Epistemography and Professional CSCL Environment Design

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Abstract: This study uses the epistemographic method to examine how professionals link ways of doing, thinking, and knowing in an epistemic frame that guides their reflection-in-action, which can inform the design of professional computer supported collaborative learning (CSCL) environments. This study examines student engineers learning design in a co-op program at a manufacturing company to investigate how participant structures, activities, and pedagogies are connected to an epistemic understanding of the profession. The analysis describes the significant participant structures in the engineering co-op program and the pedagogical techniques that are used in these participant structures. The analysis suggests that participant structures and pedagogical techniques are both orchestrated by and orchestrate the development of one of the central epistemological features of collaborative engineering design. These results suggest that epistemographic analysis is a useful tool in the development and analysis of professional CSCL environments.

Keywords: epistemology, reflection, participant structures, design, engineering, practicum, professional

Background

In this paper, we examine the method of *epistemography* as a tool for analyzing collaborative problem solving—and this as a tool for developing computer supported collaborative learning (CSCL) environments based on real-world collaborative learning environments. To do this, we conduct an epistemographic analysis of an engineering practicum.

Collaborative work on complex problems is a fundamental aspect of engineering. Most problems that engineers address are ill-structured, meaning there are many acceptable solutions and no definitive procedures to follow to produce or determine a best solution (Cross, 1994; Dym, 1994). In order to understand how professionals manage ill-structured problems, Schön (1987) argues that professionals work by accessing a “repertoire of examples, images, understandings, and actions” (p. 66) that ranges across various design problems and finding a comparable situation to the problem at hand. Schön (1987) calls this method *reflection-in-action*: a way that professionals adapt to unexpected situations that arise in design problems without interrupting the flow of activity in progress. But not all problems in engineering—or in any ill-structured domain—are open-ended in this sense. Some problems do have known solution pathways, and thus part of professional reflection-in-action also has to include the ability to recognize and solve well-formed problems.

How, then, do engineers learn the forms of reflection-in-action that characterizes their profession? Decades of research in the learning sciences shows that learning to engage in a practice, such as engineering, is a social and situated process (Anderson, Herbert, & Simon, 1997; Bandura, 1986; Lave & Wenger, 1991). It requires initiation into a community of practice—a group of people who share ways of working, thinking, and acting in the world (1999).

In professional communities of practice, novices engage in a professional practicum where they participate in the practice under the guidance of senior practitioners, or mentors (Schön, 1987). In engineering professional practica, students learn to solve design problems by engaging in actions within the practice environment. In some practica, the student is asked to start designing before he even knows what designing means. (Schön, 1987; Shaffer, 2007b). Reflective discussions between mentor and student can occur within different participant structures—different “patterns of involvement that structure a particular kind of situation within a given practice” (Shaffer, 2005, p. 7). For example, Schön argues that there are several possible combinations of who is doing the acting and who is doing the reflecting. A mentor may demonstrate a task, and a student may watch and reflect upon the mentor’s demonstration. Conversely, a student may produce a design drawing that the mentor critiques. In Schön’s work, these forms of reflection-on-action are treated as variations on a theme, but without a taxonomy or distinction as to when one or the other form might be preferred or should be used.

Shaffer (2007a) has characterized the learning that occurs in participant structures within a practicum in terms of an epistemic frame—collections of skills, knowledge, identities, values, and epistemologies that are connected in specific ways. Epistemic frame theory suggests that professionals rely on domain-specific skills and knowledge to make and justify decisions. They have characteristics that define their identities as members of the group, as well as a set of values they use to identify important issues and problems in the field. From this perspective, developing an epistemic frame means making a network of connections between these skills, knowledge, identities, values, and epistemological elements that are characteristic of the community. For example, in the engineering epistemic frame, an engineer might make a design decision to increase the safety factor of a product for the wellbeing of the client based on a completed stress analysis. In this case, the engineer is justifying the design decision by valuing the safety of the client and executing the skill of completing a stress analysis. She knows which values to consider and what information and skills to gather in order to make a design decision. Thus, one goal of a professional practicum is to build an epistemic frame.

The development of students' epistemic frames through such experiences can, in turn, be quantified using *epistemic network analysis* (ENA) (Shaffer et al., 2009). Because the learning that takes place during a practicum can be characterized by the connections between elements of a professional frame, ENA measures when and how often students make such links during their work. ENA creates a network model in which the nodes of the network represent the skills, knowledge, identity, values, and epistemology from a domain. The links between these nodes quantify how often a person has made connections between these elements at some point in time. In this way, ENA models the development over time of a student's epistemic frame—and thus quantifies their ability to think and work like professionals.

Investigating the epistemic frames of professional practices involves conducting an *epistemography*, an ethnographic analysis of the structure of a professional practicum through the lens of epistemic frames (Bagley & Shaffer, 2010; Hatfield & Shaffer, 2010). For example, Nash and Shaffer (2013) investigated the field of game design where the observed students and mentors interacting in a studio-style practicum. By examining the significant participant structures in the practicum, their analysis revealed a particular form of epistemic mentoring that mirrored a coaching model where mentors and students took indirect and unexpected path during the learning process. In general, epistemographies focus on participant structures of reflection and the overarching epistemologies that guide those structures.

In this study, we look at how an examination of the epistemological underpinnings of a professional practicum shed like on the pedagogical process of learning through reflection-on-action described by Schön (1987). In doing so, we argue that such epistemological inquiry is a useful tool in the development and analysis of CSCL environments.

The environment we analyze is an engineering co-op experience for college students. This study uses the epistemographic method to examine how professionals link ways of doing, thinking, and knowing in an epistemic frame that guides their reflection-in-action in ways that can inform the design of CSCL environments. More specifically, this study examines student engineers learning design in a co-op program at a manufacturing company to investigate how participant structures, activities, and pedagogies are connected to an epistemic understanding of the profession. We do this by addressing three research questions:

1. What are the significant activities in the engineering co-op program?
2. What are the participant structures of reflection that are used in those activities?
3. How do the participant structures of reflection relate to the epistemologies of the engineering co-op?

Methods

Participants, setting, and data collection

GammaCorp is a global engineering company that designs and manufactures high pressure hydraulic pumps and industrial tools. This study was conducted at a GammaCorp company branch and focused on two students who were new to the co-op at the time of the observations, including Kate, two students who had been in the program for several months at the time of the observations, including Noah and Amir, as well as six senior engineers who interacted with the students at various times, including Allen and Robin. All names used here are pseudonyms, and no demographic information was collected about the participants.

Data was collected in two forms: observations and interviews. A researcher was present as an observer for ten days from June to August. This included two project management meetings and seven meetings between engineers and students. Observational data was collected data in the form of audio recordings and field notes. Interviews were conducted with the four students and two engineers.

Data analysis

Observations and interviews were segmented into utterances—every time a participant took a turn to speak during a conversation. Using a grounded theory approach (Glaser & Strauss, 1967) a coding scheme was developed representing activities, pedagogies, and the key knowledge and epistemological stances of the co-op:

- **Problem Solving:** Development of a solution to a technical issue as part of an engineering design
- **Documentation:** Completion of forms and other written documents describing a design
- **Feedback:** A critique about a design artifact or design idea or an informative or corrective suggestion.
- **Modeling:** Using a tool or exemplar to demonstrate a task or idea.
- **Customer Knowledge**: Referring to the customer
- **Technical Knowledge:** Referring to technical or mathematical concepts.
- **Epistemology of Translating Customer Requests to Technical Requirements:** Describing engineering design in terms of using technical knowledge to address the customer requests
- **Epistemology of Translating Technical Requirements to Customer Requests:** Describing engineering design in terms of explaining technical requirements and details of the design to the customer

Two types of activities were identified: problem solving and documenting. Two main types of pedagogies were identified: feedback and modeling.

Epistemic network analysis (ENA) was used to investigate the underlying relationships among the activities, knowledge, and epistemologies of engineering as expressed by participants in interviews and observation. ENA has been described in greater detail elsewhere (Shaffer, 2014; Shaffer et al., 2009), but in brief, ENA models coded data by grouping the utterances (in this case answers to interview questions for a given participant) and producing an adjacency matrix for each utterance to determine which codes are linked (that is, which ones co-occur).

To identify patterns of connections in the data, ENA sums the adjacency matrices for each participant u into a cumulative adjacency matrix, C^u, where each cell C^u_{ij} represents the number of stanzas in which a codes i and j were both present. These cumulative adjacency matrices are then converted into network graphs in which each node corresponds to a code from the coded dataset and lines connecting nodes represent co-occurrences of codes in the data. Thicker lines correspond to stronger connections in the data between elements of discourse in the model.

Results

The results of this study are described in three parts below. First is a description of the two main activities of the co-op: problem solving and documenting. Second is a description of the two main pedagogical methods of the co-op: feedback and modeling. Finally, we examine the relationship between the activities and the pedagogy through the lens of a key epistemological element of the engineering practice.

Activities

The design work of co-op students at GammaCorp consists of two main activities: problem solving and documentation.

Problem solving

During the problem solving process, students attempted to meet the requests of the customer by either designing a unique solution or modifying previously made solutions. For example, midway through Amir's program after he had some experience working at the company, he was asked to design a tow cart that would house a variety of tools. When Amir received the task, a sales representative at the company had "quoted it out" to the customer. This meant that the customer already had an idea of how much the product would cost and had explained to a sales representative what he expected from the product. Amir received the quote and the customer's requests, which gave him an approximate budget and some direction on which parts to use to design the cart. Amir summarized the requests, "They want this design pump. They want it to be a six-point lift system with all these full controls. They want to be able to store this all on this cart. They want storage for these hoses. And they want to be able to lift it and drive it around a shipyard."

When Amir received this information, he approached Allen, one of the senior engineers, to get more information on what his first steps should be. Allen explained that Amir had to find a way to build and design the cart using the CAD drawing tool. Allen suggested that instead of trying to design the final product, Amir should first complete a minimal and basic design. Amir could then ask for feedback on the simple design, and then complete several iterations to design the details of the final product. Allen and Amir worked together on sketching some basic designs and discussed how the parts could potentially fit together. When Amir returned to his desk to work on designing the tow cart, he began by reviewing the sketches that he and Allen had made. After some trial and error with the CAD program, Amir figured out which pieces he could mount together and how they would fit collectively.

One week later Amir had a preliminary design, as Allen had suggested. He printed out the drawings and asked some engineers for feedback. Unfortunately, it did not go as well as Amir had expected. "They railed me on everything," Amir laughed as he recalled the meeting. For example, he had some hoses sticking out in many different places on the tow cart, which blocked the customer's access to the controls on the cart. The engineers asked that Amir make several changes and present the design to them once the changes had been made.

One week later, Amir showed the engineers a second design. This time the engineers asked Amir to make only minor changes. Once those minor changes were made and approved, Amir could finalize the design to send out to the customer.

Documentation

Once the customer approved the design, Amir had to document his work. First, he completed a part release form that released all the parts into the manufacturing system. This form ensured that the manufacturing line could produce and assemble all the parts needed for his tow cart product. Amir explained the importance of this documentation stage:

> Basically anytime that we have anything new that is designed or a design that is based off of a part, we need to release a new part into the system with all the correct coding, cost information. We've got to get that all coded and get that released into our system, so that orders can be made. It can be a hassle, but it's something we need to do, need to be able to document everything that happened with it.

Next, Amir completed a *product requirements document* (PRD), which is a document that describes the specifications and functions of a product. The PRD also includes instructions for assembly or operation. After the product was assembled, he went down to the manufacturing area to take photos of the product. He wanted to file the photos so other engineers could see a final version of the product or use the photo to show future customers, in case another customer wanted to order something similar.

While this process was relatively smooth for Amir's cart design, co-op students often needed help completing this part of their work For example, one month into the program, Kate had some difficulty with documentation for a customer's order: She didn't know what product numbers she should use. She thought she needed an "M" product number, but she didn't know how to find the right number. One of the more senior co-op students, Noah, tried to help, but he didn't know either. So Kate sent an instant message to Robin, one of the senior engineers.

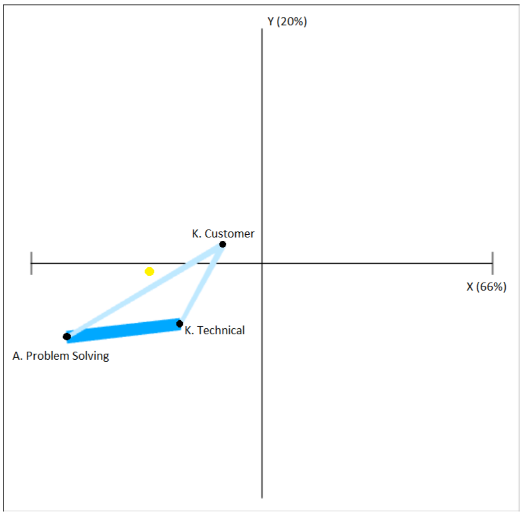
When Robin arrived, she examined the documentation on Kate's the computer. Noah said that he thought they were supposed to release the "M" parts for manufacturing. Robin explained that there were two forms of documentation to complete because there were two parts of the design that needed to be documented. Then she leaned over the computer to use the keyboard and showed Kate and Noah how to complete the documentation. Kate asked several questions about how to document, and Robin responded by showing her what forms to use and where to find the part information to complete the documentation.

Participant structures of reflection

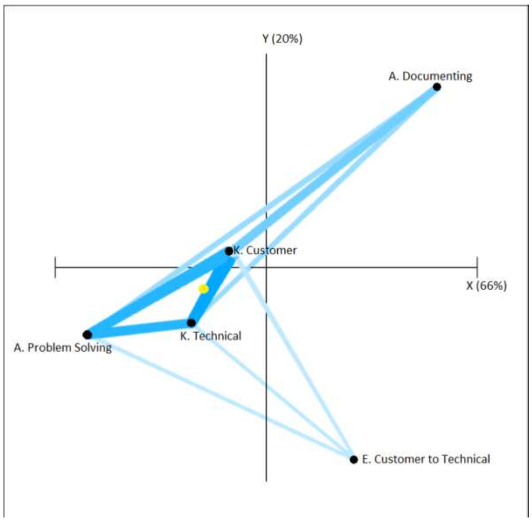
The examples in the previous section of the results show two distinct forms of activity in the co-op, each of which is a form of reflection-on-action:

In the problem solving activity, the *student* (Amir) engaged in action by creating a design artifact. He presented this artifact to his mentors, who reflected on the student's action by providing feedback. In other words, in this example of problem solving, the main form of reflection-on-action was the *mentor reflecting on student action*.

In the documentation activity, the students (Kate and Noah) initiated the meeting with a mentor. But then the *mentor* took action by completing the appropriate forms while the students watched. The students then reflected on the mentor's action by asking clarifying questions. In this example of documentation, the main form of reflection-on-action was the *student reflecting on mentor action*.



Kate: Novice Co-op



Amir: Experienced Co-op

Robin: Senior Engineer

Figure 1. Epistemic Network Models for Co-op students and Engineers

This pattern of association between activity and pedagogy was true generally throughout this practicum. Student reflection on mentor action occurred mainly during documentation and mentor reflection on student action occurred mainly in problem solving activities (see Table 1; difference significant using Fisher's Exact Test at $p < .01$).

Table 1: Number of times feedback and modeling were used in problem solving and documenting

	Feedback	**Modeling**
Problem Solving	6	0
Documenting	1	14

Epistemology

The epistemologies of translation

This part of the results section explores the epistemological foundations of engineering design as practiced at GammaCorp that may explain this correspondence of activity and the participant structures of reflection. Specifically, we note that a critical element of engineering thinking at GammaCorp is the *epistemology of translation*, which appears in two forms: *translation of customer needs into design specifications*, and the reciprocal *translation of the resulting design specifications into a form understandable by the customer*.

First, we note that the development of these epistemologies of translation is a key component of professional expertise. ENA models of participant interviews about their practice show progressive integration of the epistemology of translation between customer and the technical space of design and also the epistemology of translation back from the technical aspects of a design to customer as engineers become more advanced in their training.

Three of these networks are shown in Figure 1 above. These models suggest that both novice and experienced students made fewer connections to the epistemologies of translation than senior engineers. For example, Kate described the importance of technical knowledge and customer knowledge while problem solving, but never connected these skills and knowledge to an understanding about why engineers work in the way they do:

> There is this big piece of equipment, and they need to something to sit on, because they just have to mount some wood.

Amir, a more senior student, made strong connections in his network between problem solving and technical knowledge and customer knowledge. However, he also connected this knowledge to the epistemology of translating the technical design into a form understandable by the customer:

> A big part of this was going to be that *I wanted to have the customer be able to operate everything* on this Tow Cart standing from one point.

Robin, as a senior engineer, had a network with more robust connections to the epistemologies of translation than either of the students. Further, Robin's network shows that the activity of documentation is very closely connected with the epistemology of translation from the technical world of design to the customer.

Differences between the epistemologies of translation

The processes of *translation from customer to design* and *translation from design to customer* both exist within the ill-structured world of design. However at GammaCorp, the process of translation from design to customer is a relatively constrained activity within the broader design process. The actual product is already designed. The task that remains for the engineer at GammaCorp is to communicate the salient details of design to the client through the company's documentation software. In the first week of the co-op program, students attended a training session on how to use the documentation tools. This training took place in a classroom setting; an engineer distributed a manual, projected the software tool on a screen, and reviewed the manual page by page. Afterwards, students completed exercises in the manual. The epistemology of translation from design to customer is algorithmic: there is a specified process to follow. Determining which process to use may be complex, but the process itself follows clear guidelines. As Noah, one of the student co-ops, described it: "It's pretty... it's not like it's confusing, but it is at the same time."

In contrast, when students engage in problem solving, there are few clearly defined procedures. There were no manuals or training classrooms at the beginning of the co-to teach students to solve design problems. Instead, students were given a broad task to accomplish and came to the more senior engineers for feedback. For example, Amir said that his work as a co-op began when one of the engineers "basically gave me a rundown of what was expected of me. Basically I had to create an ID drawing of everything once I had designed the frame and everything and… we should have the really basic design done before getting into too many specifics." In other words, the epistemology of translation from customer requirements to artifact design is fundamentally more ill-formed than the process of documenting the results of a design.

Discussion

Two cycles of translation

The results above suggest that design in this engineering practicum was a combination of two different cycles of action and reflection-on-action. Moreover, the participant structures of reflection in these cycles were shaped by two related but significantly different epistemologies of translation in the engineering design process.

Translating customer needs into a design

The students started with a design task and engaged in iterative problem solving in order to translate the customer requests into technical requirements. When students needed assistance with problem solving, they initiated meetings with engineers. The engineers offered feedback on the students' design. The students then continued designing until they needed assistance again. This reflection cycle continued until the engineers collectively decided that the students had designed a solution that met the client's requests. But a fundamental property of the problems solving process was epistemological: there was no clear right answer or even single best way to go about developing an answer. The epistemology of translation from customer requirements to finished design was ill-structured, and the reflection-on-action in this context was structured as *mentor reflection on student action.*

Translating a design back to the customer

Next, students documented the design in order to translate the technical requirements into a form that was interpretable by the customer. Similar to the problem solving activity, if students were unsure of how to document a product, they initiated meetings with senior engineers. However, in meetings that centered on documentation, engineers modeled procedures and the students asked questions. A fundamental property of the documentation process at GammCorp was also epistemological: there *was* a right way to communicate the relevant features of a design to the client using GammaCorp's documentation tool. The epistemology of translation from customer requirements to finished design was relatiely well-formed, and the reflection-on-action in this context was structured as *student reflection on mentor action.*

Engineering design translation cycle

In other words, this epistemographic analysis of an engineering co-op suggests that at GammaCopr there was a relationship between forms of activity and forms of reflection that can be explained by differences in the epistemologies that guide both. There are two independent reflection cycles within the larger design process. This model, which we describe as the Engineering Design Translation Cycle (Figure 2), exemplifies a particular method of thinking about engineering design.

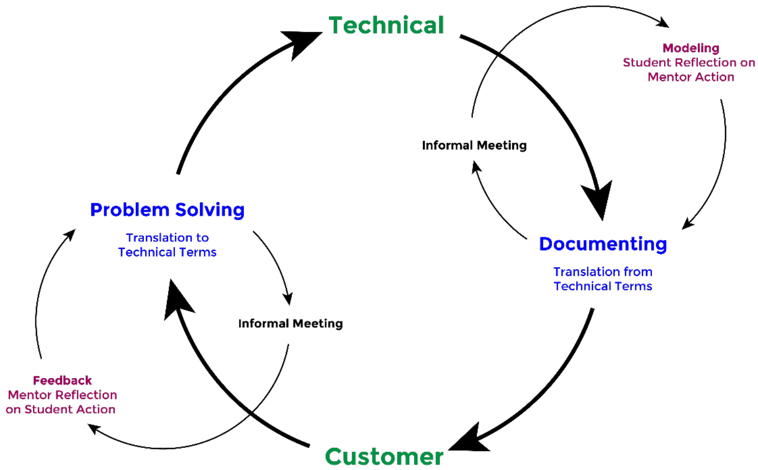


Figure 2. Engineering design translation cycle

The two forms of reflection-on-action—mentor reflection on student action and student reflection on mentor action—help students develop an epistemic understanding of translation between the customer and technical world. But importantly, one form of reflection—mentor relfecion on student action—is associated with problem solving in design, an activity grounded in the epistemology of translation from customer requirements and the technical world of design, a decision-making process that is open-ended and ill-formed. Students are encouraged to explore the design space and get feedback from their mentors. The other form of reflection—student reflection on mentor action—is associated with documentation, an activity grounded in the epistemology of translation from the technical world of the design back to the language of the customer, a decision-making process that is relatively well-formed. Students are encouraged to watch a mentor enact the correct procedure and ask questions to generate and confirm understanding.

Implications

There are several key implications of this study for the CSCL community.

First, this work suggest that in collaborative learning contexts such as a practicum in ill-structured domains like engineering design there may well-formed activities that need to be accounted for in any learning design. Second, this work extends Schön's characterization of the participant structures of reflection-on-action. It suggests that forms of reflection-on-action may be driven by the epistemological nature of the action being reflected on. In particular, in the case in question, mentor-reflecting-on-student-action was associated with ill-formed tasks, whereas student-reflecting-on-mentor-action was associated with more well-formed activities in the domain. These results have clear implications for any CSCL application designed for ill-structured domains where learning is characterized by cycles of action and reflection-on-action.

More broadly, though, this study suggests that the process of epistemography—the analysis of the epistemological features of a learning environment—is a useful tool for uncovering the rationale behind the participant structures of reflection, and perhaps of pedagogy more generally. Thus, epistemography—and its associated theory of epistemic frames and analytical method of epistemic network analysis—is a useful tool in the development and analysis of collaborative learning environments.

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