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"Changing in the Moment": Examining Enacted and Personal Pedagogical Content Knowledge of Engineering Teachers

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Purpose

Much educational research has explored teachers' pedagogical content knowledge (PCK), defined as "the knowledge of, reasoning behind, and enactment of the teaching of particular topics in a particular way with particular students for particular reasons for enhanced student outcomes" (Carlson et al., 2015, p.79). Research on science teachers' PCK has been particularly prolific, spanning topics including the nature of science teachers' PCK (Friedrichsen et al., 2009, Lin, 2017, Krepf et al., 2017), the relationship between science teachers' PCK and student outcomes (Gess-Newsome, 2015, Sadler et al., 2013, Gess-Newsome et al., 2017), the development of science teachers' PCK (Nilsson & van Driel, 2010, Findlay & Bryce, 2012), and the relationship between PCK and other variables such as content knowledge (Uzuntiryaki-Kondakçı et al., 2017, Suh & Park, 2017, Meschede et al., 2017, Gess-Newsome et al., 2017). Researchers in science education have come together to synthesize PCK findings and to develop and refine conceptualizations of science PCK (Hume et al., 2019).

Even as engineering has gained prominence as a discipline in K-12 education (NRS, 2013), research exploring the engineering PCK of teachers remains sparse. Some studies have explored technological PCK fostering student understanding of the engineering design process or EDP (Koehler, 2012, Dasgupta et al., 2017). Others examined relationships between teachers' science teaching practices and STEM PCK (Mientus, 2022). However, more studies are needed to highlight systematic ways in which teachers scaffold teaching of engineering in K-12 schools. As part of an NSF funded DRK-12 project conducting research on the implementation of the STEM-ID
curricula, we investigated the PCK of six middle school engineering teachers implementing a semester-long curricula in their 6th, 7th, and 8th grade classrooms. Several of the teachers participating in the project transitioned from teaching science or mathematics to teaching engineering. Thus, we had a unique opportunity to observe and document the conversion of teachers' personal PCK (pPCK) developed as science and mathematics teachers into enacted PCK (ePCK) in engineering. Using the refined consensus model (RCM) of PCK in science education as a theoretical and analytical lens, this study addresses the following research question: How do teachers utilize their personal and enacted PCK as they implement the STEM-ID curriculum?

Theoretical Framework

The refined consensus model (or RCM) of PCK in science education situates students' science learning in relation to PCK (Hume et al., 2019). Carlson et al. (2019) described this model as comprised of five major components:

- **Enacted** PCK (*e*PCK)— the unique subset of knowledge that a teacher draws on to engage in pedagogical reasoning during the planning of, teaching of, and reflecting on a lesson.
- **Personal** PCK (*p*PCK)—the personalized professional knowledge held by an individual teacher in science.

- **Collective** PCK (*c*PCK)—specialized professional knowledge held by multiple educators in the field
- **Learning Context**—factors influencing teaching and learning like, federal and school policies, community values, and student attributes.
- **Professional Knowledge Bases—**various aspects of a teacher's broader professional knowledge bases, including science content knowledge, pedagogical knowledge, knowledge of students, curricular knowledge, and assessment knowledge.

For the purposes of our study, we are particularly interested in adapting these conceptualizations to explore the relationship between the pPCK teachers bring to their engineering teaching experiences and the ePCK that is evident through teachers' practices and pedagogical reasoning during their teaching of the STEM-ID curricula.

Methods

This basic qualitative study triangulated interview and classroom observation data to explore PCK among engineering teachers. To analyze the data, we utilized qualitative content analysis, a form of descriptive approach (Schreier, 2012, Krippendorff, 2018). Systematic analysis and interpretation of material were used to uncover the meaning and presence of text and transcriptions of dialogues (Krippendorff, 2018). Development of a STEM-ID curriculum-specific PCK is ongoing.

Participants: Participants include six teachers from five middle schools in a large school district in the southeastern United States. Teachers reported overall teaching experience from 5 to 20 years. Three of the six teachers were veteran science teachers with at least 15 years' experience prior to teaching engineering. Two teachers had a background as mathematics teachers. One teacher, who co-taught with one of the engineering teachers, was a computer science teacher. Engineering teaching experience ranged from zero to eight years, and experience teaching the STEM-ID curricula ranged from zero to six years. The county, considered to have one of the most diverse student populations in the state, reports a 60 to 95 percent minority enrollment.

Curriculum: The STEM-ID curricula is comprised of three semester-long 6th, 7th, and 8th grade engineering courses, each designed to develop specific, foundational STEM skills leading up to a final design challenge. Table 2 summarizes the major activities included in each grade-level course. During the 2022-23 school year, STEM-ID was implemented by a cohort of six teachers in five schools, with the intention to add additional cohorts for the next three years.

Classroom Observations: Classroom observations were conducted in each semester of the 2022-23 school year. Intensive observations in which researchers observed implementation of each grade level curricula over an approximately two-week period were conducted at the end of each semester. Researchers utilized a semi-structured protocol to gather data in 80 class sessions in these intensive observation visits. The protocol included both checklist items to indicate what components of the curricula and the EDP were being implemented and space devoted to general field notes as well as specific field notes related to PCK. In order to track implementation more closely, additional short weekly observation visits (n=23) were conducted during the Spring 2023 semester.

Teacher Interviews

Semi-structured interviews were conducted with each of the six teachers who implemented STEM-ID. Four researchers conducted a total of eleven individual interviews during the 2022-23 school year. Interviews were scheduled at the end of each semester, as teachers were completing implementation. All teacher interview sessions were audio-recorded and transcribed for analysis.

To allow researchers to pose follow-up questions related to observations, interviews were conducted by the same researcher who had observed in the teachers' classroom. First semester interviews were guided by a semi-structured protocol developed by project researchers, in addition to questions intended to document implementation and elicit reflections and pedagogical reasoning related to facilitation of various components of the curricula (EDP, math/science integration, collaborative group work). For second semester interviews, the protocol was adapted to add prompts asking teachers to describe any changes in their practice over their two implementations of STEM-ID. Additionally, based on emergent findings suggesting the important role of teachers' PCK, the following question, designed to elicit reflections on a particular instance of ePCK noted in observation data, was added to the second semester interview:

> We are very interested in learning more about how teachers use their expertise to make pedagogical decisions when they are implementing STEM-ID. When I was visiting your classroom, I noticed (provide a brief but detailed description of PCK episode observed in the classroom):
> Do you remember that? If yes:
> - Tell me about your decision to _________.
> - What previous experience do you think you were drawing on in that moment?
> - Where did you learn about how to teach in that way?

Results

Personal PCK (pPCK)

Teachers exhibited pPCK practices that informed their STEM-ID implementation. Interestingly, teachers began discussing how they *could* utilize their PCK in science, mathematics, and engineering to inform curricula implementation during the preceding professional development. In their interviews, teachers also described how prior teaching experiences, especially in science and mathematics, became a part of their "teaching personality" over time. One teacher explained that thinking about how students learn science content informed the way he prepared to teach and "once you do it for a long time, you just can't take it out of your practice." Moreover, teachers leaned on and applied science and mathematics pedagogies that corresponded well to teaching engineering concepts. As one teacher explained:

> …so, the one thing that works well with the STEM-ID curriculum…is the problem-solving piece, because as a science teacher for 26 years, I…would come in, give my kids a problem, tell them the materials that they have, and they would have to solve it. So that, that part [of] my background…in science truly helps me in [implementing] the STEM-ID curriculum.

Enacted PCK (ePCK)

Teachers consistently and effectively drew on their reservoirs of personal PCK (pPCK) as they taught STEM-ID, thereby converting their existing knowledge related to teaching mathematics, science, and engineering into specific knowledge and skills used to enact STEM-ID (enacted PCK). One teacher explained, "when I noticed that a kid did not understand how to write the equation of a line, we practiced a lot of drawing first, [before] writing equations…so that they could hopefully make a connection." She modeled this practice by having students sketch an example of a physical glider as part of understanding its components. Additionally, she found her scaffolding techniques beneficial to ESL students and those with special education needs.

During another observation, we noticed a teacher's real-time response to students' misunderstanding of the histogram and its role in visualizing data. She realized this misconception's impact on the impending data analysis process, and immediately paused to teach the concept. In her interview she described that while her actions are an understanding that "every group of students have different needs," she had to learn over time how to "change in the moment" once there is no "light bulb moment."

Pedagogical Reasoning
We found clear evidence of teachers informing their teaching of STEM-ID with prior understanding about alternative understandings students may have or concepts they may find particularly challenging. In the following reflection, one teacher described how he applied his understanding of students' conceptual understanding in science:

> As a science teacher, you not only understand the content, but you also know how students learn that content. And you also understand this is important too, where they have issues with it. For example, mass and weight, that's something that kids struggle with. Um, and then calculating velocity and acceleration, they have trouble with that too, so you can kind of, so I can guess, kind of anticipate and plan for when they may have trouble with something.

Teachers also paid close attention to their students' personal needs. As one teacher described, "I recognize I have different walks of life [in my class]—language barriers and perspectives…. So, I [first] try to present something kids could relate to…some sort of a hook, to get them engaged and then dive into the deeper things." Teachers also placed significant emphasis on what they wanted students to learn and the best way to approach this. Another teacher described his thought process: "For s*ignificant* learning to take place, they have to attach that to who they are individually…and within this subject area...I like to use hands-on experiences where the students are creating something."

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Scholarly Significance

Understanding the learning needs of students is inherently relevant to their lives as learners and a critical component of teacher's PCK. Through our analysis, we were able to highlight how teachers' understanding of students' needs guided curriculum implementation. They relied on evidence-based practices in science and mathematics teaching, adopted and centered around students' needs. Elucidating the underpinnings of these engineering teachers' thinking provides important input for teaching K-12 engineering authentically. Furthermore, this has implications for teaching K-12 engineering, training teachers, and preparing students to think like an engineer.

It may also have implications for foregrounding the pedagogical reasoning underscoring authentic integration of STEM subjects.

We also began to compile PCK practices which may help to contribute to K-12 engineering PCK as espoused and practiced by teachers. The compilation of PCK specific to STEM-ID is ongoing and may also contribute to pedagogy and reasoning that may inform how we prepare K-12 engineering teachers. These preliminary results are not yet ready to be generalized. However, there continues to be a need for PCK specific to K-12 engineering. Thus, these findings may provide necessary scaffolding towards that effort. This may, in turn, help reimagine STEM and specifically, engineering pedagogy, attentive to the needs of diverse learners.

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