Board 133: ”This Seems Reasonable”: Using Epistemic Cognition and Metacognition to Justify the Reasonableness of Solutions in Senior Design

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Abstract

This work in progress paper focuses on a study to investigate how senior capstone design students use metacognition and epistemic cognition to determine the reasonableness of solutions presented by their teams. There is significant research that points to the importance of understanding how epistemic cognition and metacognition play a role in problem solving. More recent research has begun to point to the need to study epistemic cognition and metacognition together, as metacognition and epistemic cognition may develop in a similar developmental progression. Specifically, metacognition may lead to skill development in well-structured problem solving and epistemic cognition may lead to skill development in ill-structured problem solving. As undergraduate engineering curricula are built upon both well-structured and ill-structured problem solving, it is critical that the field of engineering education begin to study in-depth the impact that both metacognition and epistemic cognition have on the development of the engineering mindset. Senior capstone design is a primary opportunity where engineering students begin to translate the skills they have developed in courses that focus on well-structured problems to situations with ill-structured problems.

This research study focuses on understanding how students use metacognition and epistemic cognition to justify the reasonableness of their solutions in senior design, both internally (to other team members) as well as externally (to advisors, industry representatives, and customers). Participants of the study include civil engineering students enrolled in a senior capstone design course at a large, public, R1 institution in the southeast.

This work in progress will discuss the early stages of development of this research study, which includes the design of an ethnographically informed research methodology using participant observations, ethnographic interviews, and stimulated recall interviews. These methodological selections will be justified based on the challenges associated with studying metacognition and epistemic cognition in a situated context. The paper will conclude with a summary of data collected for the pilot study as well as next steps for the full study.

Background

Senior design is the capstone experience for engineering students that gives students the opportunity to participate in an authentic engineering design experience. The specifics of these experiences look different across engineering disciplines and institutions. Through these design projects students have the opportunity to apply their technical content knowledge and hone their communication, teamwork, and problem-solving skills. Given the nature of senior design courses, they offer an opportunity for engineering programs to integrate the outcomes of ABET criteria [1]. In contrast to much of the undergraduate curriculum, the problems that students work on in senior design tend to be more ambiguous, require the consideration of multiple tradeoffs, and have no 'right' answer. As such, engineering design problems require individuals to make decisions about what counts as knowledge by assessing various sources of information, balancing constraints, and evaluating alternative solutions. These acts can be grouped together as epistemic cognitive processes and require individuals to reason "about specific information, knowledge claims, and sources" [2]. This reasoning is influenced by a number of factors including an individual's epistemic beliefs (beliefs about the certainty, source, and simplicity of knowledge) and their need for cognitive closure (closed-mindedness and discomfort with ambiguity) [3-5]. Senior design also requires students to review strategies and knowledge they have acquired throughout their academic coursework and determine what is applicable in the context of their senior design courses. Students must also determine what knowledge they lack and develop strategies for gaining knowledge and strategies to complete and present their design. Metacognitive knowledge and skill are critical to this type of open-ended design work [6].

There is significant research that points to the importance of understanding how epistemic cognition and metacognition play a role in problem solving and learning difficult conceptual material [5-8]. More recent research has begun to point to the need to study epistemic cognition and metacognition together, as metacognition and epistemic cognition may develop in a similar developmental progression [2, 9]. Specifically, metacognition may lead to skill development in well-structured problem solving and epistemic cognition may lead to skill development in ill-structured problem solving [5]. As undergraduate engineering curricula are built upon both well-structured and ill-structured problem solving, it is critical that the field of engineering education begin to study in-depth the impact that both metacognition and epistemic cognition have on the development of the engineering mindset. To date, very little research in engineering education has focused on the development of either metacognition or epistemic cognition. Further, there is no research in our field that focuses on understanding the development of and the connections between metacognition and epistemic cognition.

The goal of this project is to explore the decisions and processes civil engineering students use during their senior design projects to understand how students assess the reasonableness of their work.

Theoretical Framework

For this project, we will be drawing from two theoretical constructs -- epistemic cognition and metacognition. In the following section, we will first describe epistemic cognition and metacognition separately. Next, we will discuss the construct of epistemic metacognition that looks at epistemic cognition and metacognition in combination. This discussion is followed by a section that discusses the value of studying epistemic metacognition in the context of engineering.

Epistemic cognition

Epistemic cognition concerns how people acquire, understand, justify, change, and use knowledge. It is distinct from cognition because the focus of epistemic cognition is on the construction and justification of knowledge, understanding, and/or true beliefs. The study of epistemic cognition emerged with Perry's [10] study into the cognitive and ethical development of male student at Harvard. This qualitative, longitudinal study established a developmental framework of nine positions that characterize students' epistemological views from simple to complex. Since this initial study, the theoretical framing and terminology used within the field of epistemic cognition has evolved making it difficult for new researchers to gain a full understanding of the most recent perspectives and how theories have emerged over time. Within the field of epistemic cognition, different researchers use different terminology to represent their theoretical frameworks. These terms include epistemic cognition, personal epistemology, epistemic beliefs, and epistemic thinking. Each term represents a slightly different framing of the overall field. Within this paper, we will use the terms that are used by the researchers who developed the theoretical frameworks.

Initial theoretical frameworks to study epistemic cognition were developmental in nature, conceptualizing an individual's personal epistemology as domain general and existing on a developmental spectrum. Two such frameworks were developed by Perry [10] and Baxter Magolda [11].

Later researchers moved away from the developmental models and conceptualized epistemic cognition as a combination of multiple dimensions. Using these models researchers also began to consider how an individual's belief differ across domains. One of the most prominent epistemic belief frameworks was developed by Hofer and Pintrich [12]. This framework consists of an individual's beliefs about the nature of knowledge (simplicity and certainty of knowledge) and processes of knowing (sources of knowing and justification). Many studies using the multidimensional frameworks are quantitative in nature.

More recently, situation and context-specific models of epistemic cognition have emerged. These models suggest that an individual's epistemic cognition is dependent on situational factors, such as interest and time. One example of a situation and context-specific model is Chinn et al.'s [4] AIR Model of epistemic cognition, which places an emphasis on an individual's aim for a task and the processes used to achieve this aim.

Each type of model for epistemic cognition is marked by different underlying theoretical assumptions and perspectives that often appear counter to one another. For example, the epistemic belief frameworks conceptualize epistemic cognition as a set of beliefs and favor the use of quantitative methods, while the situation and context-specific models place an emphasis on the situational factors that impact epistemic cognitions and require deep qualitative study of individuals within relevant contexts. As such, it is important for researchers to define their own epistemologies and rationale for selecting specific theoretical perspectives.

Metacognition

Metacognition is generally known as the knowledge and regulation of one's thinking and learning processes. Metacognition is comprised of two major components: metacognitive knowledge and metacognitive regulation (see Figure 1) [13].

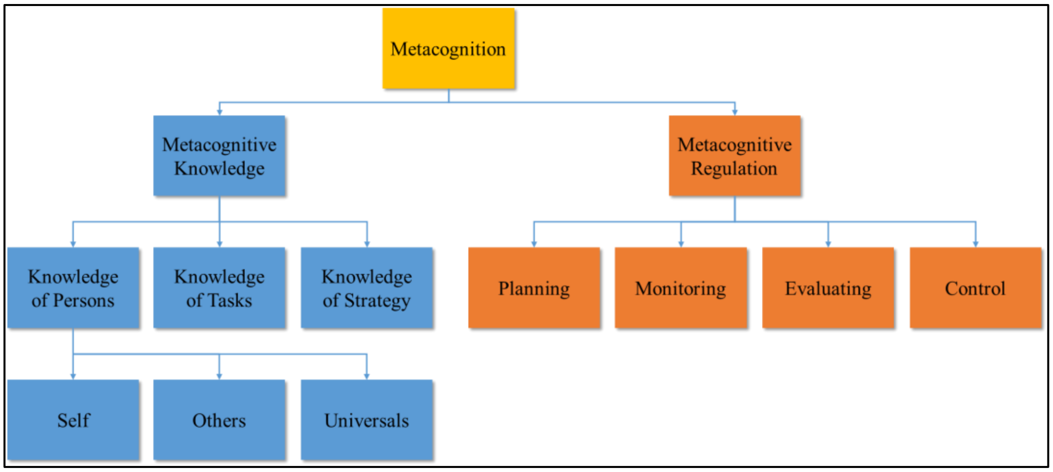

Figure 1: Taxonomy of Metacognition

Metacognitive knowledge is the knowledge that a learner holds about their learning processes. A person's metacognitive knowledge can encompass the knowledge of herself as a learner as well as the knowledge of others as learners (knowledge of persons), the knowledge held about a particular task to be engaged in (knowledge of tasks), and the knowledge of different strategies available to apply to specific tasks (knowledge of strategies). Metacognitive regulation relates to the specific skills a learner engages in during the learning process in order to make cognitive gains [14]. While there is significant debate in the metacognition community about which skills comprise metacognitive regulation, there is most agreement surrounding four specific actions: planning, monitoring, control, and evaluation. Planning involves actions taken to help the learner plan out their learning and cognitive tasks. Planning encompasses everything from gathering appropriate resources to creating a time schedule for learning to the selection of a specific environment used for learning. Monitoring involves all actions that are used to determine if the cognitive task engaged in is on track to meet the intended goal. Monitoring can involve (but is not limited to) checking progress on a particular task, checking understanding on a particular concept, and checking that the procedure currently being used will reach the intended outcome. When a monitoring action finds that a change needs to be made in order to shift back towards the intended goal, the learner engages in a control action, or an action that is taken to change current practices. Control practices can encompass finding and fixes mistakes in a problem solution, making a revising statement on the understanding of a concept, or readjusting an original plan to achieve a goal. As a task nears completion, the learner will engage in evaluation strategies in order to determine if the process used to complete a task was successful and should be stored for future use. The choice to use certain metacognitive regulation skills is directed by the task that the learning is engaging in. Metacognitive regulation skills can be conceptualized to be applied across the lifecycle of a task as shown in Figure 2, where planning occurs at the beginning, monitoring and control occur iteratively through the middle, and evaluation happens towards the end of the task.

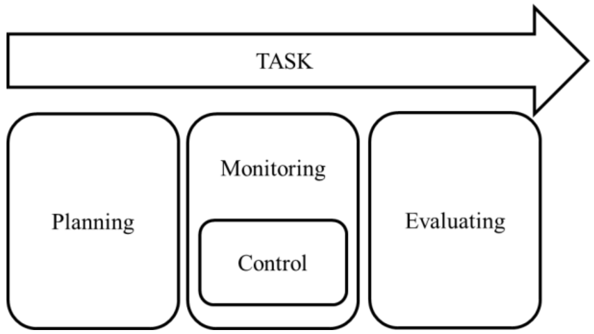

Figure 2: Lifecycle of Metacognitive Regulation through a Task

Through numerous studies, metacognition is shown to be critical to learning, especially when learning difficult conceptual material and in problem solving [15, 16]. Metacognitive ability is thought to develop starting in early childhood [17] and continuing through adolescence and adulthood, though it has also been found that metacognitive development can be taught through structured intervention [18], in both domain general and domain specific ways [19]. Methods of measurement and assessment have challenges due to the several factors. First, metacognition is a typically thought to be a non-conscious process, so it can be difficult for learners to report on their metacognitive behavior [20]. Second, researchers disagree on basic definitions of components of metacognition as well as overarching taxonomic structures of metacognition, making the development of instruments or structured interviews difficult [21]. Third, measurement methods that intervene in the thought processes of learners impact the normal metacognitive processes of the learner and thus provide inaccurate data on how learners actually perform metacognitive actions and use metacognitive knowledge [22]. Even with a number of challenges presented, the study of metacognition is critical to learning, especially in engineering where the focus is on problem solving and the learning of inherently difficult conceptual material [6, 23].

Epistemic metacognition

Throughout the study of epistemic cognition many researchers have included aspects of metacognition [2, 24, 25]. Recent work by Barzilai and Zohar [2, 9] conceptualize epistemic thinking as the combination of epistemic cognition and epistemic metacognition, reflecting the structure of non-epistemic thinking. Within the epistemic thinking framework, epistemic cognition is conceptualized using situation and context-specific models and epistemic metacognition includes the dimensions from metacognition reframed to be specific to epistemic matters. Like in metacognition, the two main categories in epistemic metacognition are skills and knowledge, while also including another category called experiences. Epistemic metacognitive skills include planning, monitoring, and evaluating processes and strategies to achieve an epistemic aim, such as evaluating changes to knowledge and understanding. Epistemic metacognitive knowledge concerns people's knowledge and beliefs about the nature of knowledge, processes of knowing, and others as knowers, for example, knowledge about source reliability. This category has parallels to the multi-dimensional epistemic belief frameworks. Epistemic metacognitive experiences are what people are aware of and feel as they use processes and strategies to construct and justify knowledge or understanding. Two examples of epistemic metacognitive experiences are epistemic curiosity and emotions about sources. Epistemic metacognition is important to an individual being able to fully engage in epistemic strategies and process at the epistemic cognition level.

Studying Epistemic metacognition in engineering

The study of epistemic cognition, metacognition, and epistemic metacognition is valuable within engineering education because it will help us understand how we can support students to become critical consumers and creators of knowledge with the skills to interpret resources, build arguments, solve complex problems, and work in multi-disciplinary environments. Engineering places an emphasis on design and problem solving, both of which require the use of reliable processes to gain knowledge and understanding, and using epistemic cognition, metacognition, and epistemic metacognition to study these contexts will help us understand how formal and informal education practices support and hinder students' development of these processes. As the engineering education community calls for more authentic learning environments for students in order to prepare them for the workforce [1, 26, 27], it is critical that we also studying the thinking and learning processes that are authentic to practicing engineers, scientists, and researchers. Though there is significant research to show the importance of understanding how epistemic cognition, metacognition, and epistemic metacognition in authentic learning, there is currently little research being conducted in these areas in the field of engineering education. Within engineering education, there are several researchers who are studying the connection between epistemic cognition and learning. These researchers are using different conceptualizations of epistemic cognition and research methods in their investigations. McNeill et al. [8] took a mixed methods approach and found that students have different epistemic beliefs about classroom and workplace problems. Faber and Benson [7] used semi-structured interviews to investigate students' epistemic cognition in two different problem-solving contexts, an engineering classroom and an undergraduate research experience. Danielak, Gupta, and Elby [28] investigated the epistemological aspects of students' identities as it relates to student retention through a qualitative study. Benson et al. [29] are investigating undergraduate engineering students' epistemic cognition and identity within the context of undergraduate research experiences through a mixed methods study. While some researchers are investigating epistemic cognition within engineering education, more studies are needed to fully understand how epistemic cognition relates to student learning, identity development, and problem solving. There are several researchers who are investigating the impact of metacognition in engineering learning. For example, Lawanto [15] used quantitative methods to investigate metacognitive engagement during design project in engineering. McCord [30] has studied metacognitive engagement in self-directed study groups in order to develop a qualitative approach that uses observations to study students' actual engagement in metacognition. Litzinger, Meter, Firetto, Passmore, Masters, Turns, Gray, Costanzo and Zappe [16] found that students who engaged more frequently in metacognitive monitoring performed better on statics problems using a think aloud protocol. Cunningham, Matusovich, Hunter and McCord [31] continue to investigate the impact of targeted instruction of metacognition on engineering learning and performance. While some researchers are beginning to investigate the impact of metacognitive engagement on engineering learning and problem solving, research outcomes are limited and are typically situated in the theoretical framework of self-regulated learning instead of isolating work on metacognition alone. To our knowledge, there is currently no work being conducted on the influence of epistemic metacognition in the field of engineering education.

Methods Development

For the observation portion of this study, we will be using an observational coding strategy used in a previous study [32]. In the original data collection, groups of engineering students who had formed study groups were video and audio recorded. The students signed up to be a part of the study and conducted study sessions to work on homework together. The researcher came to the study sessions to video record the study session. After adequate footage had been recorded, the videos were transcribed to be analyzed. The transcriptions included all verbal communication as well as any significant movements such as hand gestures or writing on a whiteboard. The transcriptions were first separated into episodes of on task engagement. The episodes were then coded according to seven predefined codes that reflect different aspects of metacognition. Finally, sub codes that further break down each of the seven top level codes were assigned to each aspect of the episode. After each episode was coded, the codes were organized and checked for intercoder agreement.

The purpose of the previous observations was to analyze the ways in which sophomore level engineering students use metacognition to process and understand the problem presented to them. The coding scheme used allowed for the study sessions to be broken down by individual lines and actions and analyzed to determine exactly which aspect of metacognition was being utilized. These observations led to the development of the current research study, analyzing metacognition and epistemic cognition in tandem to justify the reasonableness of their solutions.

Currently, we plan to observe senior design teams in civil engineering. All members of the design team must consent to be observed for the team to be accepted. Teams will set their own schedule for when they meet and will meeting in our predefined research lab. The meetings will be video and audio recorded using a multi-camera view. We plan to use the analysis procedure from the previous study to look for metacognitive engagement. In addition, we are testing a new methodological approach for analyzing the observational data for epistemic thinking. This methodological approach includes watching the video of an observation, coding with the primary categories from our epistemic framework, and generating a memo to describe the context and the observed epistemic practices.

Two types of interviews will be utilized in this study to complement data collected through observations: ethnographic interviews and stimulated recall interviews. First, ethnographic interviews will be conducted by one or two interviewers. One interviewer will ask the group the list of pre-written interview questions, and another interviewer can be present to assist in asking personalized follow-up questions when necessary or useful. These questions are designed to gather background information on the team and their project, have them verbalize some thought processes and beliefs about methods they used, and reflect on their experiences to inform our interpretations of the observational data. One concern for these questions is the use of language that is easy to understand for the participants but also probes for information pertinent to our research aim. Pilot interviews were conducted to test the questions and their responses and adjustments were made based subsequent feedback.

Second, stimulated recall interviews will consist of showing a member or members of a design team observational data and asking them follow-up questions. The data shown will consist of one or a combination of video clips and audio clips that involve the members in the interview. These will be presented to the participants to help them recall their behavior and thoughts during specific interactions of interest. The questions to be asked during this type of interview will be about their motivations, perceptions, and experiences while the events in the clip were occurring. The purpose of this interview style is to to gain a better understanding of what they think they were doing and why they were doing it. This information will assist the researchers to more accurately code and interpret the qualitative data from the observational methods.

Future Work

The next steps in this study will be the recruitment of study members and completion of data collection procedures. We will recruit student teams enrolled in the senior capstone design course in the civil engineering department at an R1 institution in the southeast. To make initial contact, we will announce the study in classrooms for this course and collect contact information from interested students. More detailed study requirements, procedures, and the consent form will be provided in a follow-up contact via email. In-person meetings with interested teams will be set up to review the study information, answer questions, and allow for team members to sign the consent forms if they choose to participate. The study will only include students that are 18 years of age or older and teams where all of its members consent to the research study.

After observational and interview data from consenting team members has been collected, the study will continue with data analysis methods. The audio and video files from each observation and interview session will be transcribed verbatim for a detailed record of the dialogue of study participants. The transcriptions will allow for qualitative data analysis with previously established coding schemes to analyze the data in the context of theoretical frameworks [7, 29]. We will analyze themes and trends that emerge through the coding methods to inform the ethnographical data and investigate student behavior behaviors relevant to metacognition and epistemic cognition practices. This data should assist in discovering information on methods these engineering design teams justify the reasonableness of their solutions during their design projects. Our plan is to begin data collection in early Spring 2019. Our team hopes to have results from initial data analysis to present at the 2019 ASEE Annual Conference & Exposition.

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