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Abstract

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Keywords

engineering integration, instrument development, engineering design, K-12 education

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EIPECK: Evaluación del Conocimiento Pedagógico para la Integración de la Ingeniería en la Enseñanza Primaria

Alternate Abstract

Existe un impulso global dirigido a la incorporación de contenidos de ingeniería en los planes de estudios preuniversitarios. En los Estados Unidos, la integración de contenidos de ingeniería se ve reflejada en la versión más reciente de los estándares de educación primaria y secundaria que guían el contenido curricular. A medida que estos estándares se implantan en los planes de estudios, los maestros enfrentan el desafío de obtener conocimientos básicos de ingeniería y la pedagogía apropiada para integrar la ingeniería de forma inclusiva. En este contexto, los programas de formación del profesorado pueden beneficiarse de herramientas de fácil implementación destinadas a medir la preparación de los futuros docentes para integrar la ingeniería en las aulas. Este trabajo describe el desarrollo y la validación de un instrumento que evalúa los niveles de preparación didáctica para integrar la ingeniería desde la perspectiva de los educadores que puede ser usado en diferentes puntos de la preparación académica de los maestros. El instrumento propuesto puede complementar otros me´todos de evaluación, como observaciones en el aula, entrevistas, y reflexiones de aprendizaje por parte del docente. Además, el instrumento se puede utilizar para determinar la eficacia de los programas de preparación docente para preparar a los futuros maestros a integrar la ingeniería en sus clases.

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integración de la ingeniería, instrumentación, diseño en la ingeniería, educación pre-universitaria

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Abstract

Global efforts are underway to include engineering in pre-college curricula. In the USA, this pursuit led to the inclusion of engineering content in the most recent version of the Next Generation Science Standards that guide K-12 science. As these standards become part of the K-12 curriculum, teachers face the challenge of gaining basic engineering literacy, while developing the associated inclusive pedagogies necessary to integrate engineering content into their classrooms. In this context, teacher preparation programs can benefit from easy-to-implement tools that measure preservice teachers' readiness to integrate engineering content in their future classrooms. This work describes the development and validation of an instrument to help assess educators' perceived levels of pedagogical content knowledge for engineering integration at single or multiple time points throughout their academic preparation. The proposed instrument can complement other assessment methods, such as classroom observations, interviews, and journal entries. Additionally, the instrument can be used to help discern the effectiveness of teacher preparation programs in preparing future teachers to integrate engineering.

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Introduction

Global efforts are underway to include engineering in pre-college curricula. In the USA, this pursuit led to the inclusion of engineering content in the most recent version of the Next Generation Science Standards (NGSS) that guide K-12 science education (National Research Council, 2012, 2013). NGSS stress the importance of engineering by expecting all students in primary and secondary grades to gain basic knowledge and skills to effectively utilize engineering design to provide solutions to future societal and environmental challenges (National Research Council, 2013). As these standards get implemented in the K-12 curriculum, preservice teachers (PSTs) face the challenge of gaining basic engineering literacy, while developing the associated inclusive pedagogies necessary to integrate engineering content into their future classrooms. In this context, teacher preparation programs can benefit from easy-to-implement tools that measure PSTs' readiness to integrate engineering content.

This paper addresses this need by developing and validating an instrument to help assess educators' perceived levels of pedagogical content knowledge for engineering integration at single or multiple time points throughout their academic preparation. The EIPECK instrument can complement other assessment methods, such as classroom observations, interviews, and journal entries. Additionally, the proposed instrument can be used to help discern the effectiveness of teacher preparation programs in preparing future teachers to integrate engineering.

Background

The National Research Council has defined engineering as a broad knowledge domain aimed at developing solutions that address specific problems with design constraints through a systematic process (Katehi et al., 2009). Although the domain includes many diverse disciplines, including mechanical, civil, electrical, and industrial, just to name a few, there is a core set of practices common across these disciplines that are considered appropriate for the integration of engineering in the pre-college classroom (Hynes, 2012; National Research Council, 2009; Pleasant & Olson, 2019; Wheeler et al., 2019). The application of the engineering design process to integrate engineering with math and science has emerged as a popular approach to enhance student outcomes in K-12 education (Wheeler et al., 2019). Programs such as Engineering is Elementary (Cunningham, 2017), LEGO® Robotics (Souza et al., 2018), the Teacher Education Program at Tufts University (Portsmore et al., 2019), and Ed+gineering (Cima et al., 2022; Gutierrez et al., 2020; Kidd et al., 2020) have paved the way for teacher preparation initiatives by developing engineering-based curricula that facilitate the inclusion of engineering instruction in K-12 settings. Prior research suggests that integrating engineering content in K-12 requires high-quality training and development programs for teachers (Brophy et al., 2008; Roehrig et al., 2012). These programs should incorporate appropriate pedagogical and domain knowledge (Brophy et al., 2008; Shulman, 1986).

Pedagogical Content Knowledge

Previous research in educational practice has attempted to capture the essential qualities, strategies, and knowledge of effective educators. Several researchers have pointed out the multiple knowledge domains (i.e., content, pedagogy, curriculum, learners) that teachers should utilize as part of their instruction (Evens et al., 2018; Grossman, 1990; Lehmann et al., 2019; Shulman, 1986; Wilson et al., 1987). Preparing teachers to integrate engineering into the K-12 classroom requires developing relevant pedagogical knowledge, basic domain knowledge, and the intersection of the two often referred to as pedagogical content knowledge (PCK) (Brophy et al., 2008; Shulman, 1986).

PCK is a type of knowledge unique to teaching that incorporates key domains that connect a teacher's cognitive understanding of the subject matter content with the knowledge of how to teach that content effectively (Shulman, 1986). Gess-Newsome (1999) identified two models of teacher cognition regarding PCK, the *integrative model* and the *transformative model*. The integrative model looks at how the three domains—subject matter, pedagogy, and content—are integrated (Gess-Newsome, 1999). The transformative model uses PCK to transform the three domains into a unique form that is subject-specific. Transformative PCK models can help shed light on K-12 teaching practices in specific subject areas and have been successfully applied in science and engineering teacher education (Kind, 2009). Thus, the model guiding the development of EIPECK (Engineering Integration Pedagogical Content Knowledge) is the transformative model of PCK. PCK models capture the knowledge of the subject matter, understanding students' conceptions of the subject, and pedagogical knowledge teachers need to communicate effectively while increasing students' level of comprehension in the relevant subject area (Jang & Chen, 2010; Shulman, 1986). The PCK framework has been widely used and adapted in the last two decades to study preservice and in-service teachers' knowledge of how to teach specific subject areas such as mathematics, science, and educational technology (Zelkowski et al., 2013).

Technological Pedagogical and Content Knowledge

An example of an extension of PCK focusing on specific areas is Mishra and Koehler's (2006) technological pedagogical and content knowledge (TPACK) framework. This work extended Shulman's original PCK framework to capture the pedagogical content knowledge associated with the integration of technology into teaching. This framework includes a new knowledge dimension that captures technology knowledge and two prior dimensions originally proposed by Shulman (1986), namely pedagogical knowledge and content knowledge. Technological knowledge was created to describe the knowledge of standard and advanced technologies needed to apply them productively in everyday life, adapt to changes in technology, and recognize how technology can assist in achieving goals (Koehler et al., 2011; Mishra & Koehler, 2006). The resulting intersection of the three types of teacher knowledge describes a new, unique body of knowledge, technological PCK. TPACK captures the knowledge required by teachers to integrate technology into their instruction. The TPACK framework led to the development of instruments to measure teachers' understanding of technological PCK (Schmidt et al., 2009), including assessments of specific technologies, content areas, and pedagogical approaches (Yanış & Yürük, 2020). Other studies have attempted to establish the specific competencies inherent to TPACK (Thohir et al., 2020).

Culturally Responsive Pedagogy

The development of the proposed EIPECK instrument builds on the foundation established by Shulman's (1986) PCK and TPACK frameworks (Mishra & Koehler, 2006; Schmidt et al., 2009) by extending the work to integrate engineering content with an emphasis on inclusive and culturally responsive pedagogy (CRP) (Gay, 2002; Ladson-Billings, 2014). The culturally responsive pedagogical knowledge domain was included in response to the calls to make science, technology, engineering, and mathematics (STEM) education accessible, engaging, and responsive to students from diverse cultures and backgrounds (Brown, 2017; Watkins et al., 2018). Culturally responsive teaching uses knowledge of students' cultural backgrounds to enhance their learning through asset-based approaches that have the potential to challenge oppressive systems (Lee & Buxton, 2010).

CRP and Engineering Pedagogical Knowledge

Prior research found that the ability to help acquire and transform student knowledge through approaches and methods that are pedagogically sound and responsive to diverse groups is at the core of successful teaching (Brown, 2017; Watkins et al., 2018). There is evidence that teacher preparation programs can help future educators gain engineering subject matter knowledge while developing pedagogical competencies to teach students from different backgrounds and cultures (Fogg-Rogers et al., 2017; Wendell, 2014). The engineering design process is an approach to solving problems using real-world contexts through a hands-on approach that, if used effectively, can engage diverse groups of students by working on problems that connect to their lives, their communities, and their cultural backgrounds (Brown, 2017; Householder & Hailey, 2012). Basic engineering literacy and familiarity with engineering pedagogical practices that incorporate culturally responsive instruction are fundamental to achieving effective engineering integration (Holly Jr, 2021; Manuel, 2022).

The potential for engineering integration to enhance student engagement and achievement is of particular significance for historically underserved populations (Estrada et al., 2016). This research acknowledges the criticality of introducing PSTs to pedagogical approaches that are inclusive and culturally responsive so that the potential benefits of engineering integration can be realized by all students. Effective integration of engineering in the K-12 context should also translate into engineering being more appealing and accessible to all students, especially those underrepresented in STEM fields. Thus, the proposed framework incorporates a dimension to assess the educator's perceived ability to design and enact instructional approaches that are sensitive to and informed by students' cultural backgrounds (Gay, 2002; Ladson-Billings, 2009, 2014). This pedagogical knowledge dimension represents teachers' understanding of CRP (Gay, 2002; Ladson-Billings, 2014), which is crucial to creating culturally and ethnically inclusive learning environments (Villegas & Lucas, 2002).

This research proposes an engineering PCK framework that contributes two fundamental domains to prior frameworks: knowledge of effective strategies for engineering integration (Cunningham & Carlsen, 2014; Hsiao, 2015; Richards et al., 2007) and knowledge of CRP (Gay, 2002, 2018; Gay & Kirkland, 2003; Ladson-Billings, 2009, 2014).

Prior Research on Engineering PCK

The growing interest in integrating engineering content in K-12 education has led to the development of approaches to assess the knowledge that teachers need to integrate engineering (Holly Jr, 2021; Hsu et al., 2011). Existing instruments that measure teachers' PCK in STEM areas mainly focus on mathematics and science (Hill et al., 2004; Pell & Jarvis, 2003; Schoen et al., 2017; Zelkowski et al., 2013). For example, Park and Oliver (2008) examined PCK for science teaching with three in-service chemistry teachers and found that teacher efficacy emerged as an affective component for PCK. They also highlighted that growth in teacher efficacy may be increased through learning the PCK domains, but "the most powerful changes result from experience in practice" (p. 278). Lee and colleagues (2007) followed 25 science educators through their first year of teaching to determine the ways in which PCK evolved through their instructional practice. In their study using a PCK rubric, novice science teachers showed limited or basic PCK, suggesting that PCK development may happen concurrently with additional classroom instructional experience.

Prior studies have begun to address the need for a framework to guide the development of engineering PCK at the pre-college level (Hynes, 2012; Perkins Coppola, 2019; Yeter, 2021). Research that has attempted to describe the PCK needed to teach K-12 engineering suggests that teachers need a thorough understanding of the engineering design process, the purpose behind all the steps, and be able to provide relevant, real-world examples to their students (Hynes, 2012; Love & Hughes, 2022; Sun & Strobel, 2014; Yeter, 2021). Sun and Strobel (2014) emphasize the importance of the specific context in which the engineering instruction occurs, noting that teachers need to understand the abilities and backgrounds of their learners and the educational setting to enact engineering instruction successfully. The authors found that the trial-and-error process in which the elementary teachers engaged as part of the teaching was essential for their construction of engineering PCK (Sun & Strobel, 2014). With a similar focus on context, other researchers suggest that engineering educators, particularly those who teach at the high school level, require PCK specific to the engineering topics of the lessons they teach (Love & Hughes, 2022; Yeter, 2021). Some of these prior studies exclude some key elements of inclusive engineering pedagogy (Holly Jr, 2021; Schmidt et al., 2009; Zelkowski et al., 2013), whereas others use classroom observation measures (Hynes, 2012; Love & Hughes, 2022; Yeter, 2021) that are not feasible for PSTs (Wheeler et al., 2019), who lack their own classroom. Others use time-intensive qualitative methods such as interviews and open-ended surveys (Sun & Strobel, 2014), making multiple assessments throughout teacher preparation onerous. Yaşar et al. (2006) proposed a quantitative instrument to assess teachers' perceptions of and familiarity with teaching design, engineering, and technology. However, this instrument has been used with in-service teachers (Hsu et al., 2011) and does not assess engineering PCK.

The findings from this study contribute to pre-college engineering education by proposing an approach to assess the levels of development of PSTs' engineering PCK domains within their teacher preparation programs. No evidence was found of a specialized instrument to assess perceived engineering PCK for PSTs that incorporates CRP.

The proposed instrument can be used to assess readiness to integrate engineering, identify gaps in PSTs' preparation, or help evaluate interventions aimed at building engineering pedagogical competencies. The survey instrument captures PSTs' self-assessment of their understanding of each domain from the EIPECK framework.

The EIPECK Framework

This research builds on Shulman's (1986) work on PCK by introducing two new knowledge domains associated with effective and inclusive engineering integration into the K-12 curriculum. One domain, engineering PCK, comprises a self-reported understanding of pedagogical approaches particular to engineering in K-12 settings. The second, awareness of CRP (Gay, 2002; Ladson-Billings, 2009), captures PSTs' awareness of pedagogy and perspectives that facilitate inclusive instruction and learning in culturally diverse classrooms (Gay & Kirkland, 2003; Ladson-Billings, 2009). This domain intends to capture teachers' awareness of CRP, which has been largely excluded from prior pedagogical knowledge frameworks (Brown, 2017; Hong et al., 2011). The EIPECK framework intends to capture four major pedagogical knowledge dimensions that assess PSTs' perceived ability to integrate engineering utilizing inclusive and culturally responsive instructional approaches (Gay & Kirkland, 2003). The framework does not include a separate dimension for engineering content knowledge because the inclusion of engineering in K-12 settings has focused on the use of the engineering design process as a way to integrate engineering into existing subjects (i.e., math and science) (National Research Council, 2009; Pleasant & Olson, 2019). Thus, the engineering content knowledge necessary to teach at the K-12 level does not typically involve mastery of engineering facts, concepts, or theories but rather requires the hands-on application of the engineering design process as an approach to solving problems using math and science concepts (Cunningham & Carlsen, 2014).

The proposed EIPECK framework includes four domains: engineering pedagogical content knowledge (EPCK), knowledge of engineering practices (KEP), general pedagogical knowledge (PK), and culturally responsive pedagogical awareness (CRPA). These domains build on Shulman's knowledge categories extending them to pedagogical knowledge considered critical for achieving effective and inclusive engineering instruction (Cunningham & Carlsen, 2014), and it is based on self-assessment measures. Each domain is defined below in the context of PSTs.

Engineering Pedagogical Content Knowledge

Cunningham and Carlsen's (2014) conceptualization of effective K-12 engineering instruction informed the EPCK domain. EPCK is a measure of the knowledge of pedagogical methods, practices, and relevant strategies for teaching engineering-related content in a K-12 setting from the perspective of the PST. It comprises pedagogical approaches such as using brainstorming in solution design, considering multiple solutions and paths, tolerating failure as part of creating solutions, and considering requirements and constraints. The EPCK domain focuses on the engineering design process as a strategy teachers can use to integrate engineering content, including acting as facilitators of learning through elicitation and questioning (Cunningham & Carlsen, 2014). EPCK includes knowledge of project-based learning and the use of engineering design challenges that prompt students to develop solutions to specific problems and reflect on, evaluate, and improve those solutions using data and evidence (Krajcik et al., 2008). Engineering pedagogy differs from traditional pedagogies in that it relies on increased interaction through hands-on activities, incorporating authentic problems and contexts of application, and providing opportunities to showcase learners' creativity (Hayes et al., 2016; Mbodila & Muhandji, 2012). In traditional pedagogy, students typically start with lower-order thinking skills such as remembering and understanding. Later, they are expected to move into higher-order skills such as applying, analyzing, evaluating, and creating (Anderson & Krathwohl, 2001). In engineering pedagogy, students are often encouraged to use higher-order thinking skills early on to help them identify and design solutions to concrete societal problems using the engineering design process. The EPCK dimension captures PSTs' knowledge of pedagogical approaches that are aligned with the application of the engineering design process as a way to design solutions.

Knowledge of Engineering Practices

This knowledge domain refers to basic knowledge about engineering and relevant engineering practices. It distinguishes engineering from science (Pleasants & Olson, 2019) by delineating specific elements of engineering practice (Cunningham & Carlsen, 2014; Cunningham & Kelly, 2017; Katehi et al., 2009). For example, asking questions is a science practice, while defining problems is an engineering practice. Constructing evidence-based explanations to answer a posed question is considered a scientific practice while designing solutions to solve a defined problem is considered an engineering practice. The engineering design process is the engineering practice most emphasized in the NGSS. Engineering design follows an iterative cycle that encourages productive failure and provides informative feedback, offering opportunities for self-regulation and learning from mistakes (Cunningham & Carlsen, 2014; Lottero-Perdue & Parry, 2017). Furthermore, it allows for multiple valid solutions to a problem rather than one unique solution. These approaches may be new to teachers and distinct from strategies used in science classrooms. Thus, acquiring KEP is critical for K-12 teachers to understand the nature of engineering and clearly distinguish between science and engineering practices (Cunningham & Carlsen, 2014; Cunningham & Kelly, 2017). KEP includes practices outlined in the NGSS, such as the ability to define problems clearly, the ability to evaluate different solutions, especially in the context of known constraints, knowledge about the nature of engineering as a discipline, awareness of different fields of engineering, and the use of the engineering design process to develop solutions (Pleasants & Olson, 2019). KEP aims to capture teachers' understanding of engineering as an applied scientific discipline that helps solve real-world problems.

General Pedagogical Knowledge

The PK domain follows the approach proposed by Mishra and Koehler (2006) in their TPACK framework. It refers to general knowledge about "the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims" (Mishra & Koehler, 2006, p. 1026). The PK dimension captures general aspects of pedagogical knowledge in the K-12 instructional domain, such as knowledge of classroom management, lesson plan development, instructional techniques, and assessment strategies for evaluating students' understanding and disposition toward learning (Mishra & Koehler, 2006; Mishra et al., 2011; Schmidt et al., 2009). This dimension was adapted from Mishra and Koehler's (2006) pedagogical knowledge dimension to capture the context of engineering integration for PSTs (Mishra & Koehler, 2006; Schmidt et al., 2009).

Culturally Responsive Pedagogical Awareness

The CRPA domain reflects a PST's familiarity with approaches to teaching and learning that use knowledge of students' cultural backgrounds to enhance student learning, and it is informed by prior work in culturally responsive teaching Gay, 2018; Ladson-Billings, 2009). Although there is a broad acknowledgment of the importance of using culturally responsive pedagogies in K-12 settings, there are few studies to date examining their use in pre-college engineering education settings (Holly Jr, 2021). The tenets of the proposed dimension incorporate considerations of students' cultural backgrounds into the pedagogical approach to teaching engineering content in K-12 settings by drawing on students' relevant life experiences and backgrounds and using them as authentic contexts and assets to promote learning (Holly Jr, 2021; Ladson-Billings, 2009). The CRPA dimension captures PSTs' perceived ability to reflect on their worldview and consider how it impacts their teaching and learning (Gay, 2002). CRPA reflects a PST's ability to observe individual and collective cultural differences in their students and the ability to use that understanding to facilitate inclusive instruction

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(Villegas & Lucas, 2002). Culturally responsive pedagogical approaches compel educators to be mindful of their instructional strategies and chosen resources, such that they promote a positive classroom climate that encourages the contributions of diverse, underrepresented populations and projects a commitment to the education of all students (Gay, 2018; Hsiao, 2015; Richards et al., 2007).

It has been suggested that culturally responsive pedagogical strategies can make learning more effective when used in diverse socio-cultural groups through asset-building approaches (Lee & Buxton, 2010). This conceptualization uses an asset-based rather than a deficit-based perspective of instruction centering around the strengths and funds of knowledge that students bring to the classroom (e.g., students' cultural heritage and knowledge of a second language) (Moll et al., 1992). The CRPA dimension aims to capture an awareness of pedagogies and perspectives that facilitate inclusive engineering instruction and learning in culturally diverse K-12 classrooms. It also incorporates PSTs' understanding of the role of engineering as a tool to support societal well-being (Hsiao, 2015; Richards et al., 2007) and to solve problems that are culturally relevant to the students. The items included in the CRPA scales build on the work by Siwatu (2011). The dimension of CRPA captures PSTs' awareness about culturally responsive pedagogical approaches such as knowledge and familiarity with students' background, identity, and language, knowledge about reflective teaching practices, and ability to build connections, communicate expectations, and elicit prior knowledge in diverse groups of students. The items included in the CRPA final scale are listed in Appendix C.

Engineering Integration Pedagogical Content Knowledge (EIPECK)

The proposed EIPECK framework incorporates all the previously defined domains of engineering content knowledge and related pedagogies. The framework captures pedagogical knowledge domains that can support PSTs when integrating engineering content into their future K-12 classrooms. The EIPECK framework builds on the PCK construct (Shulman, 1986), the TPACK framework (Mishra & Koehler, 2006; Schmidt et al., 2009), evidence-based features of successful engineering instruction in K-12 settings (Cunningham & Carlsen, 2014), and CRP (Gay, 2018; Ladson-Billings, 2009). EIPECK provides a framework to examine PSTs' level of readiness to integrate engineering into their teaching.

Method

This study presents a framework and an assessment instrument applicable to various teacher preparation contexts capturing pedagogical knowledge constructs associated with effective K-12 engineering integration (Cunningham & Carlsen, 2014).

Instrument Development

The first step to developing the instrument was an in-depth literature review of existing instruments that assess PCK for engineering integration in K-12. This review revealed the absence of instruments to assess engineering PCK of PSTs from a culturally responsive perspective. One relevant instrument focused on in-service teachers' perceptions of and familiarity with teaching design, engineering, and technology (Yaşar et al., 2006). This instrument does not examine engineering PCK distinctly from technology, and it does not include a dimension of CRP. Culturally responsive pedagogical practices were included as an element of the proposed EIPECK framework heeding reiterated calls for inclusive teaching approaches that can broaden the talent pipeline in STEM disciplines and benefit students from all backgrounds and socioeconomic statuses (Brophy et al., 2008). The development of the EIPECK instrument involved identifying critical knowledge dimensions of effective integration of engineering into K-12 education based on prior evidence-based research and best practices (Cunningham & Carlsen, 2014; Krajcik et al., 2008; Tuttle et al., 2016). The EIPECK framework captures core pedagogical knowledge domains for K-12 engineering integration and highlights the importance of mastering this knowledge to successfully integrate engineering content into teaching practice (Steinberg et al., 2015).

Item development followed an iterative process building on prior work on the TPACK instrument (Schmidt et al., 2009) combined with a review of the literature related to engineering PCK and CRP (e.g., Cunningham & Carlsen, 2014; Gay, 2018; Ladson-Billings, 2009; Siwatu, 2011). This process led to a preliminary set of items that were later evaluated, modified, and discussed by one engineering education and two teacher education faculty to align with the four knowledge domains of EIPECK. The collection of items went through several rounds of expert validation led by an additional team of four content and pedagogy experts (science teacher educator, CRP scholar, K-12 engineering education expert, and science methods educator). The experts examined the alignment between the items and the pedagogical knowledge domains of the EIPECK framework. This expert assessment led to a preliminary version of the EIPECK instrument consisting of 32 items (EPCK = 10, KEP = 6, PK = 8, CRPA = 8) with a five-point Likert scale. This preliminary version went through two

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stages of exploratory factor analysis (EFA) using two independent samples. The list of items in the initial scale is displayed in Appendix A. Next, we present the methodological approach to the validation study.

Participants

The preliminary version of the EIPECK instrument was distributed through an online survey. The validation process relied on two different samples of PSTs recruited from a large teacher preparation program at a minority-serving institution. A total of 450 participants were recruited. The first sample ($n = 335$) was used for the initial EFA to refine the dimensions and establish the factor structure. The second sample was used for consolidating the factor structure. Participants completed the survey at the end of the semester. Participation in this study was voluntary. The University's human subjects review board approved the protocol and data collection.

Sample Descriptive Data

Next, we present some descriptive data on the samples. The first sample included data from 335 PSTs from a large teacher education program in the Mid-Atlantic region. The sample included 15.5% males ($n = 52$), 83.5% females ($n = 280$), and 0.9% unspecified ($n = 3$). Additionally, 43.2% were planning to teach in early childhood grades (PreK-2), 29% in intermediate grades (3–5), 4.8% in middle school (6–8), 22.7% in high school (9–12), and 0.3% did not specify. According to their ethnicity, 63.9% self-identified as White ($n = 214$), 5.4% Hispanic, Latinx, or Spanish ($n = 18$), 18.5% Black or African American ($n = 62$), 1.2% Asian or Pacific Islander ($n = 4$), 9.6% Mixed Race ($n = 32$), and 1.5% unspecified ($n = 5$).

The second sample included 115 PSTs from the same teacher education program. The sample included 16.5% males ($n = 19$), 79.1% females ($n = 91$), and 4.4% who did not specify a gender. Additionally, 42.6% were planning to teach in early childhood grades (PreK-2), 27.8% in intermediate grades (3–5), 3.5% in middle school (6–8), 22.6% in high school (9–12), and 3.5% did not specify ($n = 4$). According to their ethnicity, 60% self-identified as White ($n = 69$), 5.2% Hispanic, Latinx, or Spanish ($n = 6$), 22.6% Black or African American ($n = 26$), 0.9% Asian or Pacific Islander ($n = 1$), 7.8% Mixed Race ($n = 9$), and 3.5% unspecified ($n = 4$).

Approach to Validation Study

A factor analysis procedure was used to determine the psychometric properties of the EIPECK instrument. Evidence of construct validity of the four knowledge domains suggested by the EIPECK framework was gathered using two iterations of EFA with principal axis factoring extraction and Oblimin rotation. EFA is a statistical procedure used in instrument development to consolidate variables and understand the underlying latent factor structure (Furr, 2017). The initial stage of EFA used the first sample to test the dimensionality of the initial 32-item scale and refine the items included in each construct by addressing low-loading items and cross-loading issues. Following this preliminary analysis, four experts in teacher education and engineering instruction revised the set of items and provided feedback on content validity. Next, we tested the dimensionality of the scale using the second sample. EFA was used to consolidate the factor structure and gather evidence of instrument reliability. Following the recommendations from Kaiser (1974), a Kaiser–Meyer–Olkin (KMO) index of 0.8 was used to evaluate the sample adequacy for factor analysis. The factor structure was determined based on Kaiser eigenvalues greater than one, the scree plot, and factor loadings greater than 0.5 (Costello & Osborne, 2005). The reliability of the instrument was examined through its internal consistency using Cronbach's alpha coefficient, with values of 0.8 or above considered acceptable (Field et al., 2012; Kline, 2013). All analyses used SPSS statistical package version 27.

Results

Descriptive Analysis

Descriptive statistics of the sample, including mean, standard deviation, and skewness of the 32 initial survey items, are displayed in Table 1. Factor analysis procedures followed recommended criteria regarding sample size and normality (Beavers et al., 2013; Hair et al., 2014). The sample size aligned with the recommendations of at least 100 cases (Hair et al., 2014), and skewness statistics with critical values between -2 and 2 (Zygmont & Smith, 2014) supported the normality assumption (Table 1). The following sections present the results from the EFA and analysis of the reliability of EIPECK.

Table 1
Descriptive statistics of initial 32 items.

Item	Mean	Standard deviation	Skewness
Q1.PK	4.17	0.65	−0.83
Q2.PK	4.1	0.77	−1.08
Q3.PK	3.51	1.32	−0.58
Q4.PK	3.86	0.94	−0.8
Q5.PK	3.89	0.98	−0.92
Q6.PK	3.87	1.01	−0.84
Q8.PK	3.99	0.92	−0.95
Q9.PK	4.19	0.8	−0.99
Q10.EPK	3.13	1.23	−0.28
Q11.EPK	3.34	1.16	−0.55
Q12.EPK	4.05	0.91	−1.06
Q13.EPK	4.17	0.86	−1.2
Q14.EPK	3.65	1.22	−0.78
Q15.EPK	3.18	1.21	−0.32
Q16.EPK	3.07	1.27	−0.15
Q17.EPK	2.79	1.34	0.12
Q18.EPK	3.13	1.28	−0.24
Q19.EPK	3.21	1.26	−0.28
Q20.KEP	2.9	1.31	−0.1
Q21.KEP	3.05	1.33	−0.23
Q22.KEP	4.24	0.9	−1.44
Q23.KEP	3.4	1.18	−0.54
Q24.KEP	3.17	1.36	−0.21
Q25.CRPA	3.94	1.03	−1.11
Q26.CRPA	3.56	1.17	−0.65
Q27.PK	4.16	0.85	−1.09
Q33.KEP	3.79	1.19	−0.88
Q28.CRPA	4.83	0.47	−3.39
Q29.CRPA	4.81	0.46	−2.69
Q30.CRPA	4.47	0.78	−1.65
Q31.CRPA	3.77	1.16	−0.71
Q32.CRPA	3.35	1.22	−0.45

Note. Mean inter-item correlation = 0.399. Cronbach's alpha = 0.958.

Exploratory Factor Analysis

EFA was applied to the sample data using principal axis factoring extraction and Oblimin rotation. When determining the rotation method, we considered the factor correlation matrix and the factor structure. The factor correlation matrix displayed some coefficients approaching 0.5 or above, which supports using oblique rotation (Tabachnick et al., 2007). The pattern matrix from the Oblimin rotation method uncovered a factor structure similar to the factor structure computed with orthogonal rotation, but it accounted for the potential associations among factors. Based on this evidence, we pursued an oblique (Oblimin) rotation. The Kaiser eigenvalues suggested the presence of a four-factor structure as originally intended by the framework. The KMO index supported the factorability (KMO = 0.946, $p < 0.01$) of the 32-item initial scale. The resulting structure explained 63.86% of the variance in the final factor solution. Most items loaded under the intended knowledge domain factors, but some items displayed low loadings or loaded on a different factor from that originally expected.

This first round of EFA suggested changes in the specific items included in each factor. For instance, two additional items loaded into PK beyond the original eight items. EPCK resulted in seven items because three items did not load this factor. Similarly, two items were dropped from KEP, which resulted in four items for this construct. The EFA also revealed an insufficient number of items loading clearly on the CRP factor or cross-loading on other factors. The research team proposed additional items for the CRP factor based on an in-depth review of the CRP literature (e.g., Gay, 2002, 2018; Hsiao, 2015; Ladson-Billings, 2009; Richards et al., 2007; Siwatu, 2011; Smolleck et al., 2006) and consultation with an expert in culturally responsive pedagogy following the approach by Zelkowski and colleagues (2013). The expert provided comments and suggestions for problematic items and, in some cases, offered additional items. A similar approach was used to re-evaluate the KEP and EPCK scales with input from two experts in pre-college engineering education. This stage resulted in eleven additional items added to CRPA, four new items added to KEP, and one new item added to EPCK.

The inclusion of these items improved the balance of items per construct in the overall instrument. Table 2 lists the number of items under each knowledge domain of the revised version of the EIPECK instrument before the second EFA. A detailed description of the items in the revised scale before the final EFA is presented in Appendix B.

Final EFA

The final EFA followed three phases: extraction, rotation, and interpretation of the factors. The first part of the analysis was the extraction of factors. Principal components, principal axis factoring, and maximum likelihood were compared to identify the method with the most stable commonalities. Principal axis factoring was considered superior since the item development followed a conceptual approach (i.e., trying to understand the shared variance in a set of X variables through a small set of latent factors) instead of the mathematical approach to extraction following suggestions by Warner (2012). The differences between initial and extracted commonalities also favored the use of principal axis factoring. The number of factors extracted was determined based on the results from the EFA evaluation and the scree plot (Figure 1). Both results suggested the extraction of four factors with a resulting structure explaining 62.52% of the variance. The KMO index (KMO = 0.880, $p < 0.01$) for 41 items indicated that the four-factor structure from the EFA is appropriate for the data.

Rotation was then used to improve the structure of the four factors using the oblique (Oblimin) method (Tabachnick et al., 2007). Based on the recommendations from Costello and Osborne (2005) for EFA, a criterion of item loadings equal to or better than 0.5 was considered an indicator of a robust factor structure. Most items loaded uniquely on their predicted factors, but six had cross-loadings on other factors. These six items were examined following the sequential approach by Furr (2017). This review suggested excluding those items leading to a final set of 35 items with no remaining cross-loadings. The final instrument showed clear loadings on the four proposed factors accounting for 63.47% of the variance in the solution. Table 3 shows the items and loadings under the proposed constructs representing the knowledge domains of EIPECK. The headings also indicate the number of items by factor (n), the sum of squares loadings (SSL), and the factor's contribution to the variance (Cont.).

Internal Consistency of Subscales

The estimation of reliability was done by examining the internal consistency of the subscales and overall instrument using Cronbach's alpha coefficient. The four subscales exhibited strong internal consistency with the following respective Cronbach's alphas: EPCK ($\alpha = 0.955$), PK ($\alpha = 0.879$), KEP ($\alpha = 0.927$), CRPA ($\alpha = 0.946$), and overall ($\alpha = 0.956$).

Table 2
Revised knowledge domains and items for the EIPECK instrument.

Knowledge domain	Number of items
EPK—engineering pedagogical knowledge	8
PK—pedagogical knowledge	10
KEP—knowledge of engineering practices	10
CRPA—culturally responsive pedagogical awareness	13
Total	41

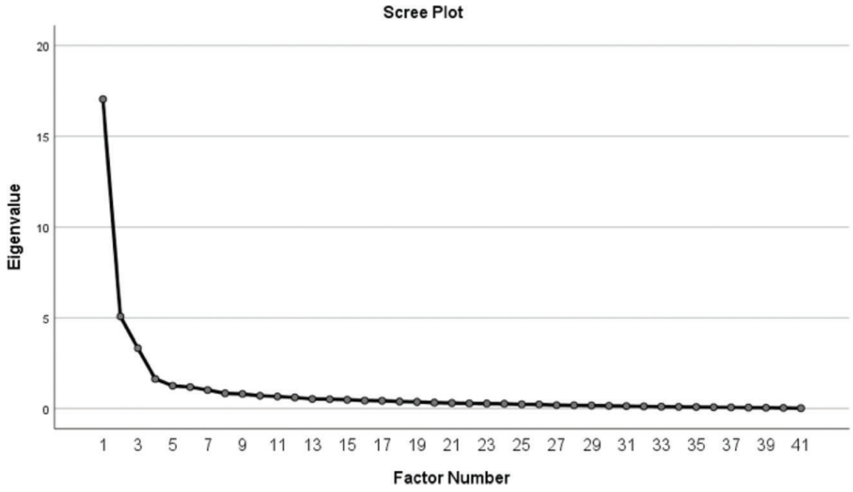

Figure 1. Final version scree plot.

Table 3
Rotated factor loadings from the second exploratory factor analysis.

Item	KEP (n = 9)	EPK (n = 7)	PK (n = 7)	CRPA (n = 12)	Factor 1 Cont.	Factor 2 Cont.	Factor 3 Cont.	Factor 4 Cont.
PK.Q1			0.65				0.423	
PK.Q2			0.734				0.539	
PK.Q4			0.69				0.476	
PK.Q5			0.556				0.309	
PK.Q6			0.729				0.531	
PK.Q7			0.589				0.347	
PK.Q8			0.692				0.479	
EPK.Q11		−0.766				0.587		
EPK.Q14		−0.769				0.591		
EPK.Q12		−0.847				0.717		
EPK.Q15		−0.627				0.393		
EPK.Q16		−0.612				0.375		
EPK.Q17		−0.796				0.634		
EPK.Q18		−0.778				0.605		
KEP.Q19	0.627				0.393			
KEP.Q20	0.707				0.5			
KEP.Q21	0.613				0.376			
KEP.Q23	0.68				0.462			
KEP.Q24	0.667				0.445			
KEP.Q25	0.706				0.498			
KEP.Q26	0.828				0.686			
KEP.Q27	0.699				0.489			
KEP.Q28	0.729				0.531			
CRPA.Q29				−0.749				0.561
CRPA.Q30				−0.817				0.667
CRPA.Q31				−0.773				0.598
CRPA.Q32				−0.616				0.379
CRPA.Q33				−0.908				0.824
CRPA.Q34				−0.686				0.471
CRPA.Q35				−0.567				0.321
CRPA.Q36				−0.542				0.294
CRPA.Q37				−0.631				0.398
CRPA.Q38				−0.787				0.619
CRPA.Q40				−0.715				0.511
CRPA.Q41				−0.742				0.551
SSL	4.38	3.902	3.104	6.195				

Note. Extraction method: principal axis factoring; rotation method: Oblimin.

As shown in Table 4, all subscales exhibited acceptable levels of discrimination considering the cutoff value of corrected item-total correlation (CITC) > 0.3, generally used to define item discrimination (Nunnally & Bernstein, 1994). In line with methodological recommendations (Kyriazos, 2018), our results indicate the strength of item loadings in all factors and a balanced number of items per factor, which provide some evidence for the construct validity of the factor solution.

In summary, we found evidence of the EIPECK instrument's robust psychometric properties. The results of the factor analysis supported the four-dimension structure of the instrument. Cronbach's alpha coefficients showed that each factor and the overall scale have acceptable internal consistency. The list of items in the final EIPECK instrument is displayed in Appendix C.

Discussion

The increased expectation for engineering integration in K-12 is driving teacher preparation programs to develop and assess PSTs' readiness to integrate engineering. This study proposes a framework and an instrument to evaluate PSTs' readiness for effective and inclusive engineering instruction in K-12 education. The instrument extends prior work (Shulman, 1986) in two ways. First, it offers a focus on PSTs, and second, it incorporates two pedagogical knowledge dimensions into its framework—effective engineering instruction (Cunningham & Carlsen, 2014) and CRP (Gay, 2002, 2018)—that assess PSTs' perceived pedagogical knowledge in content areas that are considered critical for effective and culturally responsive integration of engineering content in K-12 classrooms. The incorporation of a culturally responsive dimension of pedagogical knowledge is

Table 4
item-total statistics by EIPECK factor.

Factor	Item	Scale mean if item deleted	Scale variance if item-deleted	CITC	Cronbach alpha if item deleted
Pedagogical knowledge (PK) (α = 0.879)	PK.Q1	9.06	9.18	0.715	0.858
	PK.Q2	9.16	9.344	0.667	0.864
	PK.Q4	8.77	8.164	0.686	0.861
	PK.Q5	8.98	8.877	0.613	0.869
	PK.Q6	8.84	8.116	0.719	0.855
	PK.Q7	9.08	9.196	0.599	0.87
	PK.Q8	9.03	8.823	0.707	0.857
Engineering pedagogical knowledge (EPK) (α = 0.955)	EPK.Q11	10.51	24.006	0.823	0.95
	EPK.Q14	10.56	24.249	0.796	0.952
	EPK.Q12	10.57	23.808	0.837	0.949
	EPK.Q15	10.52	23.936	0.84	0.948
	EPK.Q16	10.63	23.637	0.841	0.948
	EPK.Q17	10.61	22.819	0.901	0.943
	EPK.Q18	10.68	23.624	0.876	0.945
Knowledge of engineering practices (KEP) (α = 0.927)	KEP.Q19	12.98	26.124	0.682	0.922
	KEP.Q20	13.19	25.909	0.735	0.918
	KEP.Q21	13.21	26.221	0.732	0.918
	KEP.Q23	13.28	25.036	0.783	0.915
	KEP.Q24	13.38	25.051	0.835	0.911
	KEP.Q25	13.44	25.894	0.773	0.916
	KEP.Q26	13.48	26.942	0.701	0.92
	KEP.Q27	13.56	27.452	0.682	0.921
	KEP.Q28	13.68	28.183	0.71	0.921
Culturally responsive pedagogical awareness (CRPA) (α = 0.946)	CRPA.Q29	15.25	28.032	0.71	0.943
	CRPA.Q30	14.96	26.477	0.77	0.941
	CRPA.Q31	15.11	26.98	0.789	0.94
	CRPA.Q32	15.1	27.256	0.701	0.943
	CRPA.Q33	15.08	26.091	0.797	0.94
	CRPA.Q34	15.12	26.958	0.797	0.94
	CRPA.Q35	15.13	27.991	0.683	0.943
	CRPA.Q36	15.22	27.943	0.73	0.942
	CRPA.Q37	15.18	27.757	0.768	0.941
	CRPA.Q38	15.15	26.73	0.744	0.942
	CRPA.Q40	15.16	27.196	0.789	0.94
	CRPA.Q41	15.24	28.112	0.736	0.942

N = 35; overall Cronbach's alpha = 0.956.

supported by evidence showing that PSTs can gain subject matter knowledge while developing pedagogical competencies appropriate for culturally diverse student populations (Fogg-Rogers et al., 2017; Wendell, 2014).

The resulting EIPECK framework is a four-dimensional instrument capturing knowledge dimensions—engineering pedagogical content knowledge, knowledge of engineering practices, pedagogical knowledge, and culturally responsive pedagogical awareness—that are considered critical for successfully integrating engineering into the K-12 curriculum. Findings suggest that the proposed instrument is a psychometrically robust measure of PSTs' self-assessment of these knowledge domains and shows good reliability and construct validity. EIPECK can be used as part of teacher preparation and training programs to help evaluate engineering pedagogical preparation. It expands prior measures of pedagogical knowledge in STEM education by incorporating dimensions associated with effective engineering instruction and culturally relevant and inclusive teaching. Based on the results from the validation study and reliability analysis, teacher preparation programs may use the proposed EIPECK instrument to assess PSTs' perceived readiness to integrate engineering into their teaching. Since each of the subconstructs in EIPECK showed high levels of reliability, we suggest creating aggregate centrality measures (means) of each dimension to track PSTs' progress in each dimension longitudinally. This instrument (final version in Appendix C) could be used in combination with other assessments to discern the impact of specific engineering interventions or training as part of teacher preparation programs. The instrument can be generally applied, regardless of the actual nature of the intervention or preparation of the PSTs, thereby allowing different training models to be compared using a common scale. We do not recommend the use of the instrument in different populations, such as in-service teachers, because we do not have empirical evidence of its validity in other populations.

Conclusion

The inclusion of engineering in national and state science standards creates a need for assessment instruments that measure teachers' PCK to integrate engineering into their courses. This research proposes a framework and an instrument to help assess PSTs' readiness for effective and inclusive engineering instruction in K-12 education. EIPECK can be used as part of teacher preparation and training programs to help evaluate engineering pedagogical preparation. It expands prior measures of pedagogical knowledge in STEM education by incorporating dimensions associated with effective engineering instruction and culturally relevant and inclusive teaching. The proposed instrument can be used in combination with classroom observations and other assessments to help determine the effectiveness of new preparation programs or initiatives.

Future research can use EIPECK longitudinally to measure individual PST growth in terms of the instrument's constructs. Longitudinal data can provide a comprehensive picture of knowledge domain growth in PSTs as they progress through teacher preparation programs. Future work can also adapt and explore the instrument's validity for in-service teachers so that it may be applied to assess the efficacy of professional development programs that include engineering.

Declaration of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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Data Availability Statement

Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data are not available.

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Appendix A

EIPECK 32-item Initial Scale

Pedagogical knowledge (PK)

1. PK.Q1. I know how to effectively use questions to guide student learning
2. PK.Q2. I know how to prompt students to ask questions
3. PK.Q3. I have experience planning lessons that involve student inquiry and exploration
4. PK.Q4. I know how to guide students to actively participate without losing control of the classroom
5. PK.Q5. I know specific strategies to guide rather than lecture students
6. PK.Q6. I know how to organize and maintain classroom management
7. PK.Q7. I know how to assess student performance in the classroom
8. PK.Q8. I can adapt my teaching based on what students understand or don't understand

Engineering pedagogical knowledge (EPK)

1. EPK.Q1. I know how to come up with an engineering-related design problem that my students can solve in the classroom
2. EPK.Q2. I know how to prompt students to come up with solutions to an engineering design problem
3. EPK.Q3. I am familiar with strategies for promoting effective group work
4. EPK.Q4. I know how to facilitate students working in groups
5. EPK.Q5. I am familiar with having students use different materials to build models in the classroom
6. EPK.Q6. I know how to have students evaluate different solutions to an engineering design problem
7. EPK.Q7. I have the necessary skills to introduce engineering-related content in my classroom
8. EPK.Q8. I have had sufficient opportunities to practice implementing engineering-related content into teaching
9. EPK.Q9. I know how to use materials to design an engineering-related challenge for my students
10. EPK.Q10. I know how to facilitate learning through an engineering design challenge

Knowledge of engineering practices (KEP)

1. KEP.Q1. I am familiar with different fields of engineering
2. KEP.Q2. I am familiar with the types of activities engineers engage in as part of their jobs
3. KEP.Q3. I know some examples of how engineering can be used as a tool to benefit society
4. KEP.Q4. I know how to facilitate a learning environment where failure is seen as an opportunity to learn
5. KEP.Q5. I am familiar with some of the approaches that engineers use to solve problems
6. KEP.Q6. I am familiar with the engineering design process

Culturally responsive pedagogical awareness (CRPA)

1. CRPK.Q1. I know how to develop and deliver lessons that connect with students' interests
2. CRPK.Q2. I am familiar with the ways in which engineering can be used to positively impact society
3. CRPK.Q3. I know specific examples of engineering-related solutions that have helped the global society
4. CRPK.Q4. I know specific examples of engineering-related solutions that have helped my local community
5. CRPK.Q5. In my future teaching, I will familiarize myself with the cultural background of my students
6. CRPK.Q6. I am familiar with the challenges faced by students in underserved communities or from low socioeconomic status
7. CRPK.Q7. In my future teaching, I will learn about my students' interests outside of the classroom
8. CRPK.Q8. I am familiar with culturally responsive pedagogical strategies to help engage my students in engineering activities that will interest them

Note. All items use a 5-point scale in which 1 = strongly disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = strongly agree.

Appendix B

EIPECK 41-item Revised Scale Before Final EFA

Pedagogical knowledge (PK)

1. PK.Q1. I know how to effectively use questions to guide student learning
2. PK.Q2. I know how to prompt students to ask questions
3. PK.Q3. I have experience planning lessons that involve student inquiry and exploration
4. PK.Q4. I know how to guide students to actively participate without losing control of the classroom
5. PK.Q5. I know specific strategies to guide rather than lecture students
6. PK.Q6. I know how to organize and maintain classroom management
7. PK.Q7. I know how to assess student performance in the classroom
8. PK.Q8. I can adapt my teaching based on what students understand or don't understand
9. PK.Q9. I know how to facilitate a learning environment where failure is seen as an opportunity to learn
10. PK.Q10. I know how to facilitate work in groups with my students

Engineering pedagogical content knowledge (EPK)

1. EPK.Q11. I know how to come up with an engineering-related design problem that my students can solve in the classroom
2. EPK.Q13. I am familiar with having students use different materials to build models in the classroom
3. EPK.Q14. I know how to have students evaluate different solutions to an engineering design problem
4. EPK.Q12. I know how to prompt students to come up with solutions to an engineering design problem
5. EPK.Q15. I know how to integrate engineering-related content into my instruction
6. EPK.Q16. I know how to use materials to design an engineering-related challenge for my students
7. EPK.Q17. I know how to facilitate learning through an engineering design challenge
8. EPK.Q18. I understand how to introduce the engineering design process to students

Knowledge of engineering practices (KEP)

1. KEP.Q19. I am familiar with different fields of engineering
2. KEP.Q20. I am familiar with some of the activities that engineers engage in as part of their jobs
3. KEP.Q21. I am familiar with some of the approaches that engineers use to solve problems
4. KEP.Q22. I am familiar with how the engineering design process is used by engineers
5. KEP.Q23. I am familiar with some of the ways in which engineering can be used to tackle societal problems or challenges
6. KEP.Q24. I know some examples of engineering-related solutions that have helped society
7. KEP.Q25. I am familiar with some of the skills that engineers apply in their profession, such as the use of math and science to solve problems
8. KEP.Q26. I understand that engineers must work within constraints when designing solutions
9. KEP.Q27. I understand what a prototype is and how it is used by engineers in the design process
10. KEP.Q28. I understand the purpose of brainstorming within the engineering design process

Culturally responsive pedagogical awareness (CRPA)

1. CRPA.Q29. I am familiar with the challenges faced by students from diverse backgrounds, such as low-income, minority, or English language learners
2. CRPA.Q30. I know how to obtain information about my students' cultural backgrounds
3. CRPA.Q31. I know how to use examples that are familiar to students from different cultural backgrounds
4. CRPA.Q32. I know how to critically examine curriculum and class materials to determine whether they reinforce negative cultural stereotypes
5. CRPA.Q33. I know how to revise instructional materials to include a better representation of cultural groups
6. CRPA.Q34. I am able to communicate expectations of success to culturally diverse students
7. CRPA.Q35. I know how to elicit my students' prior knowledge to help them make sense of new information
8. CRPA.Q36. I know how to explain new concepts using examples that are taken from my students' everyday lives
9. CRPA.Q37. I know how to adapt instruction to the needs of my students
10. CRPA.Q38. I know how to use the interests of my students to make learning meaningful for them
11. CRPA.Q39. I know how to help students develop positive relationships with their classmates
12. CRPA.Q40. I know how to develop a community of learners when my class consists of students from diverse backgrounds
13. CRPA.Q41. I know how to reflect on my own background in order to examine its influence on my values and behaviors

Note. All items use a 5-point scale in which 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.

Appendix C

EIPECK 35-item Final Scale

Pedagogical knowledge (PK)

1. PK.Q1. I know how to effectively use questions to guide student learning
2. PK.Q2. I know how to prompt students to ask questions
3. PK.Q4. I know how to guide students to actively participate without losing control of the classroom
4. PK.Q5. I know specific strategies to guide rather than lecture students
5. PK.Q6. I know how to organize and maintain classroom management
6. PK.Q7. I know how to assess student performance in the classroom
7. PK.Q8. I can adapt my teaching based on what students understand or don't understand

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Engineering pedagogical content knowledge (EPK)

1. EPK.Q11. I know how to come up with an engineering-related design problem that my students can solve in the classroom
2. EPK.Q14. I know how to have students evaluate different solutions to an engineering design problem
3. EPK.Q12. I know how to prompt students to come up with solutions to an engineering design problem
4. EPK.Q15. I know how to integrate engineering-related content into my instruction
5. EPK.Q16. I know how to use materials to design an engineering-related challenge for my students
6. EPK.Q17. I know how to facilitate learning through an engineering design challenge
7. EPK.Q18. I understand how to introduce the engineering design process to students

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Knowledge of engineering practices (KEP)

1. KEP.Q19. I am familiar with different fields of engineering
2. KEP.Q20. I am familiar with some of the activities that engineers engage in as part of their jobs
3. KEP.Q21. I am familiar with some of the approaches that engineers use to solve problems
4. KEP.Q23. I am familiar with some of the ways in which engineering can be used to tackle societal problems or challenges
5. KEP.Q24. I know some examples of engineering-related solutions that have helped society
6. KEP.Q25. I am familiar with some of the skills that engineers apply in their profession, such as the use of math and science to solve problems
7. KEP.Q26. I understand that engineers must work within constraints when designing solutions
8. KEP.Q27. I understand what a prototype is and how it is used by engineers in the design process
9. KEP.Q28. I understand the purpose of brainstorming within the engineering design process

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Culturally responsive pedagogical awareness (CRPA)

1. CRPA.Q29. I am familiar with the challenges faced by students from diverse backgrounds, such as low-income, minority, or English language learners
2. CRPA.Q30. I know how to obtain information about my students' cultural backgrounds
3. CRPA.Q31. I know how to use examples that are familiar to students from different cultural backgrounds
4. CRPA.Q32. I know how to critically examine curriculum and class materials to determine whether they reinforce negative cultural stereotypes
5. CRPA.Q33. I know how to revise instructional materials to include a better representation of cultural groups
6. CRPA.Q34. I am able to communicate expectations of success to culturally diverse students
7. CRPA.Q35. I know how to elicit my students' prior knowledge to help them make sense of new information
8. CRPA.Q36. I know how to explain new concepts using examples that are taken from my students' everyday lives
9. CRPA.Q37. I know how to adapt instruction to the needs of my students
10. CRPA.Q38. I know how to use the interests of my students to make learning meaningful for them
11. CRPA.Q40. I know how to develop a community of learners when my class consists of students from diverse backgrounds
12. CRPA.Q41. I know how to reflect on my own background in order to examine its influence on my values and behaviors

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Note. All items use a 5-point scale in which 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.