2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37582

Engineering Integration Pedagogical Content Knowledge (EIPCK): Development of a Conceptual Framework

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Engineering Integration Pedagogical Content Knowledge (EIPCK): Development of a Conceptual Framework[1]

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Abstract
There is a need for a comprehensive conceptual framework outlining engineering integration pedagogical content knowledge (EIPCK) to address the need to effectively integrate engineering into K-12 education. The aim of the study was to introduce a conceptual framework for pedagogical content knowledge focusing on engineering integration. The components of EIPCK were determined through a comprehensive review of prior literature on pedagogical content knowledge. The resulting EIPCK framework has four domains (engineering content knowledge, general pedagogical knowledge, engineering integration pedagogical knowledge, and contextual knowledge) and five components (1- Knowledge of Orientation to Teaching Engineering, 2- Knowledge of Engineering Integration Curriculum, 3- Knowledge of Students' Understanding of Engineering, 4- Knowledge of Engineering Teaching Strategy, and 5- Knowledge of Assessment in Engineering). We hope that the EIPCK framework will contribute to future research and curriculum design efforts with a focus on teacher education and professional development.

[1] This study was retrieved from doctoral thesis of Filiz Demirci.

Introduction

There has been an increased interest in integrating engineering into K-12 settings. However, there has not been a coherent determination of what constitutes teacher pedagogical content knowledge in engineering. A focus on pedagogical content knowledge can offer a unique way to integration-based content and pedagogy in engineering design education (Ali & Maynard, 2021). The conceptualization of engineering integration, as a pedagogy, epistemology, or methodology, can impact how teachers approach their practice and thus what students gain from this integration (Purzer & Quintana-Cifuentes, 2019).

Over the last two decades, researchers have conducted numerous studies to define and improve teachers' pedagogical content knowledge in engineering education (Hammack, 2016; Hynes, 2007; Viiri, 2003; Yu et al., 2012; Webb, 2015; Yeter, 2021). These scholars have developed a range of models often using expert opinion studies such as Delphi methods and developing an assessment instrument (e.g., Hammack, 2016; Webb, 2015; Yeter, 2021). Sun and Strobel (2014) defined engineering PCK for elementary teachers as methods and strategies to make engineering content comprehensible and teachable in elementary classrooms (p. 43). Hynes (2007) developed thirteen competencies for secondary school engineering PCK, under five overarching dimensions: (a) students knowledge, (b) real-world examples knowledge, (c) appropriate examples knowledge, (d) knowledge of managing the lesson/design activity, and (e) knowledge of strategies used to help students understand. Similarly, Yu et al. (2012) put forward the PCK dimensions and eighteen competencies in the K-6 teacher competency model for teaching engineering. According to Lau and colleagues, engineering PCK should include defining and limiting engineering problems, designing solutions, and optimizing design (Lau & Multani, 2018).

Still, a theoretically-grounded framework is needed to guide teacher education. Hence, in this study, we aimed to introduce a conceptual framework for engineering integration pedagogical content knowledge that K-12 teachers need to effectively teach pre-college engineering education. The development of this framework started with a comprehensive review of the existing PCK models followed by a specific examination of subject domains which were typically integrated through engineering.

Engineering Integration Pedagogical Content Knowledge (EIPCK) Framework

According to Shulman (1987), "PCK represents the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). For over three decades, many researchers conducted various conceptualization studies on PCK (Grossman 1990; Cochran et al., 1993; Loughran et al., 2012; Van Driel et al., 1998; Gess-Newsome 1999; Magnusson et al., 1999; Hashweh, 2005; Abell, 2008; Park and Oliver, 2008; Kind, 2009). Among these models, Magnusson et al. (1999)'s PCK model has been widely used in pre-service and in-service teacher education. In these prior efforts, most of the studies have argued for three knowledge domains: content (subject) knowledge, pedagogical knowledge, and contextual knowledge were the basic domains affected by teachers' PCK (Abell, 2008; Cochran et al., 1993; Gess-Newsome, 1999; Grossman, 1990).

In our approach, we identified **four knowledge domains** by adding a new one, engineering integration pedagogical knowledge, to the previously defined three domains (Figure 1). Engineering integration pedagogical knowledge is a specialized knowledge domain that is focused on ways of integrating engineering into different school subjects (science, math, etc.), reflecting the multidisciplinary nature of engineering.

Moreover, we determined **five components** to describe the pedagogical content knowledge, as a result of our comprehensive systematic review analysis of the various reports on K-12 engineering education (NAGB, 2010; NRC, 2012), national and states standards of US (NGSS Lead State, 2013; ODE, 2014; MDESE, 2016; MDE, 2019) and relevant frameworks related to engineering integration (Moore et al., 2013, 2014a, 2014b; Guzey et al., 2016; Mathis et al., 2018; Walker et al., 2018). These five components were: Orientation to Teaching Engineering, Engineering Integration Curriculum, Students' Understanding of Engineering, Engineering Teaching Strategy, Engineering Teaching Strategy, and Assessment in Engineering. Moreover, we removed one of the sub-knowledge of EIPCK and revised four sub-knowledge after receiving the opinion of two academics who had expertise in engineering PCK. In conclusion, we finalized the EIPCK framework including the eight sub-knowledge.

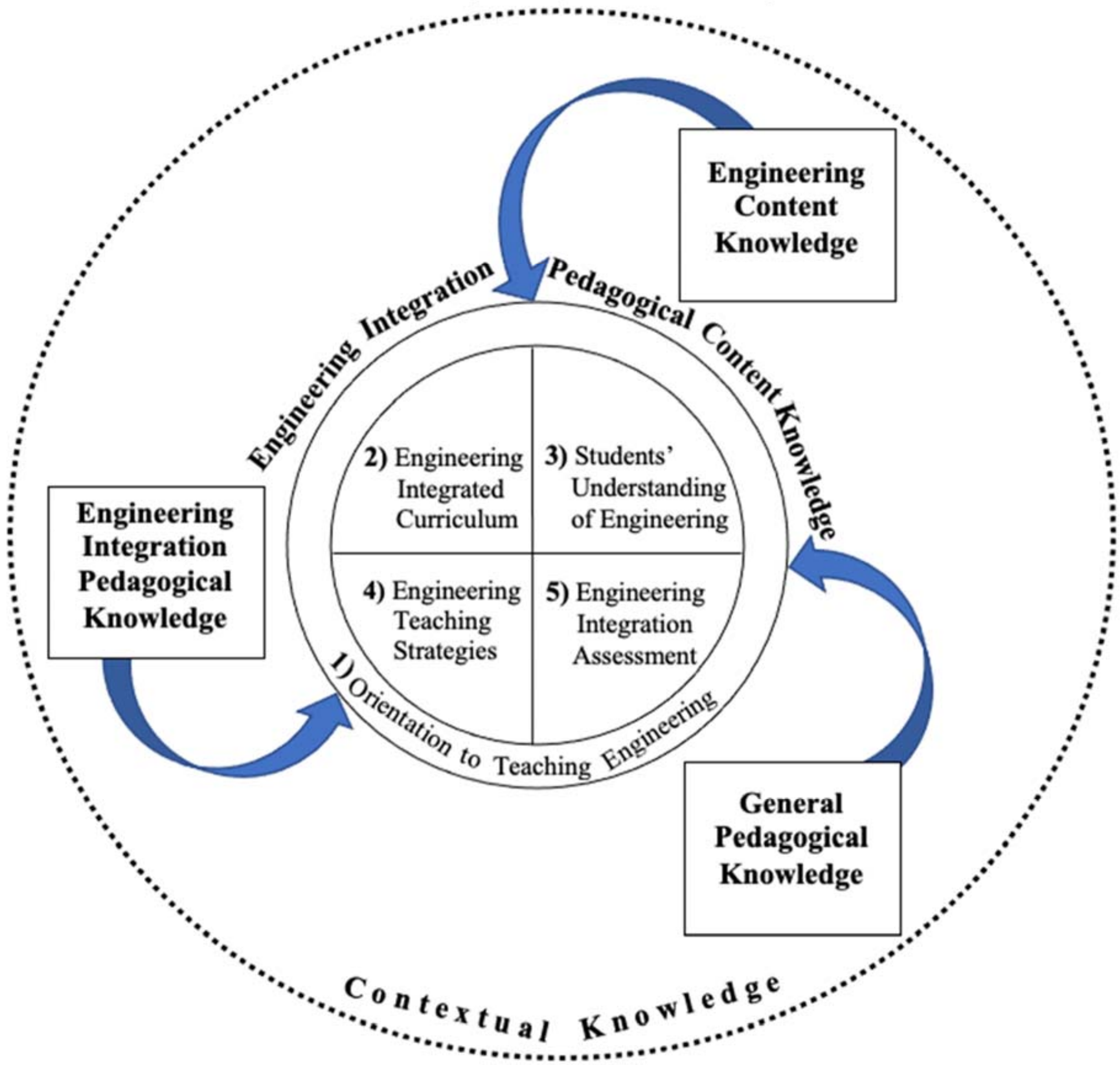

Figure 1. Engineering Integration Pedagogical Content Knowledge and The Relationship Among Teacher Knowledge

EIPCK affects four types of teacher knowledge (domains) which were described as follows:

A. Engineering Content Knowledge refers to teachers' knowledge of engineering concepts, engineering skills/practices, and engineering knowledge. The engineering concepts include concepts such as constraints, systems, optimization, trade-offs, engineering analysis, functionality, and efficiency (Hynes, 2009; NRC, 2012; NGSS Lead States, 2013). engineering skills/practices include systems thinking, creativity, optimism, collaboration, communication, persistence, and ethical consideration/conscientiousness (NAE, 2010, 2019), skills in specifying requirements, decomposing systems, generating solutions, drawing and creating representations, visualization, engaging in argument to defend best solution and redesign, communicating best solution (Yu et al., 2012; NRC, 2012). Engineering knowledge involves (a) engineering science, (b) engineering mathematics, and (c) engineering technical applications (AE3 & ASE, 2020).

B. Engineering Integration Pedagogical Knowledge refers to having a deep understanding of suitable pedagogies (such as project-based learning or design-based learning), the connections of engineering with daily life, and materials suitable for engineering activities (Marquis, 2015). This knowledge requires teachers to decide which engineering integration methods will be the most appropriate for both content and their teaching goals and objectives.

C. General Pedagogical Knowledge refers to knowledge of teachers about general principles and strategies such as classroom management and learning theories (Viiri, 2003: 353). It is a general form of information about different theories about how students learn, classroom management, lesson plan development and implementation, and assessment of students' understanding (Shulman, 1986; Koehler & Mishra, 2008, 2009). This knowledge requires teachers to understand cognitive, social, and developmental learning theories and how to apply them to students in their classrooms (Koehler & Mishra, 2008, 2009).

D. Contextual Knowledge refers to knowledge of students' specific learning contexts works departmental rules, school environment, culture, past experiences, and the other contextual factors that affect teaching (Grossman, 1990). Contextual knowledge allows better integration of culturally-responsive pedagogies (Bond & Russel, 2021)1

Main Components and Sub-Knowledge Types of EIPCK

Component 1 | Knowledge of Orientation to Teaching Engineering (KOTE)

KOTE consists of the knowledge of goals and objectives of teachers about engineering education to be integrated into the specific school subject (e.g., science) and appropriateness for student level. Orientation to teaching engineering is higher in terms of status than the other components of EIPCK (engineering integrated curriculum, students' understanding of engineering, engineering teaching strategy and assessment in engineering") (Magnusson et al., 1999). It contains the knowledge of selecting doable and manageable engineering instructional goals (Yu et al., 2012). In line with the aims and objectives of the teachers regarding engineering education, types of orientation involve "user-centered design", "design-build-test", "engineering science", "engineering optimization", "engineering analysis" and "reverse engineering" (Table 1).

- Sub-knowledge of KOTE: "Belief and knowledge of the aims and goals of engineering education at a particular grade level"

Table 1. Orientations to Teaching Engineering and Aims (adapted from Purzer et al., 2022)

Orientations	**Aim**
User-Centered Design	• Students determine the scope of the engineering challenge and solve it by prioritizing the users' needs and other stakeholders.
Design-Build-Test	• Students physically construct a prototype and test it to solve the engineering challenge.
Engineering Science	• Students generate new technological knowledge by designing controlled experiments.
Engineering Optimization	• Students try to optimize the performance of an existing system.
Engineering Analysis	• Students analyze data and solve engineering challenge by developing mathematical frameworks.
Reverse Engineering	• Students understand what the parts that make up a system or artifacts are and how they work.

Component 2 | Knowledge of Engineering Integration Curriculum (KEIC)

KEIC consists of aspects of engineering goals and objectives and teaching materials. The aspect of engineering goals and objectives includes the knowledge of aims and goals about engineering to be taught in various curriculums (eg. science and technology-design curriculums) and the standards such as engineering, science mathematics concepts/skills related to engineering teaching. The aspect of teaching materials involves the knowledge of materials such as textbooks and plans utilized in engineering teaching.

- Sub-knowledge of KEIC: "Knowledge of student outcomes related to engineering subject-specific"
- Sub-knowledge of KEIC: "Knowledge of preparing course materials appropriate for the goals and objectives of an engineering-integrated subject"

Component 3 | Knowledge of Students' Understanding of Engineering (KSUE)

KSUE consists of aspects of the learning needs and difficulties of students. The aspect of learning needs includes the teacher's knowledge about engineering concepts, skills/practices, students' motivations, interests, and pre-knowledge, which are necessary to effectively learn engineering-integrated subjects. The aspect of learning difficulties includes knowledge of teachers about learning difficulties such as students' misconceptions about the subject and some thinking skills that students need to use when learning the engineering content (Hynes, 2007; Yu et al., 2012).

- Sub-knowledge of KSUE: "Knowledge of the students' learning difficulties related to engineering-integrated subjects"
- Sub-knowledge of KSUE: "Knowledge of which prior knowledge and skills students need to have before learning engineering-integrated subjects"

Component 4 | Knowledge of Engineering Teaching Strategy (KETS)

KETS consists of field-specific teaching strategies in engineering teaching. It involves the knowledge of special strategies (user-centered design, design-build-test, engineering science, engineering optimization, engineering analysis, and reverse engineering) to engineering that the teacher uses in their teaching so that students can understand and use engineering habits of mind, practices (AE3 & ASE, 2020), and tools (Hynes, 2007; Yu et al., 2012).

- Sub-knowledge of KETS: “Knowledge of engineering field-specific teaching strategies”

Component 5 | Knowledge of Assessment in Engineering (KAE)

KAE consists of aspects of what to assess and how to assess. The aspect of what to assess includes the teachers' knowledge about what can be measured and evaluated in their engineering teaching (Hynes, 2007; Yu et al., 2012). The aspect of how to assess includes teachers’ knowledge about which assessment methods can measure and evaluate student outcomes (Yu et al., 2012).

- Sub-knowledge of KAE: “Knowledge of what to assess in an engineering-integrated education”
- Sub-knowledge of KAE: “Knowledge of which assessment methods are used in an engineering-integrated education”

Conclusion

The conceptualized framework aims to describe teachers' engineering integration pedagogical content knowledge (EIPCK) among all grades of K-12 education. In recent years, researchers have been designing and conducting many professional development studies regarding teachers' engineering PCK development (Liu et al. 2009, Reimers et al., 2015, Webb, 2015). The result of the study, especially the sub-knowledges of EIPCK we obtained can be integrated into various subjects (science, mathematics, technology), and led the design studies of curriculum and professional development programs in the future.

In addition to the most frequently used fields for PCK models in the literature (content knowledge, general pedagogical knowledge, and contextual knowledge), our study come up with engineering integration PCK domain distinctively due to engineering’s interdisciplinary nature. Similarly, Yeter (2021)’s results also demonstrated that unit-specific content knowledge and interdisciplinary application were distinctive domains in his instrument development study to elicit elementary teachers’ engineering PCK. To sum up, we hope that the framework of EIPCK will guide educational practitioners and researchers in the development of an instrument to elicit teachers' pedagogical content knowledge and eventually will be able to help facilitate the gain of insight into teachers’ teaching practices in the classroom.

Acknowledgments

This study was supported by The Scientific and Technological Research Council of Türkiye (TÜBİTAK) through 2214-A International Research Fellowship Programme for Ph.D. Students. The opinions expressed are those of the authors and do not necessarily represent those of the TÜBİTAK. The authors would like to specifically thank Associate Professor Morgan Hynes for his valuable contributions to the enhancement of the framework.

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