Creating a Metacognition Community of Practice: Transforming the Engineering Learning Community

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***Abstract*— This Research Work in Progress paper presents a Community of Practice (CoP) for Metacognition research. This paper will provide a brief overview of the current state of metacognition research in engineering education. Current work in engineering will be compared to suggested focus areas in the broader study of metacognition in education. This paper will conclude with a brief discussion of the CoP the authors are working to form to support future research in metacognition in engineering. The CoP is currently formed around five major thrust areas of research: K-12 Education, Undergraduate Education, Workforce Development, Faculty Development, and Frameworks and Methods.**

Keywords— metacognition, engineering, community of practice

I. Introduction

Metacognition is critical to learning activities such as studying, problem solving, and repairing misconceptions e.g., [1-3]. Yet despite the many benefits to learning [4, 5], knowledge about when and how students engage in such practices is lacking. Further, even with various calls for coordinated metacognition research in specific areas [4], such coordinated efforts are missing. Drawing on outcomes from a narrative literature review, we argue for the need for a collaborative Community of Practice (CoP) for metacognition to inculcate the teaching and learning of metacognition at the undergraduate level, specifically in engineering. A CoP is a "group of people who share a common concern or a passion for something they do and learn how to do it better as they interact regularly" [6 p. 1]. A CoP includes three critical elements: 1) a domain, in this case metacognition; 2) a community, in this case engineering education researchers and instructors; and 3) a practice, in this case engaging in experiences and building resources related to the research, teaching, and learning of metacognition. We chose to focus our CoP efforts specifically on engineering due to disciplinary drivers, such as a need for strong problem-solving abilities and a need for undergraduate education to yield lifelong learners able to adapt to changing technologies and societal landscapes. We specifically identify five thrust areas to form the initial basis of our CoP: Frameworks and Methods, K-12 Instruction, Undergraduate Instruction, Workforce Development, and Faculty Development. As we will argue, our proposed thrust areas are consistent with general calls for research in metacognition. After defining metacognition, we will briefly describe the methods we used for the narrative literature review and then move to our resulting arguments for the need for a CoP and for the identified thrust areas.

II. Defining Metacognition

Metacognition can be defined as a learner's knowledge about and regulation of their own cognition [7, 8]. Knowledge of cognition, or metacognitive knowledge, can be described as the insight that the learner has about his own cognitive processes [7, 8]. Regulation of cognition refers to the activities that a learner uses to oversee his or her learning [7], and encompasses knowledge of persons (the knowledge one holds about her knowledge and others' knowledge), knowledge of tasks (knowledge about the approach to learning and completing tasks), and knowledge of strategies (knowledges procedures needed to accomplish a cognitive goal).

Regulation of cognition includes metacognitive strategies such as planning, monitoring, evaluating, and controlling [7, 9]. It should be noted that there is no clear agreement, to date, on which metacognitive strategies should be included in the theoretical model of metacognition [4] though the ones we have identified are the most highly discussed strategies by experts in the field at this time [e.g., 7].

III. Metacognition in Engineering

We have chosen to focus our CoP development on engineering as a sub-group within STEM. We do not mean to imply that metacognition is less important in other disciplines but rather we see engineering as a starting point such that our CoP approach could serve as a model for other disciplines. Engineering is a logical starting point because metacognition is highly relevant to the content and context of undergraduate engineering learning. Engineering as a profession is viewed as an applied field focused on problem-solving [10]. This view of the profession translates to undergraduate engineering curricula that are heavily laden with calculation-based courses that rely on "practice problems" as an analogical mode of learning to solve problems as practicing engineers after graduation. Metacognition is essential to effective problem-solving [e.g., 11]. At the same time, metacognitive ability is believed to have a developmental trajectory [12] and there is already a

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strong research and teaching practice focus on engineering education as a trajectory that starts pre-Kindergarten and continues through professional work [13]. Considerable current educational research is focused on what and how engineering should be taught at different age-levels, though there is clear agreement that engineering education should start early in order to promote interest in and preparation for engineering careers. However, unlike other disciplines, there are not standard approaches for pre-college settings that are entrenched and difficult to change nor are there standardized tests in engineering to drive learning approaches. Being in an early adoption-phase of engineering education raises the possibility of incorporating purposeful metacognitive practices. In college settings, where engineering education has been traditionally fixed and static, recent calls for transforming engineering education likewise pave the way for including a focus on metacognition [14]. As students move into the workforce, it is critical that they possess life-long learning skills that will allow them to adapt to the ever changing societal and technological needs of our world [15].

The content and context of engineering support a focus on metacognition as a way to improve undergraduate engineering education, while also being consistent with our proposed community of practice approach. Although our intention is to improve undergraduate engineering education, we recognize that we cannot focus on undergraduate students alone and in isolation of academic and professional development because experiences prior to college and expectations of the future directly impact undergraduate students in the present. For this reason, our CoP proposes thrusts focused on pre-college education (K-12 Instruction), post-graduate contexts (Workforce Development), and undergraduate student development (Undergraduate Instruction). We also include Faculty Development as we know that transformation also requires "training the trainers" so we will need to convince faculty that teaching students about metacognition is important and worth the time away from technical content which tends to be the "holy grail" of engineering education. Finally, we have included a thrust on Frameworks and Methods as existing research has called for continuing focus in these areas particularly as metacognition can be difficult to evaluate and assess. Importantly, our thrust areas overall are consistent with general calls for research in metacognition that address definitions and taxonomic structures defining metacognition, methods of assessing metacognition, metacognitive development over time, and pedagogical interventions and training for metacognition [4]. Developing a CoP is an ideal way to advance theoretical and practical knowledge of metacognition in engineering because such an approach can leverage the shared interests that permeate these thrust areas and create a structure to foster continued collective growth.

IV. Community of Practice

A community of practice (CoP) moves beyond gathering a group of people at a workshop to discuss a common topic and instead leverages the intentional creation of networks of people who have an interest in, and identity around, the topic of metacognition in engineering. A CoP is formally defined as "a learning partnership among people who find it useful to learn from and with each other about a particular domain" [16]. The community intends to sustain themselves with a purpose of gaining, sharing, and sustaining knowledge growth around a particular domain, resulting in a shared practice which can be used to solve problems.

There are three characteristics of a CoP: a domain, a community, and a practice [6]. The structure has three levels of participation,: a core group, an active group, and a peripheral group [6]. Wenger-Trayner and Wenger-Trayner [6] posit the development of these three characteristics in parallel is what "cultivates" a CoP. Accordingly, the domain is recognized by the group as a shared domain of interest and identity and the members are committed to it. In this case, the domain is metacognition in engineering. The community shares in joint activities and work to help each other learn. Importantly, the frequency of formal interactions by CoPs can and should vary depending on the needs of the group. What their interactions enable is a shared practice; a way for practitioners to develop and share resources, tools, and experiences to help enable problem solving [6].

We believe that the fluid and self-determined nature of a CoP is what will keep people engaged and efforts sustained. By definition, not all practitioners in a CoP are involved at the same level nor are individual participants engaged at the same level constantly over time. This is evident in the CoP structure, often visualized as concentric circles from a core/coordinator at the heart of the CoP to the outermost/least engaged members [17]. During the life of a CoP, participants may move toward or away from the core depending on the alignment of their interests with the CoP. The core group is at the center and includes a coordinator and a small group of people who intend to remain engaged and whose energy and interest are sufficient to nurture the community. The active group consists of people currently knowledgeable and actively participating in the CoP research or practice areas. Peripheral participants have a connection to the community but may have less personal commitment to the CoP; they may be new to the community or part of their identity may be with other domains. Finally, there may be Transactional participants, those who have occasional, specific interactions with the CoP for purposes such as receiving artifacts (e.g., publications or tools) [17].

We believe that the CoP should include people actively involved in metacognition research and practice and should be from a variety of disciplinary backgrounds. Interdisciplinary teams, comprised of researchers with different methodological expertise and focus areas allow opportunities for scholars to gain deeper understanding of and better solutions to complex problems [18] such as improving undergraduate engineering education. However, collaboration between different disciplines, especially for researchers "heavily colored by disciplinary traditions", may not succeed without intrateam social dynamics capable of lessening the boundaries between members [19]. These borders may strengthen as research professionals join professional groups, which may reaffirm their paradigms and the differences of others' paradigms. A combination of reeducation (purposely learning and educating on methods and practices of other disciplines and their own), a collective interest in the problem, and purposeful engagement and time commitment are key elements for gaining better collaboration and deeper understanding of complex problems.

We recognize that there are potential challenges in creating a CoP. Recall that Wenger [20] states that characteristics of a community include mutual engagement, a joint enterprise, and a shared repertoire. Our very argument for the need for a CoP is perhaps the same as the biggest challenge: bringing together a group of people who already engaged in teaching and research practices individually in a collaborative way. Given that a CoP has not emerged already on its own, such a CoP may need to be seeded. Fortunately, others have developed guidance for creating and evaluating CoP. For example, Wenger, et al. [21] propose a framework in: *Promoting and assessing value creation in communities and networks: A conceptual framework*. This framework describes cycles of value to generate and assess in developing a CoP including: 1) Immediate Value, 2) Potential value, 3) Applied Value, 4) Realized Value and 5) Reframing Value.

V. Initial Research Thrust Areas

We previously identified five thrust areas to form the initial basis of our CoP: Frameworks and Methods, K-12 Instruction, Undergraduate Instruction, Workforce Development, Faculty Development. These are starting points, which we justify in this section. Figure 1 shows our five areas and anticipated intersections.

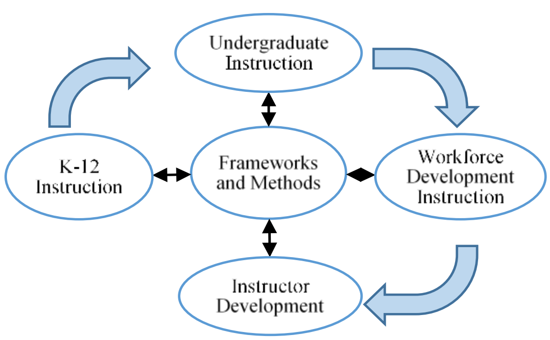

Figure 1: Metacognition Thrust Areas and Interactions

A. *Thrust Area #1: Frameworks and Methods*

Our first thrust area, Frameworks and Methods, is critical as the content of this area connects to all other thrust areas we identified. This thrust area is necessary because, simply put, metacognition is difficult to measure or assess despite solid theoretical underpinnings. Therefore, we need continued and directed work to leverage and advance theory and to develop measurement methods that work in engineering contexts.

To date, metacognition has been primarily assessed using questionnaires, such as the MSLQ , oral interviews , think-aloud protocols , direct observations , and computer tools such as eye-movement registration and log file analysis [4]. These various methods of assessing metacognition differ across a variety of dimensions; prominent among these are temporal proximity (online/offline), observer (self/outsider), specificity (aptitude/event), level of disruption (low/high), and required resources (low/high). Each of these dimensions provides their own set of strengths and challenges to any given study. For example, while self-report methods may require fewer resources to utilize in a study, there are concerns that participants lack the ability to report on behavior that may be subconscious to them and thus are poorly correlated to actual performance [22]. Think-aloud studies provide a different window into the mind that allow researchers to probe into metacognitive engagement through online measurements [5], but have the potential to disrupt the normal cognitive and metacognitive behaviors participants may engage in. Observations may provide a view of natural interactions and behaviors, but are very resource intensive for data collection and analysis and also require subjective interpretation for analysis [22].

B. *Thrust Area #2: K-12 Education*

Our second thrust area is K-12 Education. A focus on K-12 education is an important part of the metacognition CoP in engineering because students build learning skills that are important to higher education in K-12 as well as make critical career pathway decisions during this time. Existing research in this domain has contributed significantly to current understanding of how metacognitive skills and knowledge develop and what skills are necessary to support learning in general knowledge domains. Much of the literature focuses on different pedagogical interventions used to develop metacognition in general settings, as the primary focus of K-12 education is the development of knowledge and skills prior to choosing a career path. For example, inquiry teaching is the process where students use a process oriented approach to solve problems through asking questions, creating solutions, and testing results [23]. Through engaging in the inquiry process, students can develop planning, monitoring, reflection and evaluation skills. Portfolios allow students to display artifacts of their work and provide evidence as to why that artifact is relevant to learning [24]. In the process of selecting artifacts, students have the opportunity to reflect on their own learning and on how they are meeting cognitive goals. These pedagogies have been developed to support learning in areas such as science, math, reading, and writing, with minimal focus on how each of these disciplinary perspectives impact the education of engineers or how engineering education at the K-12 level is impacted. As more emphasis is placed on integrating engineering principles into K-12 curriculum to expose children earlier to engineering as a career choice and to develop mathematics and science reasoning skills, it is critical that we understand how to engage K-12 students in metacognitive thinking.

C. Thrust Area #3: Undergraduate Instruction

The third thrust area, Undergraduate Instruction, is perhaps most directly tied to the teaching and learning of engineering students. In contrast to the broad education in K-12, higher education focuses on developing knowledge and skills for specific career paths within specific disciplines. Undergraduate instruction in metacognition is less developed and coordinated. Sometimes student instruction on metacognition is included in first-year seminar courses [25]. There has been relatively little work on metacognition within engineering education. Some examples include a metacognitive intervention implemented in biomedical engineering with mixed results [1], the development of professional skills [26] development of metacognitive monitoring and control in open-ended design [27], writing to improve self-assessment in a statics course [28], and interactive metacognitive instruction within existing courses [29]. Metacognition is particularly relevant to engineering education because of its role in solving problems and lifelong learning. Engineers work to solve ill-structured and ill-defined problems [e.g., 30]. Metacognitive skill is instrumental in navigating and progressing through such problems to solutions and doing so efficiently [11] Metacognition also has a strong connection to both conceptual and procedural knowledge [31], which is key to the fundamental principle that engineering applies concepts from math, science, and other disciplines in order to solve problems. With such a strong connection to engineering work, there is great benefit to studying and developing engineering students' metacognitive development in a coordinated way.

D. Thrust Area #4: Workforce Development

Our fourth thrust area is workforce development. We identified this area as important because metacognitive skills are necessary as people move into and are sustained in the workforce. As technology progresses and job skills change over time, a focus on metacognitive development ensures that workers can meet the demand of the ever-changing needs of their job. Today's industries require workers with a large set of skills, including soft skills such as communication, teamwork, problem-solving, and higher ordering thinking skills [32]. While research on the development of metacognition in the workforce has been conducted in several different disciplines, including the writing profession [33], medicine [34], and teaching [35], research on the role of metacognition in the STEM workforce, and specifically engineering, is scarce. As the purpose of undergraduate education is to prepare students for the workforce, it is critical we understand the metacognitive needs of industry and engineers in order to ensure proper priorities for undergraduate engineering education.

E. Thrust Area #5: Instructor Development

Our final pre-identified thrust area is Instructor Development. This is an important thrust area because instructors are in a position to directly change what is happening in learning environments. Instructors in engineering, and STEM higher education more broadly, largely teach in lecture format [36] which is often how they were taught. Moreover, they tend to focus on the content of those courses rather than on the development of important skills including professional skills [37] and even learning how to learn. Despite a recognized need to teach in different ways and specifically to help students be better learners, change among faculty approaches in the classroom has been slow [38]. Even when presented with evidence for the value of student-centered approaches, such as problem-based learning, faculty are slow to adapt. An underlying cause of slow pedagogical change that is equally important, though less often discussed, is that instructors do not understand the cognitive and affective process associated with learning. STEM instructors in general are not trained in cognitive development or cognitive processes, let alone metacognition. Further, many instructors hold simplistic, inaccurate or incomplete mental theories of learning [39, 40] Instructors' underlying beliefs about learning guide their instructional choices and behaviors. Therefore, instructor development is necessary to refine mental theories of learning to make them more accurate, supporting better pedagogy. In short, instructors need to become more consciously metacognitive themselves in order to engage students in their metacognitive development.

VI. Benefits of a CoP

Creating a CoP relative to metacognition in undergraduate engineering education, could have benefits beyond those that directly engage with the CoP. First, the process of creating the CoP could serve as a model for coordinating research on metacognition in other disciplines and even for other content areas that suffer from a dispersed and uncoordinated approach. Importantly, the CoP model maintains the agency of all participants. It is not a top-down approach designed to mandate research priorities but rather allows individuals to work together to choose a project direction that meets the needs of all members. By bringing together people that are interested in and passionate about metacognition in engineering education, we will create a time and place for people to share ideas and effective research and teaching practices. Building these connections will support implementation and adoption in engineering education bringing additional participants to the periphery who can move towards the center with time. Second, participants in the CoP could serve as brokers between the Metacognition CoP and their local institutional CoPs that are likely more centered on teaching engineering content than they are on teaching Metacognition.

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