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Understanding, Current Status, and Future Directions for Epistemic Practices in STEM+CS Education

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Students graduate from school into a world that is constantly changing, and thus we need to prepare them to be successful in this environment. Traditionally, people have focused on successful academic learning on gaining factual knowledge or scoring high marks at tests. Although those are still highlighted in a sense, what has shifted for student learning is the need to generate an ability to use all the appropriate and available resources, such as, mathematical practices, cognitive, language and dialogue, to solve problems. Students now have to be able to build accurate understanding of the situation (i.e., problem, event, issues, etc.), and use the epistemic practices of the discipline to generate richer understandings of the phenomena or concepts being engaged with. As educators, we ought to realize that the next generation of students has already started using resources that we have never thought could be utilized to generate understandings of the topics studied.

One thing that is required to be successful in such a changing world is to be adaptive and adaptable. In terms of learning, to be adaptable, we need to learn how to understand the world and systems that we live within and how to successfully engage in problems within the system(s). This requires that they both understand the role of the resources that they have available, but can utilize these resources to advance their understandings of the phenomena. Being adaptive means that you can recognize which resource to use, how to use the resource, and how using the resource will advance your understandings. This moves understanding of adaptiveness beyond strategic moves to the building of foundational knowledge that has application across multiple settings.

As one component of resources, we argue that helping students develop epistemic practices is critical in encouraging them to generate better understanding of problems (or situations) as well as problem solving itself. Lily, Chiu, and McElhaney in this issue explain two types of epistemic supports students need to engage with: *disciplinary* and *pragmatic*. To understand problems, through lens of epistemic practices, students need to build understanding of the nature and characteristics of each discipline (e.g., mathematics, science, engineering, etc.). This epistemic understanding empowers students to recognize and identify why logical processes in mathematics are different to science where there is an emphasis on looking for better solutions with updated resources and knowledge even though they already have the best possible answers at hand. In terms of problem solving, epistemic practices including planning and carry out investigations, defining engineering problems, or identifying and using algorithms or computational models to test designs.

Living and figuring out the world becomes more difficult with time because the boundaries of fields are moving to be fuzzy and thus more difficult to distinguish one from another. The ability to utilize epistemic knowledge and practices will be critical as a resource as students move from school to being active participants in society. Biology and engineering, fine arts and geometry, statistics and sociology, mathematics and business are just a few examples of fields that as citizens we will be engaged with. The expectations will be that people will at least be able to identify problems to solve, and to communicate with others (e.g., professionals, knowledgeable others) across fields to help solve the particular problems being examined. For leaders, it is essential to possess rich epistemic resources to understand these broader contexts and be able to supervise/assess processes that will lead to constructive solutions to problems. Helping students move beyond a focus on factual knowledge, to generate a richer epistemic ability and understanding of how and why things work in certain ways (pragmatic epistemic practice) and what the nature and distinctive characteristics of a discipline would be (disciplinary epistemic practice), we believe would prepare them to adequately perform in the complex world and advance further from it.

In helping prepare the next generation of professionals and leaders, educators and education researchers have been discussing theories of student-centered learning, curriculum standards, instructional materials, instructional practices, and ways to support student-centered learning practices. Despite these efforts, the foci have been on how and what *teachers do* in relation to support student-centered learning, rather than what, and how, *students do* in such learning environments. The natural bridge to these disparities is (a) to determine/assess current learning environments, (b) to find/develop a framework to understand the situation, (c) to recognize what on-going efforts exist, (d) what types of teacher training would improve the current situations, and (e) to eventually engage students in full scale utilization of these resources.

In this special issue, we have focused on how to build a richer understanding of what lies ahead. Importantly, as we generate potential opportunities for learners, there is a need to recognize and engage with the complexity of this shift away from replicative versions of learning, to one where generation of knowledge is promoted through resource rich environments. While we do not suggest that the papers in this special issue are definitive, they do begin to help us understand how complex learning environments are.

A theoretical and practical article by Lily, Chiu, and McElhaney frames the notion of epistemic support in STEM+CS settings. They articulate how interdisciplinary instruction complicates epistemic knowledge and resources needed for teachers' instructional decision-making. They present a well-grounded model to explain the complexity of integrated curricula, teacher support, and instructional decision-making using prior research and data from their NSF supported project. Using the model that they presented, they highlighted opportunities and challenges that teachers experienced in elementary project-based STEM+CS lessons. At the end of the article, the authors provide recommendations on professional development: how to engage students in interdisciplinary activities and ways to help teachers understand why and how such practices should be used.

Following this theoretical yet practical article, Bae and Sahin discuss existing instructional practices on a larger scale. They conducted a meta-analysis study that examined the effect of Science Writing Heuristics approach (SWH; Hand & Keys, 1999) in Turkey. In the perspective of epistemic practices, SWH approach is "an argument-based intervention that focuses on students' immersion in the development of intellectual resources (e.g., critical thinking skills and scientific knowledge) using language as an epistemic tool" (p. 176) that has shown its success in students' academic achievement and critical thinking skills. Although Bae and Sahin's study is conducted in a small scale due to its relatively short history of SWH approach in Turkey, it is encouraging to see the effectiveness of epistemic practices in the discipline of science in Turkey, and, potentially, in more global and across-discipline contexts.

Discussing actions that teachers make to engage students in epistemic practices in mathematics, science, and engineering classroom, three studies in this issue delved in-depth to understand what teachers are currently doing and how we can view instructional practices in the lens of epistemic practices.

Estapa, Tank, and DuPont looked into elementary school student teachers and their cooperating teachers' perspectives on responsive teaching practices. Particularly, they delved into teacher noticing in the engineering lessons. The concept of teacher noticing emphasizes teaching practices that focus on what teachers notice from student learning, and how teachers respond to what they observe (notice) from student learning (Colestock & Sherin, 2016; Luna, Selmer, & Rye, 2018). They found the participating teachers rely on their pedagogical knowledge more so than what they noticed from students and the progress of student learning in order to make instructional decisions. Estapa and colleagues provide us an important task to incorporate their findings in professional development for teachers as well as preservice teacher training: How we can help teachers pay more attention to students, student learning building on the content and engineering practices, and make instructional decisions based on student learning instead of teachers' pedagogical knowledge.

Observing and analyzing two beginning teachers' uses of social, conceptual, and epistemic discursive moves, Pak investigated what goals these teachers have in mind to use each of the three instructional moves by interviewing the teachers. Pak observed and analyzed teachers' interaction with small groups of students and found that goals that teachers had for observed instructional moves were mostly social and conceptual even when they made epistemic moves. This misalignment suggests a few points for teacher educators to consider in supporting students' epistemic practices. First, it is encouraging to see that beginning teachers use epistemic moves when engaging with small groups of students. They used epistemic moves such as asking students "how to use the measurin g tools and the ideas behind accurate measuring." These moves certainly provide opportunities for students to engage in epistemic practices, and positive and successful learning experiences through epistemic practices will empower students to continue using such learning practices. However, the teachers did not acknowledge their epistemic moves in relation to epistemic goals. We need to carefully examine this finding. The beginning teachers may not understand what epistemic goals and moves mean in their instructional practices particularly if the teacher training programs that they went through highlighted the social and conceptual goals and moves much more than epistemic moves and goals. The fact that Pak observed that teachers do use epistemic moves as much as social moves could mean that they do see the importance of epistemic moves during the interaction with students. With making connections with epistemic goals, there is a potential benefit that (a) teachers can intentionally prepare instructions and make instructional decisions with epistemic goals, and (b) it will benefit students' development of epistemic practices with stronger and meaningful impact.

Kim's study on high school mathematical proof is a good example of utilizing disciplinary and pragmatic support for students' epistemic practice development. This study looked into not only teaching practices but also how students' epistemic practices develop and change when the teacher intentionally incorporates epistemic practices into lessons. Throughout the semester, the teacher in the study, gradually incorporate proving practices in everyday lessons, when the lesson topic was not quite on proving theorems. During proving practices, students should engage in reasoning and developing arguments including generalize mathematical relationships, producing and justifying conjectures, and evaluating justifications, which are the core structure of mathematics disciplinary epistemics practices. As the teacher uses proving and problem posing (using the idea of mathematical proof) in everyday lessons, the teacher observed student changes in generating arguments and in thinking about problem solving, particularly as the teacher intentionally prepared and posed more rigorous prompts. It cultivated classroom culture to a supportive community of mathematical proof-type thinking and reasoning. Lessons we learn from Kim's study is two-fold. First, teacher's uses of epistemic practices builds through an interplay between teacher and students: Teacher's implementation of epistemic practices leads to changes in students' learning and classroom culture, which encourages teacher to go further in instructional decision-making with intentional and rigorous incorporation of such instructional practices. It is natural that teachers experience discouragement when they do not see a positive change in student learning when they work hard to incorporate a new pedagogical approach. Second, encouraging students to use the proving as a resource for problem solving activity everyday will lead to rich epistemic practices – understanding that the structure of the discipline, mathematics, is centered around the logical, inductive and deductive reasoning drawn from foundational principles to relate to new mathematical understandings (Chevallard, 2006; Sierpinska & Lerman, 1996), as well as using various types of reasoning (e.g., generalization, developing a conjecture, justification, evaluation) to answer problems with *why* and *how*.

This special issue encourages STEM+CS educators to begin the discussion on epistemic practices in student learning: What it means, what we currently do in relation to such practices, what do teachers know, understand, and believe, what teacher training would be beneficial, what expectation we have for students to do, what we want to see from students' actions in classrooms, and more. Within one discipline, across multiple disciplines, or integrated learning environment, it is quite promising that when students use epistemic practices, the learning will be much more meaningful as students develop solid understanding of knowledge not only on what, but also why and how.

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