedded in a context and the application of that knowledge is dependent on that context, then students need to learn the concepts of the discipline in applied and situated contexts. As an example, Brown (*6*) found that about 5000 new words could be learned in a year if they were embedded in context, while only 200 words could be learned without an organizing context.

Substantial research has been done investigating embedded or situated knowledge in fields such as law, medicine, sailing, and copy machine repair (*7*). This research has resulted in broad ways of thinking about what it means to be a participant in a particular field and the relationship between practice and preparation for practice (*9-11*). A primary finding in this research is that embedded knowledge is vitally important for success in many professions. As one example among many, a study of naval quartermasters found that some chiefs prefer to receive new personnel that had not been formally trained (*12*). The study found that formally trained individuals typically formed misconceptions during schooling that were more difficult to correct than individuals who did not have any prior formal navigation training. Although this is a somewhat extreme example, it supports the general finding in this research that graduates may be lacking some necessary skills and knowledge because their learning occurs in a context which is vastly different from what they will encounter in their professions. The preparation of medical doctors provides a familiar example from a highly skilled, technical professional field. The education and training of medical doctors emphasizes the development of embedded knowledge with a combination of problem-based learning through case studies (13), and learning in professional contexts through residencies and internships. This emphasis on developing embedded knowledge results in new doctors whose on-the-job competence is sufficient to be successful in a profession where mistakes can cause direct harm to other people.

Considering the importance of embedded knowledge in training competent engineers, there is a troubling lack of information about the embedded knowledge of engineering practitioners. However, it is certain that embedded knowledge exists in civil engineering and that syntheses of this knowledge and its presence in engineering learning materials would be valuable to the field. Embedded knowledge may even be more important in the case of civil engineers than other professions due to the unique ways engineers are asked to apply knowledge in diverse and challenging contexts, while protecting human health and welfare (*14,15*).

Research on embedded knowledge can focus on a variety of types of knowledge. For example, the study of quartermasters generally focused on procedural knowledge. To address the evidence of low conceptual understanding and concerns of the lack of the embedded engineering knowledge, this study will focus on conceptual understanding, which is a person's fundamental understanding of core concepts. Conceptual understanding can be described as a robust and transferable understanding, or the ability to apply the concept in a variety of contexts (*1*). The focus of this study is on embedded conceptual understandings in transportation engineering.

Purpose of Study

This paper has two goals. One goal is to explore how transportation engineering faculty and practitioners think about and apply knowledge of sight distance (SD) and stopping sight distance (SSD) in geometric design. The second goal is to compare this knowledge with instructors' course notes, textbooks, and reflections of how they teach these concepts, in a selection of introduction to transportation engineering courses. SD and SSD were chosen because they are core concepts in geometric design.

METHODOLOGY

Engineers and instructors were interviewed and the resulting data were analyzed to categorize embedded knowledge of SD and SSD within geometric design.

Participant selection

Transportation engineers from around the Pacific Northwest and faculty and instructors (collectively referred to as instructors from this point forward) who teach entry-level transportation engineering courses around the country were asked to participate in this project; 29 engineers and 19 instructors accepted the offer. Additionally, 10 instructors' course notes were analyzed along with 3 popular textbooks mentioned by many of the instructors.

In an effort to create as complete a representation as possible of engineers' and instructors' understanding levels of geometric design concepts, diversity in participants was crucial to the project. This objective was accomplished by interviewing engineers from private and public sectors within four states having varying types of education and background. Engineers interviewed had between 3 and 33 years work experience. A range of instructors were interviewed: from early-career instructors to full professors; teaching at public and private institutions, small colleges and large universities; and having 1 to 17 years of engineering work experience.

Sample size in qualitative research projects is determined using the concept of saturation (*16,17*). Saturation occurs when new interviews do not provide additional data over previously conducted interviews and can require between 5 and 50 interviews, depending on the interview content and research focus (*17*). Guest et al. suggest that over 90% of findings can be recognized with as little as 12 interviews (*18*). Saturation is determined by examining later interviews for consistency in findings with previous interviews and is reached when no new data are found.

While the data set for this project includes only a small percentage of instructors and engineers in the country, saturation was reached with this sample (29 engineers and 19 instructors). In total, data collected translated to nearly 400 pages of transcriptions, 300 pages of notes, and 50 pages within 3 textbooks.

Interview Protocol

The interview protocol and the implementation of the interviews were designed to achieve three purposes: to provide multiple opportunities for participants to fully articulate their understandings of SD an SSD (*19*); to elicit evidence of the context in which participants embed this knowledge (*8*); and to access conceptual fundamentals underlying the application of the knowledge (20). Interviews utilized a clinical approach (*21,22*), with open-ended questions (*17*), where individuals' reasoning and understanding of SD and SSD were elicited through multiple pathways and probes. The semi-structured (*23,24*) interview protocol was designed to determine engineers' and instructors' understandings of SD and SSD as they relate to geometric design. The questions asked were focused on fundamental concepts as to result in data where engineers' and instructors' understandings of each concept, on a fundamental level, could be compared. The probing clinical approach frustrated some participants as they felt the interview questions were somewhat repetitive. It proved worthwhile, however, as many participants attempted to clarify their responses, which allowed the interviewer to uncover small changes in context and instances of embedded situated knowledge. Interview questions and probes used to help lead conversation are shown in Table 1.

Interviews began by encouraging participants to talk about their education, background, and experience. The body of the interview was composed of two sets of similar open-ended questions; one set relating to SD and the other relating to SSD. The questions asked participants to describe concepts, explain how they see these concepts used, and to speak of the level of importance they feel these concepts hold in transportation engineering. Additionally, engineers were asked to discuss a project they had worked on where SD and SSD had an integral, or particularly challenging, role in the project. Instructors were asked to describe how they address SD and SSD in their course and to discuss any methods of teaching that may differ from a traditional lecture style. At the conclusion of the interview, instructors were asked if they would provide a copy of their course notes. Of the 19 instructors interviewed, 10 instructors' notes were collected. The other 9 instructors were responsive to the idea of sharing their notes, but either could not easily access their notes or never sent them via email. The intention of asking for this information was to attempt to gain further insights as to how faculty implement curriculum as it is relates to SD and SSD.

Interviews were designed to last approximately 30 minutes and were conducted at the office of the participant, or if travel was not feasible, via telephone. In order to ensure that the phone interviews were truly equivalent to those conducted face-to-face, they were compared in terms of length of audio files and by word count of the transcriptions. Also, during the data analysis process, answers from phone interviews were compared, as a group, to those from face-to-face interviews. No differences were noted. Some questions were worded slightly differently for the instructors than for the engineers to access their approaches to teaching the concepts. However, instructors were also provided with opportunities to talk about SD and SSD in the context of engineering design.

TABLE 1 Example Interview Questions

Main Questions	**Sub-Question/Probes**
Tell me a little about yourself: where you went to school, when you graduated and how your career has progressed since then	What type of projects do you work on? What courses do you teach?
How would you describe SD/SSD to an entry-level engineer (to a student)?	Does it include any variables? What is your personal definition?
How do you (teach your students to) determine SD/SSD?	What calculations do you use to determine SD? Where do you find these calculations? Is there only one way you determine SD? Do you use software to determine SD? Have you ever used any other software? How do you use the software? What information does the software tell you?
What references do you use to determine SD/SSD (in the classroom)?	Do you ever use AASHTO? Is there any other manual you use? Do you use a state manual? Is your state/city manual based off other specifications?
What role does SD/SSD play in geometric design?	Is it important for safety or to meet design regulations? Is it a large role or is it just a contingency you check at the end of the calculations?
Is SD/SSD more or less important in horizontal curves than vertical curves?	What makes one more important than the other? Why do you say they are equal?
Could you tell me about a project you worked on where SD/SSD became an integral or interesting part of the project?	How did you approach this issue? Is this a common issue?

Analysis of Interview Transcriptions

The interviews were audio recorded, transcribed, and analyzed with the qualitative research program NVivo (*25*), a software program used in qualitative research to help store, organize, and analyze data using methodologies from the field (*26*). Audio files, transcriptions of audio files, and PDFs of course notes were uploaded into the program. Themes in the data were coded. For example, the answer each engineer gave to the question *how would you describe SD?* was coded as *ENGR Describe SD:* a first-pass code. Second-pass codes were then developed. For example, a sub-code named *Mentioned AASHTO* was created for times when an engineer mentioned that he or she used the AASHTO Manual (*27*) to help describe SD. Additional analyses were conducted iteratively to ensure that all interviews had been analyzed with the same codes; a practice called the constant comparative method (*26*).

Research results partially resulted from counting the number of times items were coded in specific categories, and how many times they were coded for each participant. For example, there were 3 quotes in the sub-code *ENGR Describe SD-Mentioned AASHTO-,* so it can be concluded that 3 out of 29 engineers (10.7%) mentioned the AASHTO manual in the response to this one specific question. A compilation of counted codes, like the previous example, can lead to the creation of statements such as: *very few of the engineers (10.7%) mentioned the AASHTO manual while describing SD. The majority (46.1%) referenced SSD while describing SD. Therefore it can be assumed that engineers associate SD with SSD more than they associate it with the AASHTO manual.*

Further example sets of codes used for data analysis of interviews in NVivo are presented in Table 2. Creating numerous summary statements, like the examples included in Table 2, result in an accurate and coherent picture of the conceptual understandings of the participants.

Using the previously defined coding and analysis procedures the data was examined to find embedded knowledge. Knowledge was considered embedded if it fit one of the following three criteria:

- Text from participants' discussions about engineering designs that was not otherwise present in other portions of interview data.

- Instructors explicit mention of concepts that were part of engineering design but that he or she did include in the course.
- Knowledge commonly cited by engineers and not by instructors.

TABLE 2 Example of NVivo Coding Process

Engineers:			
First-pass code	Second-pass code	%	Example of Summary Statement
Describe SD	Mentioned AASHTO	10.7	Many engineers mentioned SSD when describing SD
	Mentioned SSD	46.1	
	Threat/obstacle	30.7	
	How far you can see	42.3	
Role of SD/SSD in Geometric Design	Most important role	82.8	Most thought SD/SSD were the controlling features in geometric design
	Role must be balanced	17.2	

Analysis of Instructors' Printed Material

Course notes and textbooks were used in conjunction with verbal responses to gain a holistic view of instructors' teaching approaches. Material related to SD and SSD was analyzed in three textbooks. Printed material was analyzed by searching for evidence of specific approaches to concepts (e.g., deductive teaching, inductive teaching, and problem- and project-based learning). The order, style, and complexity of the information were also studied.

RESULTS

Results are presented, first, by the common findings among engineers and instructors, followed by the differences that are considered to be embedded or situated knowledge. Findings related to the presence, or lack thereof, of this embedded knowledge in teaching materials and textbooks follow. Finally, the results are used to draw conclusions about the match between practitioner's embedded knowledge and the ways in which transportation is taught, and make recommendations on addressing the gap between instruction and practice.

Common Knowledge

Considering the content of the entire interview, engineers and instructors have similar understandings of SD and SSD as they relate to geometric design. For example, participants from both groups spoke of traffic signals, vertical and horizontal alignments, and obstacles when describing SD and SSD. Almost every participant interviewed referenced the AASHTO manual at some point in the interview (most instructors did not teach with it, but still acknowledged its importance in geometric design). The importance of SD and SSD for safety was also acknowledged in the majority of interviews. When defining SD and SSD, both groups of participants often mentioned one term while speaking of the other and often situated the terms in context. Participants' descriptions of SSD were typically like one of the following quotes:

> *Instructor 11:* ***[SSD is]*** *related to sight distance...interrelated, but throwing a speed in there…is how we differentiate between the two.*
>
> *Engineer15: I guess kind of the spin-off of my response to sight distance. Again, a driver's perception of a hazard or an object in the roadway and that driver having ample distance to stop to avoid the object or the hazard.*

While on the surface level engineers' and instructors' responses show a similarity in understanding and basic definitions, further analysis revealed differences in embedded knowledge.

Embedded Knowledge

While engineers and instructors generally had similar understandings of SD and SSD, the use of context in their definitions and the methods with which they described determining SD and SSD were very different. Engineers also commonly discussed situations where minimum criteria could not be met. Finally, the use and value of computer software in teaching revealed embedded approaches to SD and SSD. Each of these differences will be discussed individually in sub-sections below.

Defining Terms and Context

Instructors defined the term SD with much less context than engineers. The majority of instructors (13 of 19) only embedded one additional concept into the definition. Two instructors embedded 2 terms and 4 instructors embedded 4 terms. Engineers were much more elaborate in their definitions of the term, with the majority (20 of 29) embedding 3 or more contexts into the concept. Only 3 of the 29 engineers embedded only 1 additional context. Below are quotes that show varying levels of embedded knowledge when participants described SD. The contexts given in each quote are bolded.

> *Engineer 1: I would describe it as the distance that you can see from any particular* ***spot*** *on a roadway,* ***in-between any obstructions*** *on the road,* ***off*** *the road,* ***or created by the road*** *itself.* (4 contexts given)
>
> *Engineer 20: ...It's the* ***clear*** *distance that you could see to perceive an* ***object*** *or a* ***hazard*** *or an* ***oncoming vehicle*** *on the roadway.* (3 contexts given)

> *Instructor 17: Simply the amount of visibility available to the driver* ***at any particular point along the roadway***. (1 context given)
>
> *Instructor 18: I guess the distance that you could see down the road* ***at any point along the roadway***. (1 context given)

These quotes on describing SD show that even though many instructors and engineers often fundamentally think about the subjects in the same manner, engineers tend to give a more embedded definition that includes site-specific terminology, while instructors seem to search for definitions encompassing all circumstances.

Determining SD and SSD

The way in which engineers and instructors determine SD and SSD was very different. Nine engineers mentioned that SD and SSD can be found in the field, and all 29 engineers mentioned it could be found by looking it up in the AASHTO, local, state, or city manual. Instructors most often discussed teaching students to find SD and SSD by looking up the equations in the text (7 instructors) or course notes (10 instructors). Only four instructors mentioned referencing AASHTO, and only one mentioned referencing a local manual:

> *Engineer 19: As far as determination in this agency, again, we use the formulas and tables in our (state) Manual.*
>
> *Instructor 11: The same way [as sight distance], using calculations and using the tables [from the text].*

Instructors usually limited their references to textbook and course notes which effectively limits the context to only that specific course, while the engineers' references were more broadly embedded in regional or legislative requirements.

Instances When SD and SSD Minimum Criteria Are Not Met

When discussing engineering design projects that included concepts of SD and SSD, engineers often cited projects where minimum design criteria were not met. Engineers commonly referred to this as the biggest challenge with SD and SSD in geometric design, and indicated that this situation often lead to more iteration in a design and/or using signs or warnings for the upcoming hazard. For example, Engineer 10 discussed mitigating the problem:

> *Engineer 10: If you've already looked at it [the minimum sight distance criteria] and there's nothing you can do with it- you can't take the right of way, then you have to find ways to address it to make sure it's safe, to alert the drivers ahead of time by using different types of either signing or beacons or something like that to let people know and alert [them] to an upcoming situation hazard.*

The problems associated with designs that do not meet the minimum criteria were a central part of the engineers' ways of thinking about SD and SSD, but were entirely absent from the instructors' interviews, course notes, and textbooks.

Use of Computer Software

The majority of engineers (21 of the 29) stated that they frequently used computer programs to help them determine SD and SSD. Two other engineers stated that co-workers use programs but, by choice, these engineers chose to calculate SD and SSD by hand. Most frequently mentioned of the programs were MicroStation and AutoCAD and their respective 3D add-ons. Engineer 26 explained the simplicity and ease of use of Microstation's 3D program, InRoads:

> *Engineer 26: ... basically our design manual, all the parameters and criteria are built into our program.*

Engineer 2 explains why computer programs are an integral part of his work day and describes the multiple uses of design software:

> *Engineer 2: [We use] AutoCAD or MicroStation to process data. And then InRoads is our geometric design software. We could do stopping sight distance calculations within there.*

Unlike the high percentage of engineers, only three instructors spoke of teaching with computer programs that are frequently used in the field. An additional four instructors stated that they use computer simulation programs as learning tools, but that these programs are not similar to those which working engineers use in design. Of the 15 instructors that do not use professional design programs, none denied the importance and frequent use of these programs in the transportation field. Many instructors stated that their reason for not incorporating these programs in their classroom was due to limitations such as lack of time, money, and resources. Instructor 18 described his dissatisfaction with including professional software in the classroom and describes his attempt to still introduce his students to the programs he knows they will see in the future, saying:

> *Instructor 18: [Programs have] too steep of a learning curve and we only have three or four weeks to cover geometric design, it's really just enough time to get through the theory and hand calculations.*

He continued by mentioning that although he doesn't teach the software, he does give a demonstration of it in class. He feels students gain a better understanding if they see what the final outcome of an engineering design looks like.

This attempt to incorporate even a small view of transportation software into the classroom is more than many instructors include. Instructor 2 describes his reason for not including geometric design software in his course:

> *Instructor 2: I used to [include software into the curriculum], but I found it to be kind of distracting. Students are more concerned with learning the software itself than learning the concept. And so, I've since gone away from that. I mean it's useful from the standpoint of going into practice and being able to hit the ground running… [MicroStation] is a very powerful software, but it takes a long time to use and there's just not enough time to do that in a classroom setting.*

For a majority of the engineers interviewed, a significant amount of their time working with SD and SSD involves working with design software. While the instructors did not discredit the importance of the software, they seemed challenged by how to effectively include, and teach, these intensive computer programs in a college classroom setting. Because of these challenges, 16 of the 19 instructors purposefully did not use computer aid design programs in their course.

Knowledge of SD and SSD in Textbooks and Course Notes

In the textbooks used by instructors, topics were often presented in ways largely removed from the contexts of the working field. Many concepts were defined by variables and not necessarily by the functional use of the concept. Definitions of these terms were embedded in paragraphs and surrounded by variables. Context was sometimes visible in the text but often hard to find. For example, the index of one transportation textbook leads the reader to find the definition of SSD in the middle of one chapter. This definition states that SSD is the sum of two equations from the previous chapter. When the reader references the previous chapter, the explanations of the two equations are in different sections and defined by another set of variables. If the reader looks at the paragraphs above and below the equations, a definition for each equation can be inferred but is not simply stated. Disconnected definitions and definitions defined by variables, like this example, create challenges for novice learners trying to grasp the embedded understanding of a term. This is also an excellent example of an important point in the discussion of embedded knowledge; it is not that the students learn about SD and SSD without any context, but rather that the context they learn it in is different from the one they will be applying it in. The cross-referencing and equation-based approach of the textbook can be viewed as a form of deeply embedded knowledge. The problem is that it is embedded in a context that will not necessarily help students as they transition to practicing engineers.

The definitions given by the instructors during the interviews were much more straightforward than the definitions found in the text. When Instructor 9 was asked how she would describe SSD to one of her students she gave this simple yet complete definition:

> ***Instructor 9:*** *...stopping sight distance is the required distance for the time from when somebody initially perceives an object or something that requires an action to the ending when a vehicle stops. So it includes two components; the time that the vehicle [is] traveling while the reaction [is] happening and the time that the vehicle [is] decelerating and stopping.*

Course notes provided somewhat of a bridge between the theoretical explanations of the text and the complete, contextualized definitions given by the professors. Course notes often paralleled the text by defining concepts in terms of variables and going into great depth by showing derivations of the equations. Minimal emphasis (although more than in the textbooks) was placed on explaining the real world value of the geometric design concepts in the course notes. Some instructors broke from the lecture to include their own engineering-design-related board examples or computer demonstrations. One instructor even had an entire lecture devoted to the contextualized use of geometric design concepts. However, these examples of embedded knowledge represent a small proportion of the total.

Complete data was not collected on homework assignments, examinations, and course projects; and course instruction was not observed. It is possible that these resources contained more design-like embedded knowledge than course notes and textbooks. Because course instruction was not observed, it is hard to speculate which portions of notes instructors emphasize and explain the most. Furthermore, instructor descriptions of their courses showed that their lectures are more closely related to the text than to practice-based knowledge contexts. Even considering the possibility of real-world design projects or verbal emphasis on contextualized facets of the class notes, the data collected here shows that the majority of the material presented in class was not embedded in contexts that are relevant to practicing design engineers.

DISCUSSION

The results presented here suggest that students are learning concepts without the context that would allow them to usefully apply them in engineering practice. It is worth noting again that the problem is not that the instructors somehow fail to include context, but rather that the context of the courses is different. For example, many transportation engineering design their courses for coverage of large quantities of equation-based problem solving at the expense of real-world problem based concepts. courses include additional content rather than more real-world examples of core concepts. In these curricula, it is rare to see mention of many of the vital concerns of any transportation design, including referencing relevant design manuals, efficient use of technology, or the host of interactions and compromises with other professionals (e.g surveyors or city officials). Thus, while the emphasis is on ensuring that students possess broad content knowledge, they are not developing sufficiently embedded knowledge that would allow them to directly apply this knowledge in the working field.

When considered together, the subtly different ways of approaching SD and SSD between practicing engineers and instructors suggest that in the two contexts (engineering practice and engineering education) the concepts would appear to be very different. For the engineers, SD and SSD are demands from other people (legislators or the authors of pertinent codes) that cannot always be met, but must always be considered within the context of designing safe and efficient roads. For the instructors, and even more markedly so for the textbooks, SD and SSD are values to be calculated. In the first understanding, they are dynamic, socially defined ideas, while in the second they are abstract and rigid relationships between variables. Both conceptualizations are correct in their own context, but imagine the conundrum of a student used to manipulating equations and variables who is suddenly asked to design a road in a case where the project constraints conflict with one another. This case, while frustratingly common in engineering practice, is not even considered possible in the student's previous context.

Recommendations

Bringing embedded knowledge to the classroom and improving student learning requires new approaches to learning and instruction. Although these issues are not mutually exclusive, they are approached independently in the discussion below.

Learning Embedded Knowledge

Evidence from this and other studies indicates that most university educators use a lecture-based deductive approach (*28*). Lecture was specifically mentioned by 15 of the 19 instructors as a primary way of educating students. The limitations of lecture as the sole approach to classroom learning have been established and multitudes of alternative approaches, have been shown to improve student learning (*28-30*); they will not be discussed further here. The focus of the recommendations is not on how the classroom environment should be designed, but instead on how the content is organized and approached.

The commonly used deductive approach is potentially problematic, especially when considering the tasks that students are asked to complete as practicing engineers and the embedded knowledge required to complete these tasks. A deductive teaching approach generally refers to providing students with rules and equations and then asking them to use these equations to solve problems. This is in stark contrast to an inductive approach where students are provided with data or relevant problems and are guided in making sense of the data themselves, including identifying key relationships and variables (*13*). The instructor's role in inductive learning is to ask probing questions and to provide appropriate resources (*31*). The benefits of inductive teaching include emphasis on critical thinking, learning knowledge within a common context, and increasing students' involvement in course learning.

Aside from the more general benefits, the results of this study suggest that the ways in which inductive learning is embedded in the context of engineering problems would provide an additional benefit to students preparing to enter the workforce. In a sense, courses designed around inductive learning would provide graduates with small bouts of content-specific and relevant work experience. These benefits could be enhanced by drawing on the research into problem- and project-based learning (*32*). Researchers in this area have identified the benefits of using "real-life" problem-solving as a teaching tool. If inductive learning was encouraged while solving an engineering problem actually drawn from engineering practice, students' learning would be improved and would be more relevant to engineering practice.

Teaching Embedded Knowledge

Although the research provides clear suggestions as to what kinds of learning encourage the development of embedded knowledge, the fact remains that most undergraduate engineering courses do not use these methods. The most obvious possible reason for not including inductive, problem-based learning is that the instructors might lack relevant or recent design experience, and are therefore not able to integrate it into their courses. A similarly straightforward explanation would be the ever-present problem of time-constraints. As admitted by instructors in this study when discussing software, this integration requires a substantial time commitment, both in terms of the instructor's efforts in preparing the material and the class time taken up in presenting it.

For those instructors who do lack relevant engineering design experience the integration of engineers is vital if the tenets of situated cognition mentioned previously are accepted, and if it is believed that tacit knowledge of a field is not in written form (found to be true in many research studies e.g. *5*). There are several approaches to accomplish this. Senior design courses across the country include mentorship and assessment from engineering practitioners (*19*). While clearly valuable, this extensive commitment is probably not reasonable across a variety of junior and senior level design courses. Recent course development and implementation efforts include practicing engineers as students in senior level design courses, providing substantial potential for interaction between students with and without engineering design experience (*33*). This potential is amplified by online or remotely delivered courses, providing access to individuals off campus. Finally, online studio based learning environments have been developed that allow for feedback from individuals at remote locations that can be anonymous (*34*). Admittedly, in all cases these require time-strapped working engineers to commit time to engineering education. Substantial involvement by engineers in senior design courses indicates that involvement is possible, but it is likely to be the most significant challenge.

The findings of this research, however, highlight an additional problem limiting the development of embedded knowledge in engineering courses. Somewhat surprisingly, most of the instructors interviewed in this research have some engineering design experience; 10 of the 19 instructors hold professional engineering licenses, and 6 of the remaining 9 had more than 5 years working experience. Their reasons for excluding these contexts from the classroom therefore must be something more complicated than a lack of experience. Similarly, the way the instructors in this sample spoke about the inclusion of design software shows that their time-management decisions in course design are actually prioritization decisions. Instructors said that they could not teach about the software because they had "just enough time to get through the theory and hand calculations" In other words, many of the participants in this study chose to teach SD and SSD separate from the context of engineering practice not because they did not have the knowledge and understanding, but because they would rather not. This poses an entirely different challenge, and one that must first be more fully understood through further research.

CONCLUSION

Transportation engineering instructors' and transportation engineering practitioners' understandings of geometric design principles were found to be similar in content, but not in context. While the amount, depth, and degree of information each set of participants knew were alike, the applications in which each set of participants chose to frame their knowledge was different. The context of undergraduate transportation engineering courses may be placing students at a disadvantage because they are not gaining the embedded knowledge that is necessary to help them apply their knowledge in practice.

In order to help students develop knowledge embedded in the context of engineering practice, research projects characterizing the embedded knowledge of practitioners are necessary across engineering subjects. Researchers could find the answers to questions like; what makes engineers' and instructors' understandings different, did they learn these concepts differently, and how could instructors learn to incorporate the knowledge unfamiliar to them into their classrooms? Additionally, by comparing instructors' methods of teaching to engineers' processes of using knowledge, researchers could help instructors develop pedagogy that would more productively prepare their students for the working field.

There is great potential for this type of research to improve engineering education and student preparation for the engineering workforce. By investing in the improvement of courses devoted to future engineers, we are ultimately investing in the future of our nation's infrastructure, safety, and wellbeing.

REFERENCES

1. Montfort, D., S. Brown, et al. An Investigation Of Students' Conceptual Understanding In Related Sophomore To Graduate-Level Engineering And Mechanics Courses. *Journal of Engineering Education*. Vol. 98, 2009, pp. 111-129
2. Andrews, B., S. Brown, et al. (2010). Student Understanding of Sight Distance in Geometric Design: A Beginning Line of Inquiry to Characterize Student Understanding of Transportation Engineering. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2199, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 1-8.
3. National Academy of Engineering. *The engineer of 2020: Visions of engineering in the new century*, The National Academies Press. Washington D.C., 2004.
4. McMasters, John H. Thoughts on the Engineer of 2020 An Early 21st Century [Aerospace] Industry Perspective. Presented at The Future of Engineering, Science and Mathematics: Who Will Lead? Harvey Mudd College, Claremont, California 2006.
5. Sternberg, R. J. and J. A. Horvath, Eds. *Tacit Knowledge in Professional Practice: Researcher and Practioner Perspectives*, Lawrence Erlbaum Associated Inc., Mahwah, NJ, 1999.
6. Brown, J. S. Situated Cognition and the Culture of Learning. *Educational Researcher.* Vol. 18, 1989, pp. 10.
7. Lave, J. and E. Wenger. *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press, Cambridge, England, 1991.
8. Robbins, P. and M. Aydede, *The Cambridge Handbook of Situated Cognition*. Cambridge University Press, New York, 2009.

9. Wenger, E. *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press, New York, 1998.

10. Wenger, E. *Communities of Practice and Social Learning Systems*. Sage Publications, Ltd. Vol. 7, 2000.

11. Wenger, E. *Cultivating communities of practice : a guide to managing knowledge*. Harvard Business School Press, Boston, Mass, 2002.

12. Chaiklin, S. and J. Lave, *Understanding Practice: Perspectives on Activity and Context*. Cambridge University Press, Cambridge, UK, 1996.

13. Prince, M.J., Felder, R.M., & Brent, R. Does Faculty Research Improve Undergraduate Teaching? An Analysis of Existing and Potential Synergies. *Journal of Engineering Education,* Vol. 96, 2007, pp. 283-294.14.

14. Vincenti, W. *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore: The Johns Hopkins University Press, 1990.

15. Pirtle, Z. How the models of engineering tell the truth. In I. van de Poel & D. Goldberg, *Philosophy and engineering: An emerging agenda, Philosophy of Engineering and Technology*, New York: Springer, Vol. 2, 2010, pp. 95-108.

16. Miles, M. B. and M. Huberman. *Qualitative Data Analysis*. Sage Publications, Thousand Oaks, CA, 1994.

17. Patton, M. Q. *Qualitative Research & Evaluation Methods*. SAGE Publications Inc., Thousand Oaks, California, 2002.

18. Guest et al. How Many Interviews are Enough? An Experiment with Data Saturation and Variability**,** *Field Methods* Vol. 18, 2006, pp. 59-82.

19. Wolcott, M.P., S. Brown, et al. A model for faculty, student, and practitioner development in sustainability engineering through an integrated design experience. *ASCE Journal of Professional Issues in Engineering Education and Practice*, Vol. 137, 2011, pp. 94-101.
20. Trowbridge, David E., L. C. McDermott. Investigation of student understanding of the concept of velocity in one dimension. *American Journal of Physics*, Vol. 48, 1980, pp. 1020-28.
21. Ginsburg, H. *Entering the child's mind : the clinical interview in psychological research and practice*. Cambridge University Press Cambridge, England, 1997.
22. Greenspan, S. I. *The Clinical Interview of the Child, Third Edition*. American Psychiatric Publishing, Inc., Washington D.C., 2003.
23. Maykut, P. Morehouse, R. *Beginning qualitative research: A philosophical and practical guide*. Falmer Press, Washington D.C., 1994.
24. Sommers-Flanagan, R. *Clinical interviewing*. Wiley, New York, 1999.
25. QSR International (2006). Nvivo (Version 9.1.106.0) [Computer software]. Cambridge, MA: QSR International. Retrieved July 28, 2011. Available from http://www.qsrinternational.com/products_nvivo.aspx.
26. Lincon, Y.S. and E. G. Guba. *Naturalistic Inquiry*. SAGE, Newberry Park, California, 1985.
27. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets.* 2004. AASHTO
28. Hake, R. R. Assessment of Physics Teaching Methods. Presented at UNESCO-ASPEN Workshop on Active Learning in Physics, University of Peradeniya, Sri Lanka, 2002.

29. Jones, S. and H. Tanner. Teachers' Interpretations of Effective Whole-class Interactive Teaching in Secondary Mathematics Classrooms. *Educational Studies in Mathematics* Vol. 28, 2002, pp. 265-271.

30. Chi, M. T. H. Active-Constructive-Interactive: A Conceptual Framework for Differentiating Learning Activities. *Topics in Cognitive Science,* Vol. 1, 2009, pp. 73-105.

31. Bligh, J. Problem Based Education in Medicine: An Introduction. *The Fellowship of Postgraduate Medicine*. Vol. *71,* 2005, pp. *323-326.* http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2398141. *Accessed July 28, 2011.*

32. Savin-Baden, M. *Problem Based Learning in Higher Education: Untold Stories.* SRHE and Open University Press, Buckingham, England, 2000.

33. Kyte, M., M. Dixon, et al. Process for Improving Design of Transportation Curriculum Materials with Examples. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 2199, Transportation Research Board of the National Academies, Washington D.C., 2010, pp. 18-27.

34. Hundhausen, C. 2008. "OSBLE." http://osble.eecs.wsu.edu. Accessed July 29, 2011.