Exploring How Knowledge is Categorized within Engineering Practice

Abstract: *Describing how knowledge is used on interdisciplinary projects differs between cognitive scientists and academics. This study aims to explore how knowledge is categorized by practicing engineers in the context of an interdisciplinary engineering project through the use of phenomenological interviews with practicing engineers. Findings suggest that engineers classify knowledge based on requirements and how these shape their responsibilities. While this method of classification has overlap with academics use of the construct "disciplines" and cognitive scientists' use of the construct "domains," dissimilar aspects could impact how knowledge is accessed and utilized in the future by students in engineering programs.*

Context

Interdisciplinary engineering projects require a vast amount of knowledge spanning multiple disciplines and fields. How to describe the knowledge used on projects differs between cognitive scientists, who tend to use the construct "domain," and academics, who tend to use the construct "discipline." But little is known about the impact of how knowledge is studied (domains) and taught (disciplines) on students and how this translates to knowledge use in engineering practice. Therefore, this work focuses on understanding how knowledge is categorized in engineering practice as a way to identify challenges students might face when transitioning between these different frameworks.

Further supporting our work here has been research conducted by Schoenfeld (1991) who found that students and practitioners used math formulas in very different ways. This suggested that students could be successful in school but lack the ability to use a domain's conceptual tools in practice. Similarly, we are interested in what ways engineers categorize knowledge and how this differs from the way engineering is taught. This has implications on students who are transitioning to the workplace and could limit their ability to apply knowledge learned in an academic setting to the work setting.

Cognitive science research suggest that human knowledge is specialized and tied more directly to specific domains (Hirschfeld & Gelman, 1994). For this research, we define a domain as a cluster of facts, processes, and concepts that are grouped together based on a common them to form high level and abstract thinking. Though it is important to note that there is no consensus within the field on what constitutes a domain, how to identify them, or how many there are (Hofer & Pintrich, 1997). Domains then become a way to describe the order and grouping of knowledge but may hinder our understanding of categorization as it utilizes terminology that differs from the terminology used by the population of interest.

From an academic standpoint, we see disciplines as conceptually and administratively different units with some connectedness and interrelationships. For example, Chemical and Mechanical engineers are two different disciplines but both take courses in thermodynamics. While these courses both have the same name, they have a difference in emphasis as Mechanical engineers learn about machinery and Chemical engineers learn about reactions.

We approach this work from a situative perspective by interviewing engineers about real-world interdisciplinary projects that they are currently involved in as we believe knowing and doing are interlocked and inseparable (Brown, Collins, & Duguid, 1989).

Purpose

The purpose of this study is to explore how knowledge is categorized by practicing engineers in the context of interdisciplinary engineering projects.

Methodology

Phenomenological interviews were conducted with engineers representing different areas of knowledge involved in two different interdisciplinary project. The first project focused on designing a machine that would make remote measurements. The second project involved the design of a water treatment system to treat contaminated ground water. Overall, the projects required significant and ongoing interaction between the engineers in an effort to meet all of the project requirements.

This paper draws from four of the interviews conducted, 2 from each project. Interview questions were designed to explore how the engineers thought about knowledge and how their knowledge related to the knowledge of others on the project. Interviews lasted on average 50 minutes and were audio recorded and transcribed. Analysis occurred in Dedoose and was guided by how engineers talked about knowledge in relation to other engineers on the project (Dedoose, 2017).

Relevant text was identified within the interviews, marking anytime the engineers spoke about their work in relationship to other aspects of the project (Auerbach & Silverstein, 2003). Next, we inductively coded the relevant text before sorting codes into categories. From there, we identified a common theme and came up with the claim presented in the next section.

Findings and Discussion

Claim: Engineers primarily discuss their design in terms of external requirements and how these requirements shape their responsibilities.

When looking to see how engineers talk about their work in comparison to other project components, we found that engineers primarily interacted in terms of how their design has been impacted by other project components and has t.

> *Yeah it is [the mechanical engineer's] job to make sure the thing fits into the structure appropriately. He is the one that said I want you to put screw holes there if you can because that is where it is going to attach to the overall spacecraft. ~Propulsion Engineer*

In the above quote, we see that based upon the mechanical engineer's responsibility to design the container, he had to relay specific instructions on where the propulsion engineer needed to include screw holes in order to attach the propulsion system to the container. We see here how the design responsibilities of one system (ensure everything fits securely inside the container) instigated an interaction with another subsystem in terms of a necessary requirement (placement of screw holes). It is important to note that the engineer here made no mention of *how* he was going to fulfill this requirement, only that the requirement was placed on him by another system. A similar notion was echoed by a mechanical engineer.

> *So there are lots of input from other team members on kind of non-physical requirements and stuff and I have to somehow turn that into a physical manifestation that fits within a volume constraints, and mass constraints of the mission. ~Mechanical Engineer*

Here the mechanical engineer was referring to how interactions with other subsystems, including non-physical requirements, must be translated into a "physical manifestation" in order to fit within his given set of constraints. These outside requirements partially drove the design and influenced how the engineer worked within his own constraints. Though the engineer never mentioned *how* he would do this, he simply focused on the idea that it was his responsibility to figure it out. This idea is clearly evident in the following quote by the same engineer.

> *…how are we going to verify the fused manifold process? Does it have an impact on biocompatibility? Every design that I produce for the bio team, has a review with the scientists where they really pick at the materials, the surface finishes, the processing, all that sort of stuff that is related to that. ~Mechanical Engineer*

Not only do we see the mechanical engineer working within their own system constraints to verify the fused manifold process (can it withstand the forces it will be subjected to), he was regularly interacting with other subsystems (biology in this example) in an effort to meet set requirements, in this case, the requirement for the fused manifold to be biocompatible. These requirements, while not always explicit from the beginning of the project, helped shape what the engineer was ultimately responsible for designing and creating.

Engineers only vaguely and indirectly referred to the content knowledge necessary to fulfill their project responsibilities.

> *So I have had to go back, I mean I took those classes eons ago, so I had to go back and refresh my memory about how they all worked. ~Propulsion Engineer*

The Propulsion Engineer was discussing the use of a new technology and how they had to refresh their memory about the concepts that drove the system. Overall, the engineer exhibited little concern about his ability to understand and re-learn the material but instead placed a greater emphasis on how his system interacted and affected other systems.

Engineers on another engineering project also described similar interactions with the other engineers on the project.

> *We have a sanitary sewer connection here. For gravity, sanitary sewer is all gravity flow. You have to have the right slope and you need to have the right elevations. You have to have enough size of your pipe and slope of your pipe to make it all work. It takes a lot of coordination to make sure that you can get the flows you want to the existing sewers. ~Mechanical Engineer*

Here we see the engineer talk about the coordination of getting the right flow of water to the sewer. This is dependent not only the aspect of the project he is responsible for (sizing of the pipes) but also coordinating with other systems (like civil engineers for the slope of the pipe) in order to meet an overarching goal of the project (discharging treated water to the sanitary sewer). Therefore, his responsibility of sizing pipes required him to interact with other systems to ensure correct flow. Again, we see the emphasis placed not on the content knowledge necessary to achieve the correct flow but instead on the shared responsibility of ensuring correct flow is achieved.

We also see how a change in design from one system can impact the requirements of another system which requires communication.

> *We have weekly design meetings where we sit there with all the discipline leads and say, "Okay, this is what we're working on, these are our challenges, we're changing this over here, we're adding a pump here, and then electrical needs to know, "Oh, you're adding a pump, I need to route power to that and make sure we have enough power for it and so and so*

forth." There's a lot of interdisciplinary coordination that goes on…
~Environmental Engineer

The above quote demonstrates how changes in one system are a focal point of interaction with other systems. We see in this quote how the addition of a pump spurs an interaction between the pump people and the electrical engineers because the pump people have set a new requirement for the electrical engineers (the need for additional power and routing of power). This demonstrates how changes in one system translates to a change in requirements and responsibilities of another system.

In the next example, we see how the environmental engineer laid out a general plan that outlined a set of requirements before communicating with the necessary systems.

Just rough sizing of equipment and having an idea of the site layout and say, "Okay, I think the equipment should go here," and just in general and that type of thing. Then I work with our civil engineer and what not to lay out the site and our architect and our structural to lay out the foundation and all that kind of stuff, but our... Typically I'll get involved and determine the bigger scale decisions and concepts of, "Here, this is what I think we need, and how to do it," and then I let our discipline engineers run with that and do the calculations and the sizing and talk to the vendors and that kind of thing. ~Environmental Engineer

The environmental engineer had a solid idea of the requirements of the project and was able to sketch a rough plan before relying on the individual engineers to do the detailed work. Here, we see how project requirements trickled down to individual system requirements and was used as a form of communication between the different engineers on the project. The engineer here talked in terms of what the different engineers would be *responsible* for doing such as the structural engineer to lay the foundation and others to "do the calculations." The emphasis is again on what the engineers are responsible for designing and creating and only a vague reference of *how* they are going to do it (with calculations).

Conclusion

Overall, we see through the above examples how engineers interact in terms of system requirements and how these requirements then shape the engineering design. Engineers place importance on their responsibilities and the resulting requirements and less on the discipline-specific knowledge necessary to complete their design. This was demonstrated in the examples above and echoed throughout the other interviews as well.

A common thread within the examples above is the idea of responsibility and how this dictates what an engineer is assumed to know or has the ability to figure out. The idea of responsibility being a marker of content knowledge has been found in other interdisciplinary project settings when engineers were presenting their work (Authors, in-press). This is interesting because we see engineers' work being divided and driven by their responsibilities and not by the discipline organization set by educational institutions. This suggests that when students choose an engineering discipline, it is less constraining and concrete than originally thought. Instead, the space between disciplines, in terms of the ability to fulfil responsibilities, is more plastic and transferable (with adjustments) to other engineering disciplines and fields.

Students are often taught the discipline-specific knowledge with little focus on system interactions. The findings presented here are further evidence that organizing people based on their academic discipline does not accurately reflect how engineering practice is organized. As engineers continue to work on larger and more detailed interdisciplinary projects, it is important to understand how they utilize knowledge on these projects. This is especially important from an academic standpoint as many people believe that engineering education is geared towards preparing students to work in industry. Therefore, to ignore how engineers actually work and organize in practice, could hinder the transition for students to the workplace.

Recommendations/Implications

In many ways engineering education is seen as a way to prepared students to work in industry. But the way academic setting categorize disciplines compared to where engineers place emphasis is disconnected. Therefore, we suggest research should work on identifying ways to better align these two practices. Additionally, the findings here can be used within industry as a way to better understand and prepare for new hires who have recently graduated.

Alternative Explanation

Our research design and analysis procedure could have directly influenced our finding but the finding presented here was not one of the original research questions and so we did not initially go into this study looking for what we found. Additionally, our interview questions were vague and open-ended so we did not prompt the engineers' organization of talking. Additionally, it seems unlikely that participants routinely answered using similar constructs throughout a 50-minute interview if this is not how they normally talk and organize their thoughts. There is a possibility that the projects we studied were unique and so everything we found is unique to these projects only but that seems unlikely since both projects were drastically different in content and purpose.

Future Research Plans

Future research plans aim to identify the knowledge domain of practicing engineers and engineering students. Defining the knowledge domain of these two groups will assist researchers in understanding in what ways engineers and students differ in their categorization of knowledge. Implications for this include how students are taught engineering and refocusing on linking concepts that are most widely utilized in practice.

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