Comparing Students and Practicing Engineers in Terms of How They Bound Their Knowledge

Grace Panther and Devlin Montfort
Oregon State University
Corresponding Author Email: Grace.Panther@oregonstate.edu

CONTEXT

Research in conceptual understanding has shown that students are not developing the foundational knowledge necessary that will assist them later on in their academic and professional career. Additionally, when the knowledge is categorized as closely related to important and real problems, students are more likely to be motivated and have a greater ability to learn. Many educational problems are intentionally decontextualized, meaning that students are often learning in contexts that are not important or relatable to students which could influence how that knowledge is categorized. Understanding how students categorize knowledge can provide insight about their ability to apply knowledge in different contexts and how it impacts their preparation for engineering practice.

PURPOSE

The purpose of this paper is to compare how practicing engineers and students organize their knowledge into categories and realms of knowledge when working on or presented with an open-ended, multidisciplinary engineering problem.

APPROACH

Phenomenological interviews were conducted with 19 practicing engineers who worked on two different multi-disciplinary engineering projects. Practicing engineers were asked about their role in the project and their responsibilities. Semi-structured clinical interviews were conducted with 42 senior-level engineering students from a large university and a technical college. Sampling was conducted through email solicitations sent by the instructors of the senior-level courses. Engineering disciplines represented in the sample include Biological, Chemical, Civil, Computer, Electrical, Environmental, Embedded Systems, Industrial, Mechanical, Nuclear, Renewable Energy and Software engineering. During the interviews, students were presented with one of the real-world multidisciplinary engineering problems and were asked to discuss how they would complete a portion of the design that most closely related to their area of expertise.

RESULTS

Students were found to categorize knowledge differently compared to practicing engineers. A majority of the students referred to the interfaces between project roles as fixed and well-defined while practicing engineers spoke about these interfaces as dynamic and ill-defined.

CONCLUSIONS

The results presented here further emphasize the importance of utilizing real-world engineering examples to motivate students and assist them in developing foundational conceptual knowledge. Understanding how students categorize knowledge has provided insight into how differences between the contexts of engineering education and engineering practice could affect students' preparation to enter the workplace. Possible implications include what courses engineers are required to take and how to better design foundational courses such as physics and math to help students rehearse key skills and make connections to their own success as engineers so that key concepts relate to important and real-problems to help motivate students to learn.

KEYWORDS

Multidisciplinary, Categorization of Knowledge, Epistemology

Comparing Students and Practicing Engineers in Terms of How They Bound Their Knowledge

Grace Panther and Devlin Montfort
Oregon State University
Corresponding Author Email: Grace.Panther@oregonstate.edu

Introduction

Research in conceptual understanding has shown that students are not developing the foundational knowledge necessary that will assist them later on in their academic and professional career (Hake 1998, Streveler, Litzinger, Miller, and Steif 2008, Streveler, Brown, Herman and Montfort 2014). But it is expected that students develop conceptual understanding as required by accreditation agencies (ABET, 2016; Engineers Australia, 2016). How and to what extent students are able to build fundamental and flexible knowledge that can be applied to a range of circumstances is dependent on how the knowledge is categorized (Bransford, Brown and Cocking 1999, Brown, Collins and Duguid 1989). Categorization of knowledge depends on the links students make between concepts and the circumstances in which they apply (Säljö 1999, diSessa 2002, Ivarsson, Schoultz and Säljö 2002). But research has shown that students often struggle with the actual categorization process (Chi and Roscoe 2002, Chi 2005). To alleviate this issue, researchers suggest that problems should be closely related to important and real problems to aid in categorization, increase motivation, and enhance the ability to learn. (Pintrich, Marx, and Boyle 1993, Sinatra 2005). Therefore, the research presented here utilizes real-world engineering problems to gain a better understanding of how students categorize knowledge compared to practicing engineers. Understanding how students and practicing engineers categorize knowledge can provide insight about how they learn and how that learning impacts their preparation for engineering practice.

Purpose

The purpose of this paper is to better understand how students and engineers organize their knowledge into categories and realms of knowledge when discussing an open-ended, multidisciplinary engineering problem.

Methods

We identified and utilized two real-world engineering problems for our research with the assumption that meaning and knowledge is constructed through experiences. Selecting two real-world engineering problems occurred with the assistance of engineering faculty who teach senior design courses and drew upon their industry contacts. The problems had to meet the following criteria in order to be considered for our study: 1) an engineering project that involved multiple disciplines in which individuals worked across disciplines throughout the project, 2) represent different types of common engineering work, and 3) at least 3 engineers on the project willing to participate in a 50-minute interview. This resulted in the selection of two engineering projects that were significantly different. The projects differed in innovativeness – Project A required the development of innovative technology and components and their application in largely unknown environments, while the Project B utilized well established best practices to maximize efficiency in solving a familiar problem in a new location. In total, 19 engineers volunteered to participate in phenomenological interviews lasting approximately 50 minutes each – 12 from Project A and 7 from Project B. The interview questions were designed to elicit insight about knowledge domains through questions such as “What were you responsible for designing and creating?” and “How do you know the work you complete is correct?” All participants were offered compensation but only participants from Project B accepted.

Once the practicing engineer interviews were completed, engineering students were recruited. Recruitment of engineering students occurred at both a large public university (> 20,000 students) and a technical college (< 5,000 students) by contacting senior design course instructors that corresponded to the disciplines represented in the real-world engineering projects. Senior design course instructors either emailed the recruitment solicitation directly to their class or posted it on their classroom management software (ex. Canvas). Interested students emailed the researcher directly and coordinated a time for a 50-minute interview. A total of 13 students were recruited from the technical college spanning five engineering disciplines: Civil, Mechanical, Software, Embedded Systems, and Renewable Energy. From the large university, 29 students participated spanning eight disciplines: Civil, Mechanical, Computer, Biological, Nuclear, Environmental, Chemical, and Electrical.

Student interviews were based on clinical interviews designed to elicit student reasoning with the help of the interviewer. The interviews utilized a simplified project description of Project A and Project B. Students only responded to questions about one of the projects, which was dependent upon their discipline. During the interviews, students first read the project description and selected a role they felt most comfortable and prepared to talk about. For example, a civil engineering student read Project B and selected the area surrounding the building (parking, run-off, etc) before being asked what they think they would be responsible for designing or creating. The students were asked to focus on a singular role when responding to questions in order to provide focus to the interview and to gain an understanding of how students categorized their knowledge relative to a specific project role.

All of the interviews were recorded and transcribed before data analysis occurred. Data analysis began with a read-thru of all of the raw text with a broad research question in mind: “how does the interviewee divide their knowledge into categories?” (Auerbach and Silverstein 2003). In pursuit of this question, the analysis focused on discussions about responsibilities, design decisions, and interactions between engineers working on the same project. Next, we coded the data for repeating ideas which resulted in a theme about how students and engineers bound their knowledge. Within this theme, we analysed student responses to one question: “Are there aspects that you think you have to rely on other people to assist you with?” For comparison purposes, we analysed practicing engineer responses to a similar question “Are there certain areas that you’ve had to rely on others to assist you with?” This question was purposefully left open-ended to allow students and practicing engineers to answer it as they saw fit. Next, we created finer grain codes that identified the ways students and practicing engineers bound their knowledge which are presented in the following section.

Results and Discussion

Our findings show that students mostly referred to the interfaces between knowledge domains as fixed and well-defined compared to engineers who saw these interfaces as dynamic and ill-defined. In other words, students treated these interfaces as consistent, predictable and easily perceived. Students viewed their interactions with the interfaces in terms of receiving facts and figures, while the practicing engineers treated the interfaces as a fuzzy grey area that required them to interpret and negotiate.

For example, many students said something similar to this quote:

As long as I had all the information [I could do my design]. [Student]

The information the student was referencing is the information necessary to complete their design and signifies that the student sees a clear divide at the interface between what they know and what others know, and a fairly simple process of communicating the necessary knowledge across the interface. This is in contrast to how the practicing engineers spoke about the grey area that exists at interfaces which is seen in the following example.

> *The design manager has kind of the ability to give input over the different disciplines and make decisions when we may wanna to go one way or the other. [Practicing Engineer]*

Like many of the engineers, this participant's response focused on the circumstances where two disciplines have a conflicting idea about a design component. This response takes for granted that there are multiple solutions from different perspectives, and moves on from that assumption to discuss details of how to manage the interface between project roles and disciplines.

We build on the previous idea of students seeing interfaces as a simple communication process by showing that students often view communication at interfaces as one-directional.

> *Yeah, I'd definitely be relying on other people for information like air space and how much liquid I can bring on the actual trip, how much weight I can take up, and all that stuff. [Student]*

Here, the student speaks about receiving design parameters – like weight – from "other people" showing that the student sees a division between what they know and what others know. This quote makes it clear that the student is treating this interdisciplinary information as design parameters and constraints, without acknowledging their own role in providing information or negotiating constraints across those boundaries. While this reflects typical practices in an academic setting, the student fails to recognize that there is room for negotiating these parameters with a well-formed and supported argument. Unlike the students who speak about receiving knowledge in a one-directional path, the practicing engineers' discussions at the interfaces occur on a bi-directional path or in a circular motion.

> *And I have relied on their input on whether or not the wall thicknesses are appropriate. Especially whether or not it is manufacturable, is it something they can actually build reasonably. And particularly strength and what kind of inserts will work for the threaded screws and all that sort of stuff. I have been able to go back and forth with them on some of that. [Engineer]*

The mechanical engineer in this example was trying to determine if the designed polycarbonate manifold that is thermally fused together could be produced and how it could integrate with other components of the design. The key words in this quote are "input" and "go back and forth" indicating that the engineer sees knowledge at the interface as negotiable. Additionally, the phrase "is it something they can actually build reasonably" shows awareness by the engineer that while his design might fit the given parameters, it may not be manufacturable revealing that a grey area exists at interfaces in engineering. This quote is a prime example of how engineers do not see a clear divide in knowledge but instead negotiate and re-synthesize information as design progresses.

In the next examples we show how students and practicing engineers refer to interfaces relative to the process of engineering design.

> *Like, gathering information there's gonna be a lot of outside communication and then the design work I think happens like more within me and then within my department.[Student]*

The student is focused on gathering information through communication with others on the project and says "…the design work I think happens like more within me…" suggesting that design occurs in solitude once parameters are defined by an authority. Again, this exemplifies the idea that students treat interfaces as unambiguous and straightforward. On the other hand, practicing engineers see these interfaces as ambiguous which can be seen in the following example about one discipline asking another for an adjustment.

> *…they may come to me and ask for an adjustment and then I've got to coordinate that with everybody else, structural and everybody to make sure that it's not going to be a problem. [Engineer]*

Here, we see how one engineer asked for an adjustment which caused a ripple effect in the design by other engineers. This shows how design parameters are often fluid and changing and open for negotiation.

Conclusion and Next Steps

In sum, a majority of students defined interfaces (and thus knowledge boundaries) as fixed and well-defined unlike the practicing engineers who spoke about these interfaces as dynamic and ill-defined. This supports findings from similar studies that show students struggle bridging the divide between what they learn in class and the “real” world (Elby 2001, Hammer and Elby 2003, Lising and Elby 2005).

Understanding how students categorize knowledge at interfaces has provided insight about how students’ categorizations differ from practicing engineers. This echoes previous research that suggests that students’ development of knowledge is likely to be bound in an academic or classroom context (Brown et al. 1989). The research presented here adds to the body of existing literature by suggesting a shift from understanding personal epistemology to understanding epistemic practices. Additionally, our findings suggest the need to incorporate epistemic practices found in engineering practice early on in the educational experience so that students are prepared to enter engineering practice. For example, by providing students more opportunities to work on open-ended and ill-structured problems that have multiple “correct” solutions.

Next steps include a more in-depth analysis comparing the students with practicing engineers. By doing so, we hope to uncover additional dimensions of epistemic practices in which students and engineers differ. Additionally, we plan on proposing modifications to teaching practices that could expose students to the epistemic practices commonly found in engineering practice.

References

Auerbach, C., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*. NYU press.

Bransford, J. D., Brown, A., & Cocking, R. (1999). How people learn: Mind, brain, experience, and school. *Washington, DC: National Research Council*.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32-42.

Chi, M. T. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The journal of the learning sciences*, *14*(2), 161-199.

Chi, M., & Roscoe, R. (2002). The processes and challenges of conceptual change. *Reconsidering conceptual change: Issues in theory and practice*, 3-27.

Elby, A. (2001). Helping physics students learn how to learn. *American Journal of Physics*, *69*(S1), S54-S64.

Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET). (2016). *Criteria for Accrediting Engineering Programs, 2016-2017,* Baltimore, United States.

Engineers Australia. (2016). Stage 1 Competency Standard for Professional Engineer. Accessed August 27, 2017 at <https://www.engineersaustralia.org.au/sites/default/files/shado/Education/Program%20Accreditation/110318%20Stage%201%20Professional%20Engineer.pdf>

diSessa, A. A. (2002). Why “conceptual ecology” is a good idea. In *Reconsidering conceptual change: Issues in theory and practice* (pp. 28-60). Springer Netherlands.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American journal of Physics*, *66*(1), 64-74.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences*, *12*(1), 53-90.

Ivarsson, J., Schoultz, J., & Säljö, R. (2002). Map reading versus mind reading. In *Reconsidering conceptual change: Issues in theory and practice*(pp. 77-99). Springer Netherlands.

Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics*, *73*(4), 372-382.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational research*, *63*(2), 167-199.

Säljö, R. (1999). Concepts, cognition and discourse: From mental structures to discursive tools. *New perspectives on conceptual change*, 81-90.

Sinatra, G. M. (2005). The" warming trend" in conceptual change research: The legacy of Paul R. Pintrich. *Educational psychologist*, *40*(2), 107-115.

Streveler, R. A., Litzinger, T. A., Miller, R. L., & Steif, P. S. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education*, *97*(3), 279-294.

Streveler, R., Brown, S., Herman, G., & Montfort, D. (2014). Conceptual change and misconceptions in engineering education. *Cambridge handbook of engineering education research*, 83-102.

Acknowledgments

This material is based upon work supported by the National Science Foundation under grant number 1361107 and 1642022. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.