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A Case Study on How Instructors' Pedagogical Knowledge Influences Their Classroom Practices for First-Year Engineering Courses

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Abstract

This complete research paper details an investigation into the influence of instructors' pedagogical knowledge on their classroom practices in the context of teaching first-year engineering courses. First-year engineering courses are critical for introducing students to the field and its teaching methods, providing essential skills for success in advanced topics, and highlighting the significance of instructors' pedagogical knowledge in employing diverse pedagogical strategies and engaging lesson plans. Despite the importance of pedagogical knowledge, limited research exists on its influence on classroom practices in first-year engineering courses. The central question driving this research is: How does instructors' pedagogical knowledge influence their pedagogical practices for first-year engineering courses? For this study, we chose the model of teacher professional knowledge and skill (TPK&S), which includes pedagogical content knowledge (PCK). A descriptive case study was utilized as a methodology for this work to delve into the phenomenon. The context of the study was a first-year introductory engineering course offered at a large public research institution. This is a pilot study for an NSF-funded project "Advancing Student-Centered Teaching for Disciplinary Knowledge Building in Engineering" (DUE2215989). The study involved two instructors, Chandler and Joey (pseudonyms), chosen through purposive sampling, with varying levels of teaching experience. Data collection involved direct classroom observation using the Teaching Dimensions Observation Protocol (TDOP) and semi-structured interviews conducted after the observations. Thematic analysis was used to categorize the data based on the constructs of the theoretical framework. The analysis identified three key themes: the substantial impact of instructors' subject-specific professional knowledge on pedagogical practices; the influence of the interplay between personal pedagogical content knowledge (PCK) and classroom context on teaching approaches, and the role of instructors' beliefs and prior knowledge as filters guiding the alignment of teaching practices with their convictions. This work holds significant implications for current and future first-year instructors in that this paper will showcase how the instructors in this study use their understanding of the content and their students to teach, which is a critical aspect of helping students successfully integrate into engineering.

Introduction

Improving the percentage of undergraduate engineering students and enhancing undergraduate graduation rates has been identified as a priority for engineering education. To achieve this, many regional, national, and international assessments have been recommended to also enhance the caliber of engineering graduates. Greater focus is being given to how engineering instructors use pedagogical knowledge in their practices to achieve these more general objectives [1]. Instructors' pedagogical knowledge affects their classroom practices, which in turn affects both the effectiveness of students' learning and their attitudes about learning [2]. What instructors bring to the table is the primary factor that influences how they make decisions concerning college-level courses and activities [3]. Understanding how instructors' pedagogical knowledge is put into practice for the best possible student learning and accomplishment would help us to create sustainable progression.

Retention statistics persistently demonstrate that American engineering students who discontinue their studies do so during the first two years of their program [4]. Effective classroom practices can greatly help in enhancing the retention rates of engineering students [5]. These practices can be defined as the use of the best practices in pedagogical strategies [1], assessment to inform instruction [6], a deep understanding of the subject matter [7], and positive instructor-student relationships and a supportive classroom environment [8] to enhance student learning and contribute to their success. The purpose of the study is to understand how instructors' pedagogical knowledge influences their classroom practices for teaching first-year engineering courses. The study is guided by the research question: How does instructors' pedagogical knowledge influence their classroom practices for first-year engineering courses? The work begins with an overview of related works on the influence of instructors' pedagogical knowledge on their classroom practices followed by a discussion on the theoretical framework, the methods guided by the framework to investigate the case study, and the findings and implications of the research.

Literature review

First-year engineering courses serve as the foundational setting in which students are introduced to the field of engineering as well as the pedagogies specific to engineering teaching and learning. These courses serve as a crucial foundation, imparting essential knowledge and honing fundamental skills that set the trajectory for students' academic success. Studies have shown that future success in advanced coursework of engineering students can be predicted by their academic performance in first-year courses [9]. In addition, these courses can help students identify areas of engineering that interest them and guide their career choices [10]. Thus, the significance of the first-year engineering courses extends beyond mere academic introduction; they are integral in shaping the future academic journeys of aspiring engineers.

Understanding how instructors' pedagogical knowledge affects their classroom practices is crucial. Pedagogical knowledge includes a wide range of pedagogical strategies to effectively manage a classroom and engage students [11]. This includes the use of instructional strategies that accommodate diverse student needs, the design of impactful and engaging lesson plans, etc. Pedagogical knowledge, when wielded adeptly, serves as a powerful tool influencing both student motivation and academic performance. One notable advantage is the capacity for educators to employ a variety of teaching strategies tailored to diverse learning styles [12], thus enhancing student engagement and interest in the learning process. This adaptability can foster a positive classroom environment, motivating students to actively participate and invest in their academic pursuits. However, over-reliance on specific pedagogical strategies may lead to rigidity in classroom practices [11], limiting adaptability to individual needs and preferences. When faced with limitations in time and resources, implementing complex pedagogical strategies might become challenging, potentially impacting the depth of their application.

Effective classroom practices include the use of the best practices in pedagogical strategies to accommodate diverse student needs, all while navigating within the constraints of available resources. The purpose of pedagogical strategies is to create self-sufficient learners who can use their knowledge and build on it as needed [13]. There are several pedagogical strategies such as active learning [14], collaborative learning [15], self-regulated learning [16], cooperative learning [17], problem-based learning [18], project-based learning [19], etc. which have been proven effective in actively involving learners in their education. Any given educational system's efficiency is determined by its instructors' teaching strategies, and these strategies are in turn driven by their knowledge and beliefs.

Teaching from one's own experiences is typically mentioned as the primary justification for choosing pedagogical strategies [20]. Instructors generally teach their students by following the ways they were instructed when they were students. Hence, most of these beliefs are typically generated by instructors' personal experiences which influences them to maintain comparatively conventional teaching methods [21]. Studies [22] - [23] have revealed that instructors' beliefs about teaching are aligned with their practices in the classroom. Other studies [24] - [26] have discovered that instructors' professed ideas and practices do not correspond to what they really do in the classroom. Authors [22] have found although instructors in higher education have positive beliefs about collaborative learning, their practices do not align with their beliefs due to their formal as well as informal educational experiences.

There is, however, limited research on how instructors' pedagogical knowledge influences their classroom practices. Hence, it seems opportune and essential to conduct additional research on engineering instructors' classroom practices. The next stage, drawing on this body of literature, is to investigate the influence of pedagogical knowledge on classroom practices by leveraging a model of teacher professional knowledge and skill (TPK&S) [11].

Theoretical framework

For this study, we choose the model of teacher professional knowledge and skill (TPK&S) that includes pedagogical content knowledge (PCK) proposed by Julie Gess-Newsome [11]. PCK is the knowledge that instructors have about both the content they teach and how to teach it effectively to their students [12]. The model recognizes the fundamental importance of pedagogical knowledge and contextualizes PCK within that framework, encompassing the intricate nature of teaching and learning. The model has been leveraged in the context of STEM education to better support student learning [27], [28]. The main components of this framework (see Appendix A) are discussed below.

Teacher professional knowledge bases (TPKB)

Teacher professional knowledge bases (TPKB) are expert-defined general knowledge bases, not specific to any topic. The model [11] identifies several components of TPKB, which include knowledge of assessment, pedagogy, subject matter content, students, and curriculum. In this study, we are focusing on pedagogical knowledge. Pedagogical knowledge may include techniques for managing a classroom and keeping students engaged, like asking questions or using strategies to help different students based on their needs.

Topic-specific professional knowledge (TSPK)

Topic-specific professional knowledge (TSPK) refers to instructors' topic-specific knowledge and typically is designed for a specific level of students compared to TPKB which is generic

[11]. This category includes topic-specific knowledge of student difficulties, content representations, pedagogical strategies, the difficulty level of teaching different topics, etc. Once the focus shifts towards teaching a particular subject or topic, TSPK is derived from TPKB.

Teacher amplifiers and filters

When instructors turn their knowledge into practices in the classroom, they personalize it based on their beliefs. For instance, an instructor who sees teaching as simply delivering information might not use instructional strategies that involve understanding a student's current knowledge and challenging their misconceptions. In this situation, the instructor's belief serves as a filter, shaping their acceptance or rejection of specific instructional methods. Instructors' personal views, their perspective on the societal objectives of education, their role in the classroom, prior knowledge, preference for pedagogical strategies, and the structure of the content in their subject area act as amplifiers or filters based on the context and can influence accordingly how they learn and apply new information in their classroom [11]. Since amplifiers and filters can play a crucial role in transforming TSPK into actual classroom practice, understanding this construct will be instrumental in addressing the research question.

Classroom practice

Classroom practice includes all activities and events that occur within the learning environment. Classroom practice is influenced by the interplay between personal PCK/PCK & Skill (PCK&S) and the context of the classroom. According to Gess-Newsome [11], personal PCK includes instructors' personalized understanding, rationale, and planning for instructing a specific topic in a specific manner to achieve improved learning outcomes for individual students whereas, personal PCK&S refers to the act of instructing a specific topic in a specific manner to achieve improved learning outcomes for individual students. Apart from instructors' personal PCK/PCK&S, the classroom context also shapes their classroom practices.

This framework was employed for the study because it offers to assess how instructors' pedagogical knowledge influences their classroom practices. The data collection in this work was guided by focusing on the pedagogical knowledge of TPKB, TSPK, instructors' belief or philosophy and prior knowledge as amplifier and filter, and classroom practice (personal PCK/PCK&S, classroom context).

Methodology

Research design

A descriptive case study was used as a methodology for this work. Usually, a descriptive case study is utilized to explain a phenomenon and the setting where it happens [29]. The purpose of this type of case study is to show significant linkages between various sources of information about the topic being studied [30]. The fundamental advantage of a descriptive case study is its strength to gather information from numerous sources, each of which is equally significant in terms of giving in-depth knowledge pertaining to the subject being examined [31].

Context of the study

The context of the study was the first course in a two-part course series for general engineering students at a large public research university. Every year, the university admits numerous undergraduate engineering students, and it is mandatory for all engineering majors to take this course. Typically, freshman engineering students enroll in this course. The class meets biweekly (twice a week) for 75 minutes in Fall and Spring semesters. For this descriptive case study, the two sections of the course were picked as the units of analysis.

Participants

The instructors who led the selected sections were the participants of the study. The instructors were chosen based on purposive sampling. Purposive sampling, also known as judgmental or selective sampling purposefully selects particular persons or groups to engage in the study based on their distinctive qualities or domain-specific knowledge that is pertinent to the research topic [30]. The instructors were enlisted for the pilot study of the NSF project (DUE2215989). The class size was the same for each section (around 72 students). The sections were taught by two different instructors. The length of instructors' experience in teaching the class was another significant factor. Chandler Bing is an instructor of record, and Joey Tribbiani is an associate professor of practice. Their teaching experience for this course varies from two semesters to six semesters. After the classroom observation, the researcher conducted a semi-structured interview with the participants.

Data collection

Data were collected through direct classroom observation and semi-structured interviews focusing on pedagogical knowledge, one of the teacher professional knowledge bases of the theoretical framework. The semi-structured interviews were conducted after the observations. It offered the benefit of asking questions to the participants based on what was found in the classroom observations by the researcher.

Direct classroom observation

Direct classroom data was collected using the Teaching Dimensions Observation Protocol (TDOP) proposed by Hora and Ferrare [32]. The TDOP protocol (see Appendix B) was leveraged for observation. Six categories make up the protocol, including instructor-student interaction, technologies used for teaching, pedagogical strategies, student engagement, and potential cognitive demand [32]. Data was recorded every two minutes for every category using a set of established codes. Along with the codes, thorough notes were taken at each time interval, and an analytical memo was created after every observation. Given that every class had a similar weekday schedule, another important element was the class timetable. For the pilot study, the researcher performed two classroom observations. She observed each section at a different time. This helped the researcher to compile an analytical memo reflecting on the observation.

Semi-structured interview

The main goal of employing semi-structured interviews for gathering data was to learn more about the subject of study from the selected participants who have relevant personal encounters, perspectives, opinions, and beliefs [33]. Interviews were conducted with the two instructors of the two class sections. Each interview took about 45 minutes with an interview protocol (see Appendix C). The purpose of the interviews was to understand more about the choices made by the instructors regarding the best ways to teach general engineering courses, and their personalized teaching philosophies. The interviews were audio recorded, and each one was then transcribed.

Data analysis

A thematic approach was utilized for data analysis to find and examine patterns, themes, and significance in datasets [34]. A priori coding [35] was leveraged to categorize data based on the constructs of the theoretical framework. The constructs are topic-specific professional knowledge, amplifiers and filters (instructor beliefs, prior knowledge), and classroom practice (personal PCK/PCK&S, classroom context). These constructs were used as categories. By having these pre-determined categories, the researcher ensured that the data was analyzed in a consistent and systematic manner. Moreover, it helped to ensure that the analysis was aligned with the research question and increased the theoretical rigor of the research.

The researcher used Excel to build a codebook focusing on semi-structured interviews. More emphasis had been given to interview data, because of its ability to provide valuable insights into the perspectives and perceptions of instructors about their classroom practices. The codes that appeared in semi-structured interviews were included in the codebook using several columns such as category, code, definition, and some example excerpts. The researcher refined the codes as needed while analyzing the data. This involved consolidating similar codes, adding new codes, or removing codes from the categories. Since the codes were organized into categories, it made them more manageable and easier to navigate [35]. To uncover the underlying themes that capture the essence of the information, the researcher grouped related categories and codes together and looked for overarching concepts or ideas that tie them together. This involved examining the relationships between different categories and codes, looking for patterns in the data, and considering how they relate to the research question.

Trustworthiness

Among the eight “big-tent” criteria for the quality of qualitative research, triangulation ensures the credibility of the research [36]. Credibility is a term used to describe how trustworthy, realistic, and plausible research findings are. Triangulation is a method used in qualitative research to increase the validity and reliability of findings by using multiple methods, data sources, and perspectives to investigate a phenomenon. The significance of triangulation is that it allows researchers to corroborate and verify their findings using a range of sources and methods, which reduces the risk of bias and enhances the credibility and trustworthiness of the study [36]. Triangulation is done in the research by corroborating multiple data sources such as observations, and semi-structured interviews with the instructors. It enhanced the credibility and trustworthiness of this qualitative research and helped to mitigate bias and subjectivity.

The researcher also provided a detailed and comprehensive description of the phenomenon being studied throughout the work. This thick rich description captured the complexity, depth, and richness of human experiences and perspectives and it allowed the researcher to analyze and interpret the data more meaningfully [35]. It also increased the credibility of the research findings by providing detailed evidence to support the conclusions drawn from the data. Overall, triangulation as well as thick, rich description enabled the researcher to provide a more nuanced and detailed understanding of the phenomenon being studied and increased the credibility and trustworthiness of the research findings.

Results/ Findings

The researcher first reported the emerging codes under the appropriate categories - topic-specific professional knowledge, amplifiers and filters (instructor beliefs, prior knowledge), and classroom practice (personal PCK/PCK&S, classroom context). These categories and codes were then used to identify the themes that emerged from the analysis. The themes, along with supporting excerpts, are listed below.

Theme 1: These first-year instructors' topic-specific professional knowledge such as experiences of teaching the course, and knowledge of students' understanding, and difficulties influence their pedagogical practices.

Joey discovered that students tend to be disinterested in scoping their projects and are more focused on designing the project to achieve quick results, rather than investing time in making design decisions, identifying stakeholders, and exploring various design options.

> The more difficult concepts I think are getting students to think more broadly and deeply about the problems that they're exploring. And really take it past a superficial level. It's really easy, especially for first-year students to just kind of not take seriously some of the more holistic issues that go into design. So really thinking about stakeholders and how that has a real impact on your design.

During the direct classroom observation, the topic was scoping the project which involved evaluating each team member's alternative using their team's criteria. Student engagement was mostly between low (35%) and medium (43%) for most of the time of the class (See Appendix E). Joey's experience of teaching SolidWorks multiple times has allowed him to develop tactics to teach the subject effectively, despite the students' struggles:

> The concrete ones are actually very easy to teach. Now I've done it a couple of times. So like I can teach SolidWorks. The students sometimes struggle with it but it's like the same questions you get all the time. There are tactics that I can use something that's not super super hard.

This suggests that the teaching approach of these first-year instructors have been shaped by their understanding of the course material and awareness of the common challenges students encounter. On the other hand, Chandler found that topics such as MATLAB, CAD, and the design process are more straightforward to teach than abstract concepts like ethics, which he enjoys teaching but has found students to be disengaged during classroom instruction:

> I like teaching ethics. I generally enjoy those lectures, but I find that students are so disengaged, like, automatically when you start talking about ethics. It's not all of them, obviously, but you know, a part of your class just shut down immediately, when you say, oh, today, we're going to be talking about ethics.

He reported the reason behind it is students' difficulty in applying abstract concepts to real-life experiences, which can lead to a loss of interest among students. During direct classroom observations, the researcher also noted that student engagement when teaching ethics varied between low (19%) and high (38%) of the observed interval, with engagement being the lowest when Chandler focused on administrative tasks and presented classifications of ethics from presentation slides (see Appendix D). To increase student engagement, Chandler leveraged a lot of discussion-based activities in class such as think, pair, share, quietly thinking prompts, etc. This is a piece of evidence that these instructors' knowledge of students' attitudes towards the subject is important in shaping their classroom practices. It suggests that these first-year instructors may need to be aware of students' preconceptions and attitudes toward a subject and use strategies to engage them effectively.

Theme 2: The interaction between these first-year instructors' personal PCK and classroom context influences their classroom practices.

According to Chandler, his personal experiences and storytelling can engage students more effectively than simply providing information, "I can throw content at them all I want, but if I'm telling them a story from my life, I can see that they're much more engaged, much more interested". It humanizes him and makes him a more relatable person. The classroom observation reveals the same, Chandler gave a lot of anecdotes/examples (ANEX) for 38% of the observed time (See Appendix D). This suggests that these first-year instructor's personal PCK, in this case, the ability to relate content to personal experiences, is influencing their teaching approach. Chandler also likes to run a fun and casual classroom; hence he has to draw the line between being a relaxed and authoritative figure. He remains friendly, relaxed and calm until he must put down the barriers and lay down the law if the situation happens. He shared one example:

> I've had students come up to me and be like, Hey, Professor, Bing, you know, could you give me some other assignment instead of, you know, this one? I hate this one. I'm like - Nope, can't do that. You got to do it, just like everybody else.

Joey, on the other hand, has a background in professionals. While teaching the course, he tries to bring that in as examples to "instill the skills that they need, so they can be self-motivated". He does a lot of team-based activities. Although it's daunting for a large class to engage one-on-one with every student, he engaged one-on-one with team members of each team which made the classroom smaller. Hence, he leveraged individualized instruction (IND) mostly compared to other teaching methods (see Appendix E). Joey emphasizes more on integrating a level of autonomy for the students to have some agency within the guidelines of the course. The classroom observation also confirmed this. They were allowed to use any platform for the project and choose any project that they wanted to work on. In previous semesters, all students had to work on the same project. He also acknowledged that too much autonomy can be overwhelming for students:

> trying to integrate a level of autonomy for the students to have some agency in sort of selecting a little bit of what they're learning within the guidelines of the courses……if you give too much agencies, they just like freeze because there are just too many decisions to make ….. I try to have clear expectations but also flexible expectations to account for ….. I would rather spend an hour of my time working with the student to get back on track than an hour of my time just writing emails telling explaining why they have zero and all their assignments.

Joey's ability to balance clear expectations with flexibility in the classroom shows how his personal PCK is shaping his teaching approach. Additionally, his interaction with students, such as spending time working with them individually, suggests that he is adapting his teaching practices to the needs of their classroom context. So, these first-year instructors' personal PCK and the classroom context in which they teach are both important factors that can influence their pedagogical practices. Effective teaching requires a balance between these factors to engage and meet the needs of students in the classroom.

Theme 3: These first-year instructors' beliefs and prior knowledge work as amplifiers or filters based on the situation for their classroom practices.

Both instructors have different positions and experiences in teaching the course. Based on their positions, they have different course loads and assignments of responsibilities outside of the classroom. Chandler is an instructor of record position, and it is his second time teaching the course. Previously he worked as a GTA for this course. On the other hand, Joey is an associate professor of practice, and it is his sixth time teaching the course. Compared to Chandler, Joey has mostly figured out what possible challenges he might face, what students' expectations are, and how to adapt classroom practices. Chandler, being relatively young, holds the belief that he can establish a better rapport with his students, and vice versa: "I am young, they can relate better to me, and I can relate better to them."

Both instructors have different focuses or goals for teaching. "Accessible, and engaging is the core focus of teaching" for Chandler. He puts a lot of effort into engaging students in the classroom. The observation revealed that the class was mostly instructor-focused (See Appendix F). He utilized a lot of teaching methods as well as pedagogical strategies to engage students (See Appendix D). Joey's goal "from a philosophical standpoint, is trying to be supportive of the students and meeting them where they are" to keep them stay in engineering for the right reason. He believes in giving students autonomy and agency. The observation aligned with his beliefs. It was found that the teaching method was mostly student-focused instruction where students were the primary actors (See Appendix G). In the class, students performed small group work/discussion (SGW) 54% of the observed time with peer interaction (PI) 51% of the observed time (See Appendix E).

Rather than just being their instructors, both of them want to be the facilitators for the students. Merely being their instructor, Chandler also wants his students to see him as "an advocate for them as well as an ally in their instructor journey". Joey sees his role "as a facilitator or a coach along with as an instructor" in imparting knowledge to them. Chandler's approach to teaching has been shaped by his own experiences as a student and his previous experience as a GTA:

> I'm a product of the professors that have taught me how to teach…., I worked with him as GTA for three semesters. He and I had very similar approaches to the classroom, to begin with….A lot of the materials and a lot of the activities that I either worked on or delivered with him or developed for him for his class when I was a GTA; are still some of the things that I use today in my class. So, the project I'm doing was his idea.

This experience has influenced his classroom practices, as he continues to use materials and activities developed during that time. This shows how these instructors' prior knowledge and beliefs can amplify their classroom practices by providing a foundation for their approach to teaching. On the other hand, Chandler's focus on making the content accessible and engaging to all students filters his classroom practices:

> You can be the most engaging lecturer in the world, but if your content isn't accessible to all of your students if you're explaining it at a too high level if you're explaining it in a way that certain students may not be able to understand based on their instructor, personal, cultural, etc, upbringing, or history, then you're not reaching them. And at the same time, I think an engaged classroom is a classroom in which learning is happening.

This suggests that these first-year instructors' beliefs and values influence how they approach teaching and shape their practices, filtering out teaching methods that don't align with their core focus. Effective teaching requires instructors to recognize their own beliefs and experiences and how they may be shaping their practices, and to adapt their practices to meet the needs of their students and the context in which they are teaching.

Discussion

The study provides valuable insights into how instructors' pedagogical knowledge may impact their classroom practices, particularly in first-year courses. This understanding has the potential to be used to develop more effective professional development programs for first-year engineering instructors, as well as to design more effective engineering courses. By examining the experiences of two instructors who teach first-year engineering courses, the study sheds light on the challenges these instructors face when teaching abstract concepts, such as ethics, teamwork, and project scoping, and how they use different pedagogical strategies to engage their students. From Joey's experience of teaching SolidWorks, it is evident that the knowledge of the course material and the common difficulties students face have a significant impact on his classroom practices. Similarly, Chandler's experience of teaching ethics highlights the importance of understanding students' attitudes toward a subject and using strategies to engage them effectively.

By possessing a deep understanding of the subject matter and being aware of students' understanding and potential difficulties, instructors can design more effective teaching strategies. The findings suggest that these instructors took time to understand their students, sympathize with them, and adapt their teaching methods accordingly to have a positive impact on student learning outcomes. This is especially important in first-year engineering courses, where students may be experiencing a range of challenges as they adjust to the academic demands of college.

The study also provides a detailed analysis of two instructors with different prior experiences and teaching goals, which allows for a more nuanced understanding of how these instructors' pedagogical knowledge and beliefs influence their practices.

Grossman and her colleagues [37] found that PCK was a critical factor in effective teaching. Similarly, Shulman [7] suggested that PCK is essential for effective teaching, and it is the knowledge that is unique to teaching. This study adds to the growing body of literature on the importance of instructors' personal PCK in teaching engineering and the interaction between instructors' personal PCK and classroom context in shaping their classroom practices. Svinicki and McKeachie [38] noted that instructors' beliefs about teaching and learning can significantly influence their teaching practices, including their choice of teaching strategies, assessment methods, and approaches to student engagement. This study’s focus on the role of instructors' personal beliefs and prior knowledge highlights the need for instructors to be self-aware and reflective of their beliefs to create a supportive learning environment for students.

While this study provides valuable insights into the relationship between instructors' pedagogical knowledge and classroom practices in first-year engineering courses, it is essential to acknowledge certain limitations that may impact the transferability and scope of the findings. Since the study focused on a specific first-year introductory engineering course at a large public research institution, caution should be exercised when extrapolating these findings to diverse educational contexts. The study involved two instructors, Chandler and Joey, selected through purposive sampling. While their perspectives provided valuable insights, the limited number of participants may not capture the full spectrum of instructional practices within first-year engineering courses. Besides, the direct classroom observations conducted using the TDOP are subject to potential observer bias. While efforts were made to maintain objectivity, the interpretation of classroom practices and engagement levels may be influenced by the observer's perspective. Acknowledging these limitations is crucial for interpreting the findings of the pilot study accurately. Future research endeavors will attempt to address these constraints by employing larger and more diverse samples, collecting student feedback, utilizing mixed methods approaches, and considering longitudinal perspectives to capture the dynamic nature of pedagogical knowledge and practices in engineering education.

Implications

There is a need to investigate and further understand the complex relationship between first-year instructors' pedagogical knowledge and their classroom practices. It may be important to explore how instructors acquire and develop topic-specific knowledge, how they use this knowledge to inform their teaching, and how this knowledge impacts student learning outcomes. The beliefs and prior knowledge of first-year instructors can significantly impact their classroom practices. These factors can work as amplifiers or filters depending on the situation, influencing the way instructors approach their teaching, the strategies they use, and the decisions they make about the content they cover and how to cover it. For researchers, this finding underscores the importance of studying the impact of instructors' beliefs and prior knowledge on their classroom practices. Understanding how these factors can inform the development of effective instructor training programs and the design of research studies that explore the best practices for improving teaching and learning outcomes. These programs can emphasize the integration of topic-specific professional knowledge (TSPK) and provide instructors with practical strategies applicable to engineering courses. Additionally, given the challenge of changing deeply held beliefs, professional development initiatives [39] can incorporate reflective practices and ongoing support to help instructors recognize and overcome any negative biases. Research [40] suggest that teaching activities are built upon teachers’ beliefs. By providing opportunities for instructors to critically examine their beliefs and their alignment with evidence-based teaching practices, professional development initiatives can help instructors identify and challenge any biases or misconceptions that may hinder effective teaching. Moreover, leveraging peer mentoring and communities of practice can offer opportunities for instructors to learn from each other and share successful strategies for overcoming negative beliefs or biases in their teaching. The findings also highlight the importance of considering the diversity of first-year instructors' experiences and expertise when conducting research on teaching and learning. Researchers may need to account for differences in instructors' backgrounds and experiences when examining the impact of professional knowledge on pedagogical practices.

First-year instructors may need to be aware of how their personal PCK interacts with the classroom context. They may need to consider the learning styles of their students and the subject matter being taught when developing their classroom practices. For example, they can adapt their teaching strategies to accommodate different learning styles, modify their lesson plans to address specific student needs, and seek out professional development opportunities that focus on PCK development in specific subject areas. Besides, first-year instructors may need to be aware of their own biases and consider how they may be impacting their teaching, as well as seek out opportunities to learn and improve their pedagogical practices. As such, they need to continually reflect on their practices and be open to adapting their beliefs and prior knowledge to new contexts. By doing so, they can better tailor their classroom practices to the needs of their students, which can lead to improved learning outcomes.

Conclusion

This complete research paper sheds light on the intricate relationship between instructors' pedagogical knowledge and classroom practices in first-year engineering courses. The study reveals that these first-year instructors' deep understanding of subject-specific content significantly influences their pedagogical approaches. The dynamic interplay between personal PCK and classroom context emerges as a crucial factor, with these instructors tailoring their practices to align with both their teaching styles and student needs. Moreover, these instructors' beliefs and prior experiences act as filters or amplifiers for their classroom practices. This research provides valuable insights for current and future first-year engineering instructors, guiding them on leveraging content expertise, balancing personal PCK with classroom dynamics, and being mindful of the beliefs shaping instructional practices. As engineering education seeks to enhance retention rates and produce well-prepared graduates, these findings contribute to the ongoing discourse on effective classroom practices in the field.

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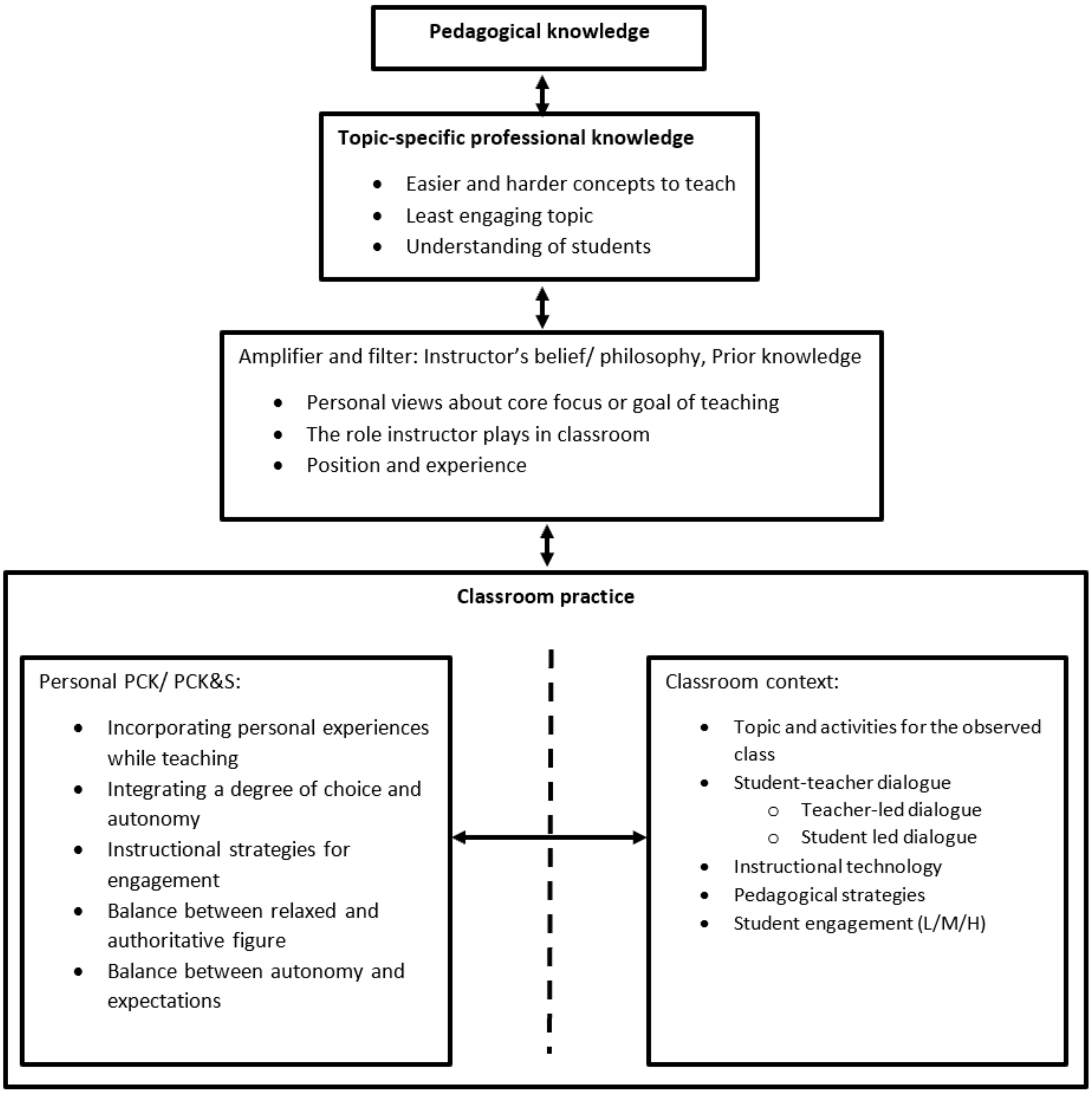
Appendix A

Model of teacher professional knowledge and skill including PCK and influences on classroom practice (Adapted from [11])



Appendix B

Teaching Dimensions and Observations Protocol (TDOP)
Code Definitions & Coding Rules

Teaching Methods

Teacher-focused instruction (teacher is the primary actor)

L **Lecturing**: The instructor is talking to the students and not using visuals, demonstration equipment, actively writing, or asking more than 2 questions in a row in a Socratic manner.

LW **Lecturing while writing**: The instructor is talking to the students while actively writing on a chalkboard, transparencies, digital tablet, or other material. The instructor must either be writing or referring to what they are writing (or have already written). This code also captures real-time drawings of graphics (e.g., molecular structure, physiological processes), and if the use of visual representations is of interest, this should be included in the notes section. (Note that this code also captures writing/drawing in front of students without speaking, as a separate code for silent writing was deemed superfluous).

LVIS **Lecturing from pre-made visuals**: The instructor is talking to the students while referencing visual aides, such as slides, transparencies, posters, or models (e.g., plastic model of molecular structure, examples of sedimentary rocks, multi-media). The instructor must be referring to the topic contained in the visual, but the visual serves only as a reference point for the material and not as a live demonstration of phenomenon.

LDEM Lecturing with demonstration of phenomena: The instructor actively uses equipment (e.g., lab equipment, computer simulation) to convey course content. The objects must be in active use in relation to the topic and must be used for more than a simple reference point (e.g., "here is an example of a sedimentary rock") to demonstrate a process or phenomenon in class (e.g., "here is how sedimentary rock erodes over time" while physically demonstrating this process).

SOC-L Socratic lecture: The instructor is talking to the students while asking multiple, successive questions to which the students are responding. Student responses are either guiding or being integrated within the discussion. <u>A minimum of 2 relevant</u> <u>student responses is required to use this code.</u> (Note that SOC-L can be co-coded with other types of lecturing, such as LW, if the instructor is doing both writing AND interspersing his/her talk with questions).

WP **Working out problems:** This code refers to the instructor working out computations or problems. These can include balancing a chemical equation, working out a mathematical proof, or designing equations or Punnett squares, etc. The intent of the code is to capture the working through of some sort of problems in front of students. (If the computations/problems are on a slide and the instructor is actively working through problems, then this will be co-coded with LVIS. If this process is being written out, then this code will be co-coded with LW, and if students are being asked to participate in the problemsolving process via questions, code SOC-L).

IND **Individualized instruction:** The instructor provides instruction to individuals or groups and not the entire class. This often occurs while the instructor is roaming the classroom, but students or small groups may also approach the instructor. This code is usually co-coded with SGW or DW (see below). It is important to recognize that this code should not be used to classify the types of student-teacher interactions that are occurring in a large class setting – instead, use this code only when students are engaged in SGW or DW and the instructor is directly interacting with one or more students.

MM **Multimedia**: The instructor plays a video or movie (e.g., Youtube or documentary) <u>without speaking</u> while the students watch. If the instructor is talking over a video, movie, or simulation, then co-code with LVIS.

A **Assessment**: The instructor is explicitly gathering student learning data in class (e.g., tests, quizzes, or clickers).

AT **Administrative task:** The instructor is discussing exams, homework, or other non-content related topics.

Student-focused instruction (students are the primary actor)

SGW **Small group work/discussion**: Students form into groups of 2+ for the purposes of discussion and/or to complete a task.

DW **Deskwork:** Students complete work alone at their desk/chair.

SP **Student presentation**: Groups or individual students are giving to the class or are otherwise acting as the primary speaker or instructor in the classroom. In this instance, only select this code and none others as long as the primary instructor is not actively taking the lead in teaching the class.

Student-Teacher Dialogue

Teacher-led dialogue

IRQ **Instructor rhetorical question**: The instructor asks a question without seeking an answer and without giving students an opportunity to answer the question.

IDQ **Instructor display question:** The instructor poses a question seeking information. These questions can: seek a specific fact, a solution to a closed-ended problem, or involve students generating their own ideas rather than finding a specific solution.

ICQ **Instructor comprehension question**: The instructor checks for understanding (e.g., "Does that make sense?") and pauses for at least five seconds, thereby indicating an opportunity for students to respond.

Student-led dialogue

SQ **Student question**: A student poses a question to the instructor that seeks new information (i.e. not asking to clarify a concept that was previously being discussed) **and/or** clarification of a concept that is part of the current or past class period.

SR **Student response to teacher question**: A student responds to a question posed by the instructor, whether posed verbally by the instructor or through digital means (e.g., clicker, website).

PI **Peer interactions**: Students speaking to one another (often during SGW, WCD, or SP).

Instructional Technology

CB **Chalkboard/whiteboard/Smart Board**

OP **Overhead projector/transparencies**

PP **PowerPoint or other digital slides**

CL **Clicker response systems**

D **Demonstration equipment**: These could include chemistry demonstrations of reactions, physics demonstrations of motion, or any other material being used for the demonstration of a process or phenomenon. The objects must be in active use in relation to the topic. This can also include objects such as rocks being passed around a classroom.

DT **Digital tablet:** This refers to any technology where the instructor can actively write on a document or graphic that is being projected onto a screen. This includes document cameras as well as software on a laptop that allows for writing on PDF files.

M **Movie, documentary, video clips, or Youtube video**

SI **Simulation:** Simulations can be digital applets or web-based applications.

WEB **Website:** Includes instructor interaction with course website or other online resource (besides Youtube videos). This can include using a website for student responses to questions (in lieu of clickers).

Pedagogical Strategies

HUM Humor: The instructor tells jokes or humorous anecdotes; this code requires laughter from at least a couple of students.

ANEX Anecdote/example: The instructor gives examples (either verbally through illustrative stories or graphically through movies or pictures) that clearly and explicitly link course material to (a) popular culture, the news, and other common student experiences, or (b) widely recognized cases or incidents that illustrate the abstract (both types are co-coded with CNL).

ORG **Organization**: The instructor writes or posts an outline of class (i.e., advance organizer) or clearly indicates a transition from one topic to the next verbally or through transitional slides. This transition from one topic to another can indicate a change in topics within a single class or from a previous class to the present class. These transitions must be verbally explicit statements to the class (e.g., "Now we're moving from meiosis to mitosis") as opposed to ambiguous statements such as "Now we'll pick up where we left off on Monday." This may also include statements concerning how concepts covered in different portions of the class (e.g., lecture, homework and lab) may overlap.

EMP **Emphasis:** The instructor clearly states that something is important for students to learn or remember either for a test, for their future careers, or to just learn the material well

Optional Dimensions

Potential Student Cognitive Engagement

CNL **Making connections to own lives/specific cases**: Students are given examples (either verbally through illustrative stories or graphically through movies or pictures) that clearly and explicitly link course material to popular culture, the news, and other common student experiences. Students may also be given specific cases or incidents in order to link an abstract principle or topic (e.g., flooding) with a more readily identifiable instance (e.g., 2013 floods in Boulder, Colorado). For this code to be used, the observer will need to make a judgment that the specific case is something meaningful to students, such as a local historic item or location, or a widely recognized incident. In general, a high bar is required here that is based on specificity and salience to students, such that showing a picture of a sedimentary rock will not be sufficient for this code, but if the picture was of the Grant Canyon and named as such, it would be coded as CNL. This code will be particularly important in biology (e.g., Dolly the sheep) and geoscience courses.

PS **Problem solving:** Students are asked to actively solve a problem (e.g., balance a chemical equation, work out a mathematical equation/algorithm). This is evident through explicit verbal (e.g., "Please solve for X") or written requests (e.g., worksheets) to solve a problem. **This is coded in relation to closed-ended exercises or problems where the instructor has a specific solution or end-point clearly in mind.**

CR **Creating**: Students are provided with tasks or dilemmas where the outcome is open-ended rather than fixed (e.g., students are asked to generate their own ideas and/or products rather than finding a specific solution). The task can be delivered verbally
or in written form. **This is coded in relation to open-ended exercises or problems where the instructor does not have a specific solution or end-point clearly in mind.**

Pedagogical Strategies

HUM Humor: The instructor tells jokes or humorous anecdotes; this code requires laughter from at least a couple of students.

ANEX Anecdote/example: The instructor gives examples (either verbally through illustrative stories or graphically through movies
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EMP **Emphasis:** The instructor clearly states that something is important for students to learn or remember either for a test, for their future careers, or to just learn the material well.

Student Engagement

VHI	**Very High:** More than 75% of the students in the immediate area of the observer are either (a) actively taking notes, or (b) looking at the instructor/course materials
HI	**High:** Between 50% and 75% of the students in the immediate area of the observer are either (a) actively taking notes, or (b) looking at the instructor
MED	**Medium:** Between 25% and 50% of the students in the immediate area of the observer are either (a) actively taking notes, or (b) looking at the instructor
LO	**Low:** Less than 25% of the students in the immediate area of the observer are either (a) actively taking notes, or (b) looking at the instructor

Appendix C

Interview protocol

After observing the class, the researcher will email each instructor to schedule a Zoom meeting. She chose Zoom because this platform is helpful for recording as well as transcribing. Each participant will be notified in the email that their talk will be audio recorded. This interview is set to last no more than an hour.

Introduction:

The purpose of this study is to comprehend the knowledge and beliefs of instructors regarding classroom practices for first-year undergraduate engineering courses. The research study does not aim to assess your methods or expertise. Instead, we are attempting to get more knowledge about teaching and learning and, ideally, about the strategies used by instructors to enhance student learning.

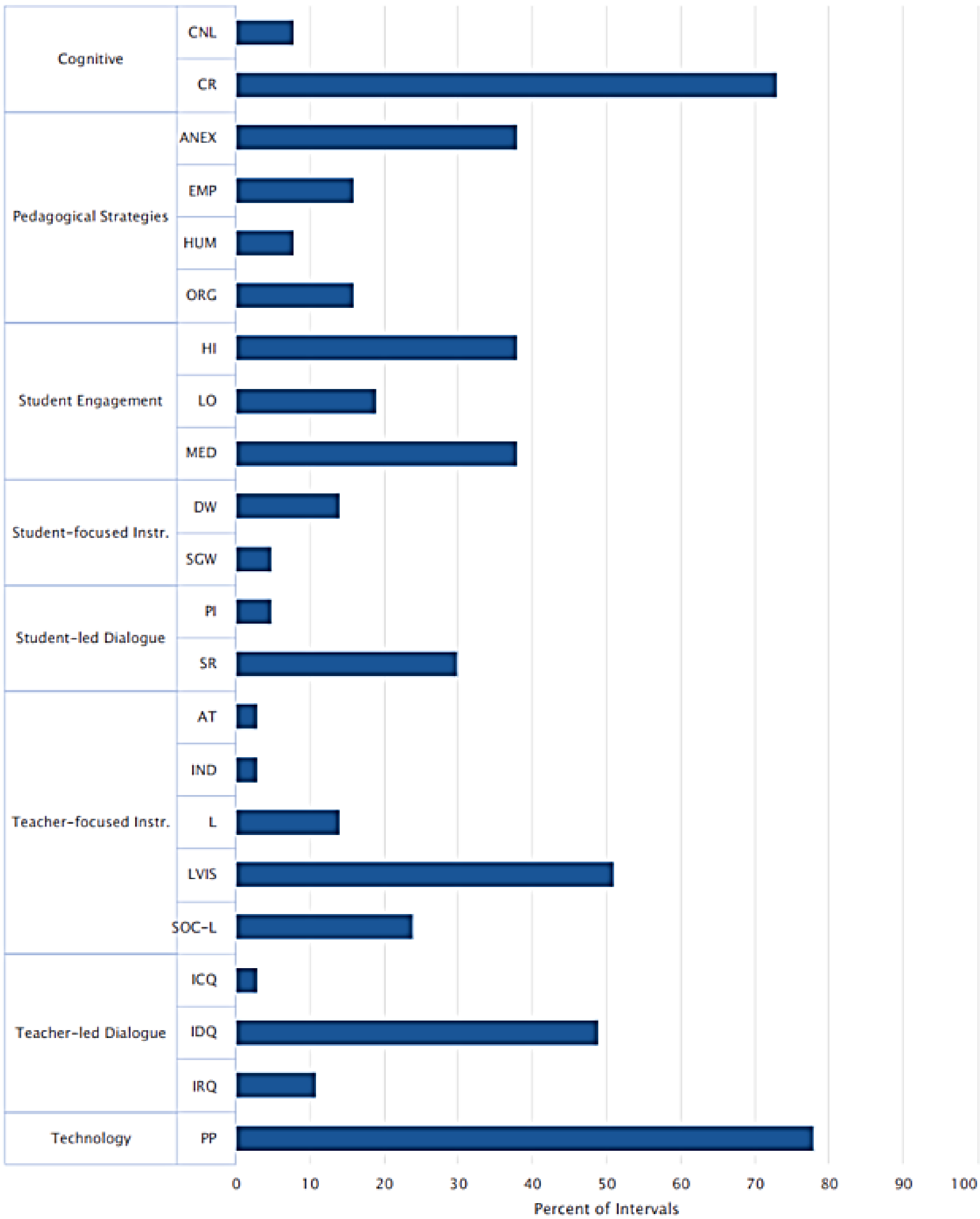
Questions:

1. How long have you been in this position at this university? How long have you been teaching the course?
2. What is your personal philosophy of teaching?
3. How does your philosophy of teaching influence what pedagogical practices you use in your class?
4. What type of activities or pedagogical strategies do you use to engage students in the classroom?
5. What are some challenges you have experienced in relation to these practices?
6. Are there some topics/concepts in this course where students are more engaged than others? If yes, what strategies do you use to teach these topics?
7. What are the hardest concepts in this course to teach?
8. Do you face any challenges in your attempt to teach students these concepts? If yes, what are some of these challenges?
9. How do you know when your students understand?
10. Is there anything else you think I should know about how you approach teaching this course?

Post Interview Comments and/or Observations:

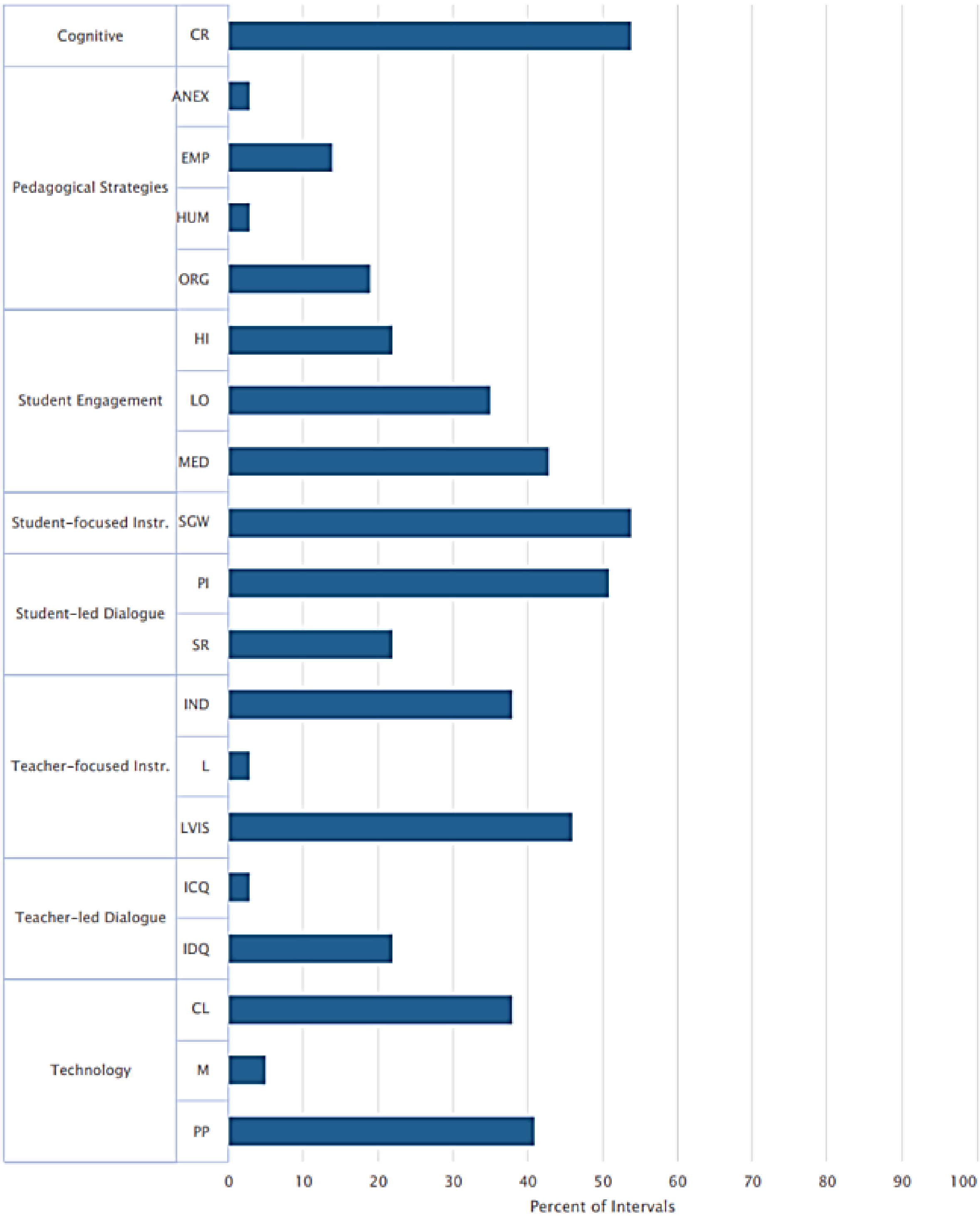
Appendix D

Percentage of overview of observed codes from the direct classroom observation of Chandler Bing's class



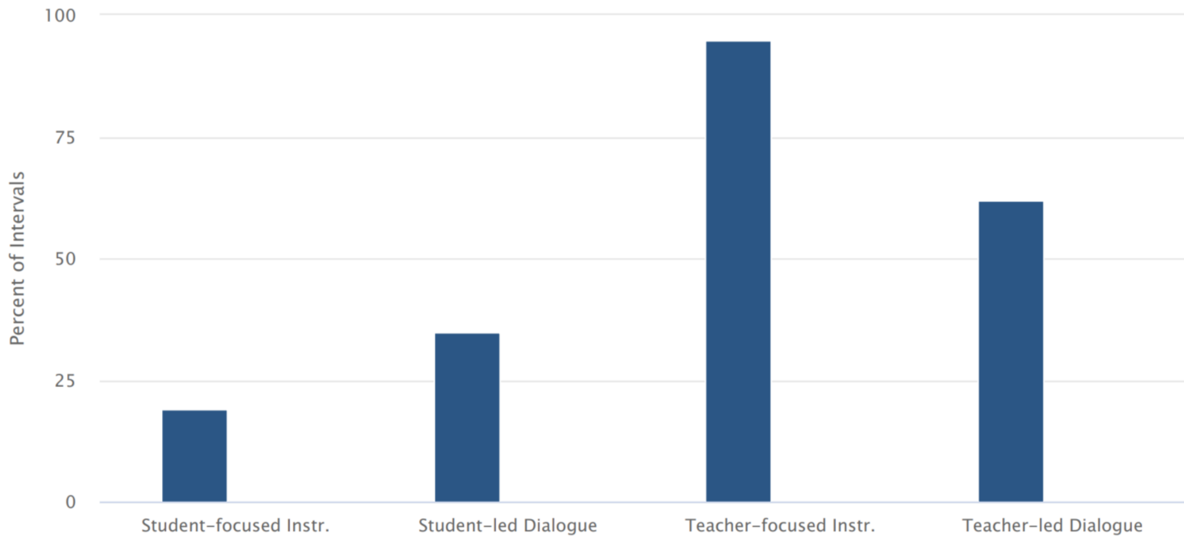
Appendix E

Percentage of overview of observed codes from the direct classroom observation of Joey Tribbiani's class



Appendix F

Percentage of particular observed codes, i.e., teaching methods and student-teacher dialogue from the direct classroom observation of Chandler Bing's class



Appendix G

Percentage of particular observed codes, i.e., teaching methods and student-teacher dialogue from the direct classroom observation of Joey Tribbiani's class