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"We learn things to solve real-life problems": Understanding how nature of engineering beliefs situate developing pedagogical content knowledge in a modular engineering education professional development program

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“We learn things to solve real-life problems”: Understanding how nature of engineering beliefs situate developing pedagogical content knowledge in a modular engineering education professional development program

Abstract

Increasing numbers of studies in STEM fields indicate that there are higher gains in student outcomes in classroom environments implementing evidence-based teaching approaches focused on learners and their learning when compared to traditional lecture-based classrooms. However, despite the compelling results, studies show that lecture is still the most common instructor behaviour in undergraduate education. Professional learning programs have been shown to be crucial in closing this gap and promoting sustained adoption of student-centred teaching approaches in undergraduate education. In order to understand how faculty members in engineering experience the development of their pedagogical understandings and practice, we invited seven engineering professors of different ranks and disciplines to participate in a professional learning program, Scholarship of Pedagogy and Application of Research Knowledge in Engineering (SPARK-ENG), designed specifically for engineering education. The participants' interactions during the community of practice and individual and group interviews after completing their modules were recorded, transcribed, and analysed through a thematic analysis process. The study findings indicated that the participants demonstrated a complexity of pedagogical understanding and preferences toward practical aspects of engineering education based on external constraints and perceptions about engineering knowledge and engineering teaching. They further valued community-based interactions to develop pedagogical reflection and possibilities of implementation in their own classroom situations. The study points to the need for further research and discussion surrounding professors' epistemologies of disciplinary knowledge and unique cultures of certain professions to support the development of effective student-centred pedagogies in university professional development programs.

Practitioner Notes

1. Professional learning programs for university instructors need to be contextualised within their specific disciplines.
2. University instructors are eager to enhance their undergraduate teaching and open to learning new pedagogic approaches.
3. Learning about effective teaching flourishes when instructors form an interactive, collaborative community.
4. Instructors' beliefs about the nature of engineering impacts their perspectives of teaching undergraduate engineering courses.
5. Instructors develop conceptual understanding of pedagogy through practical strategies, especially given the opportunity to try new approaches in their classes.

Keywords

teaching development, situated learning, student-centred learning, disciplinary practice

Authors

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Introduction

Calls in higher education have specifically noted the need for faculty to consider a change from lecture-based teaching towards a more evidence-based, student-centred approach. These calls are supported by the increasing number of studies that indicate overall gains in student outcomes in environments that implement student-centred pedagogical approaches, as compared to traditional lecture-based classrooms (e.g., Dębiec, 2017; Derting & Ebert-May, 2010; Freeman et al., 2014; Salinas & Garr, 2009). However, despite these compelling results, studies have also shown that in engineering undergraduate education that lecturing is still a primary instructor behaviour; in a small-scale survey of engineering educators teaching in Canadian universities, about 95% of instructors responded that the main instructional mode that they use is lecture (Nelson & Brennan, 2018). Although Canadian engineering educators acknowledge that “while Canadian engineering educators believe their institution places a middling value on teaching, they themselves put a strong emphasis on their teaching” (Nelson & Brennan, 2018, p. 8), at one university student reports of experiences other than lecture-based instruction are also limited with respect to their undergraduate engineering education (Nelson & Brennan, 2019).

Student-centred pedagogical approaches have been correlated with increases in student mastery of engineering skills and competencies, increases in student success rates and retention, particularly for underrepresented minorities, and increases in employability in the engineering field (Beichner et al., 2007; Krause et al., 2015; Nair, 2020). Shifting the culture of undergraduate engineering education from teacher-centred instruction to more student-centred approaches may effectively address both the development of graduate attribute based skills desired by industry and the learning needs of a diverse student population.

The Canadian Engineering Accreditation Board (CEAB) describes the engineering skills and competencies required by engineering graduates in terms of the CEAB Graduate Attributes (Engineers Canada, 2016). The Graduate Attributes include professional skills beyond technical expertise, for example, teamwork, design, communication skills, ethics, professionalism, and an understanding of the impact of engineering on the environment and society. The Graduate Attributes, with the exception of ‘knowledge base in engineering,’ are typically not well-supported via independent approaches for learning and lecture-based instruction. Diversity is also increasing with respect to undergraduate engineering students in Canada, with females, international students, and Indigenous students becoming a greater proportion of student enrolment in recent years (Engineers Canada, 2019). As a response to this evidence and the need to prepare undergraduate engineering students for their work in a complex and transitioning world, the promotion of student-centred pedagogical approaches could be seen to be essential.

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This study examined how engineering faculty members experienced their learning about student-centred pedagogies through an online, module-based professional learning program called Scholarship of Pedagogy and Application of Research Knowledge in Engineering (SPARK-ENG). The authors are part of a team of educational developers and researchers who are creating 12 modules to this end.

The modules under development are organized into four themes: *Philosophy of Teaching and Learning* (Nature of Learners, Nature of Learning, Equity, Diversity and Inclusion in Teaching); *Fostering Learning Opportunities* (Interactive Lectures, Classroom Discourse, Empowering Students to Learn); *Designing Courses for Learning* (Problem-based Learning, Team-based Learning, Assessment Practices); and *Scholarship of Teaching and Learning* (Forming an Identity as an Educator, Professional Learning Communities, Researching Educational Practices in Engineering). See Figure 1 for the program infographic.

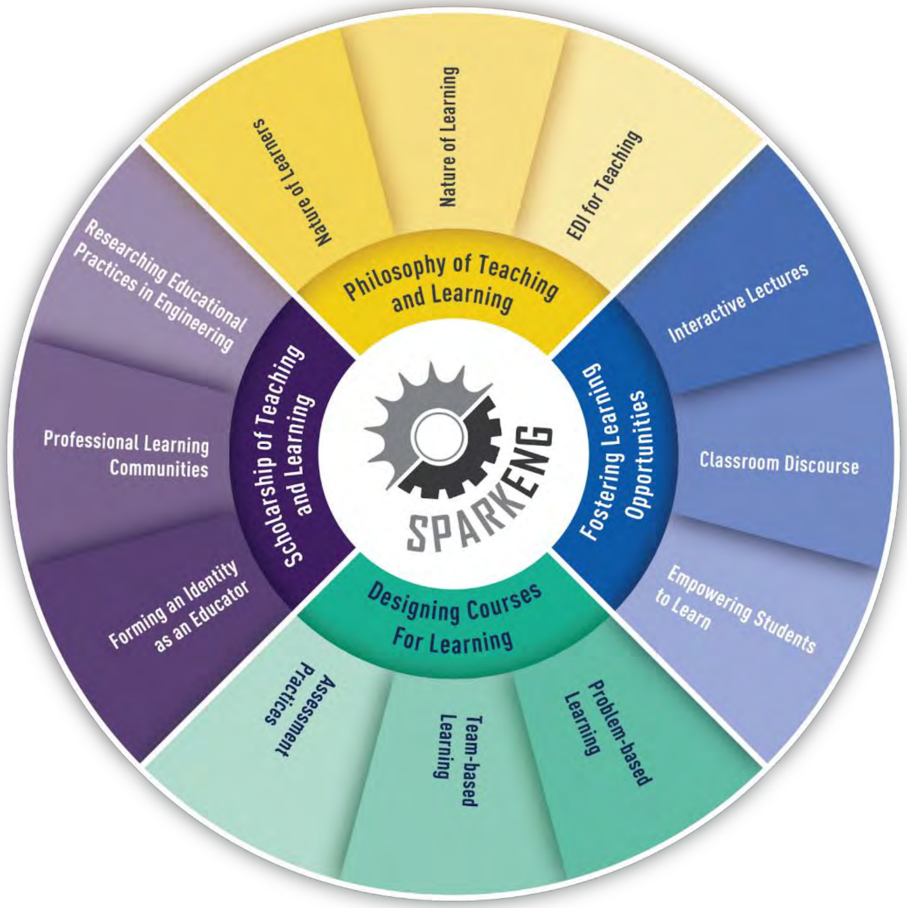

Figure 1

Scholarship of Pedagogy and Application of Research Knowledge - Engineering (SPARK-ENG) program of 12 modules organized into four themes

These modules are being developed by experienced educational researchers from the Faculty of Education in partnership with experienced engineering educators at the Canadian university where they will be implemented for new professors in the Faculty of Engineering as part of their progress toward tenure. Each module is based upon established educational literature and research, including recent post-secondary engineering education research findings.

During the program development process, the team piloted two of the modules in order to gain an understanding of how the faculty members (participants) engaged with and learned about student-centred pedagogies along with the concepts and evidence that support these. We specifically examined the following questions:

1. How do engineering faculty members experience and develop or change their pedagogical perspectives as they work through these two pilot modules?
2. How, or if, do the module elements help them to reflect on and possibly transform their teaching approaches in their classrooms?

Conceptual Framework

Understanding of pedagogy: Pedagogical content knowledge

In pursuit of excellence in teaching, pedagogical content knowledge (PCK) has been considered as a model for the development of instructor knowledge, skills and practice for decades (e.g., Berry et al., 2015; Gess-Newsome, 1999; Shulman, 1987). PCK represents the professional capacity to teach subject matter to students, including the instructor's understanding of subject matter knowledge (content knowledge), and their knowledge of students' backgrounds, common misconceptions, and understandings of the practices that are effective in teaching the knowledge in classrooms (pedagogical knowledge) (Shulman, 1987). Content knowledge and pedagogical knowledge are interrelated and interwoven within the context of classroom communities and are closely related to the effective development of students' conceptual understanding and learning within the culture of specific disciplines (Loughran et al., 2004; Mansor et al., 2010).

As subject content knowledge and pedagogical knowledge are different knowledge domains, there have been ongoing concerns about how to balance these domains as a blend of pedagogical content knowledge that is contextually effective and that promotes student learning. Subject content knowledge of the instructor is critical, yet it alone is not sufficient for quality teaching. Research has indicated that scientists with a great amount of scientific knowledge are not necessarily effective teachers of science when they lack pedagogical understandings of students' backgrounds and lack appropriate epistemologies and communication skills to interact with students (e.g., Burton & Burton, 2016). However, when instructors lacked subject matter knowledge, their teaching performance was less confident and flexible and less able to explore students' ideas, curiosity and needs for learning in classrooms (Rollnick et al., 2008). Thus, recognising the importance of balancing PCK domains could be considered to be critical for effective teaching.

Post-secondary instructors are knowledge experts as they hold higher degrees in their own disciplines. They have a great amount of content knowledge and skills in their fields, yet many instructors do not have much teaching experience and pedagogical knowledge when they begin to teach in university classrooms (Behari-Leak, 2017; Van Waes et al., 2018). University lecturers have expressed some difficulties with teaching, describing their lack of understanding of how to teach and interact with students and how to guide students with gaps and diversity with respect to their knowledge and abilities (Fraser, 2016; Wood et al., 2011). Indeed, Nelson and Brennan

(2018) report that over 93% of the engineering faculty participants in their study learned by doing and only about half reported having accessed a new faculty orientation or a workshop on teaching and learning at the start of their career.

Based on their own experiences as students, and as they work with undergraduate students in their classrooms, faculty members do develop a certain level of understanding of skills and techniques for teaching and they begin to learn how to recognise and work with students' difficulties in learning (Van Driel et al., 1997), however this involves considerable pedagogical reflection and years of teaching experience. Further, after years of teaching, engineering educators' pedagogical practices may remain teacher-centered rather than student-centred without explicit exposure to how students cognitively and socially experience their learning and how this learning transfers to new contexts as they become working professionals such as engineers (McKenna & Yalvac, 2007). University instructors have recognised this lack of pedagogical understanding and skills and their need for professional development (PD) opportunities where they might develop their teaching competencies in order to support deeper understandings of their learners (MacPhail et al., 2019).

Various PD programs at universities have been developed to provide instructors with opportunities to develop their teaching practice (e.g., MacPhail et al., 2019). At universities, many PD programs are designed for instructors across disciplines and provide teaching strategies and approaches for generalised contexts, but university lecturers have expressed that they prefer more discipline-specific PD programs (MacPhail et al., 2019; Winberg et al., 2019). Additionally, engineering instructors have been found to consider non-targeted PD programs as not directly applicable to their engineering context and are thus less likely to attend instructional development workshops or other learning opportunities (Nelson & Brennan, 2021). Shulman (2005) has proposed that instructors' understanding of pedagogies need to be developed in the context of specific professions and that these unique context-dependent teaching strategies could be termed 'signature pedagogies' (see Figure 2 below).

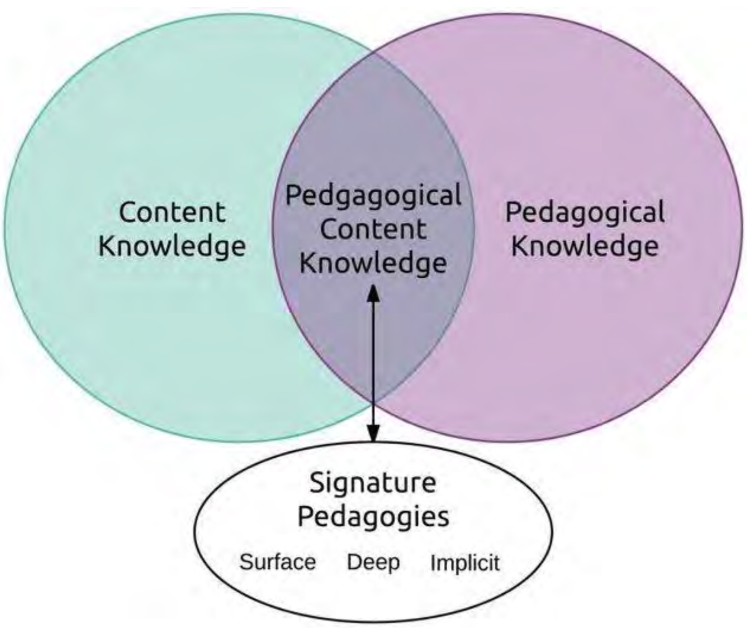

Figure 2

Signature pedagogies in education (Smith & Kanuka, 2018)

Signature pedagogies include the characteristics of teaching and learning of specific disciplinary knowledge, skills, and cultural norms within professions. Professional knowledge and performance are often discipline-specific and situated in the culture of professions, thus, to teach students to become professionals in their own fields includes knowledge development, but also ways of acting, performing, and practicing as professionals in their fields. Domain-general PD programs for teaching might not provide beginning instructors these specific pedagogical strategies and thus not be sufficient to develop the pedagogical content knowledge needed to fully understand and develop signature pedagogies in their field. Thus, an effective PD strategy might aim to develop and situate educators' PCK in the context, culture, and practice of specific disciplinary fields and professions in higher education.

Situated learning

Situated learning theory (Lave & Wenger, 1991) postulates that learning occurs as a result of socially and culturally embedded interactions and relationships (Ebbers, 2015; Vermunt, 2014), and is thus situationally (socially and culturally) dependent. This is congruent with the theoretical conceptualisation of signature pedagogies within the PCK domain (see Figure 1 above) as “learning is seen as a process of enculturation in socially organized practices, through which knowledge, understanding, and practices are developed” (Vermunt, 2014, para 2). In this study, we frame situated learning as a “a process of interaction and relationship around a specific domain and which occurs within a social, cultural, and historical context, resulting in spontaneous learning” (Ebbers, 2015, p. 650). Thus, learning is seen as a change in mental models that may result from interacting with a particular environment in a given context within a given community (Goel et al., 2010; Smith & Semin, 2004).

These contexts for learning are often situated in domain-specific communities of practice (CoP) within which novices and experts engage authentically in specific ways of thinking and doing (Ebbers, 2015). Situated learning thus involves becoming a certain kind of person (participant) within a particular cultural context (culture of CoP) of a particular community (CoP). Learners are actors and learning is a lifelong process that results from acting within various situations (Brown et al., 1989). Participants of a CoP “interact with the values, norms, and true culture of a specific community or organization” (Altalib, 2002, p. 5). In this model, the result of learning, competence, is defined as “action [that] is not grounded in individual accumulations of knowledge but is instead, generated in the web of social relations and human artifacts that define the context of the activity we are examining” (St. Julien, 1994, p. 261). Situated learning then, is a conceptual framework that enables understanding of these complex interrelations: the webs of knowledge and the development of competence and pedagogical content knowledge within a CoP.

The related literature on professional development in an academic context emphasises the need for “development [that] takes place where faculty spend most of their time” (Boud, 1999, p. 3) and “within groups and environments with which academics identify” (Boud & Brew, 2013, p. 211). The context that the participants are situated within in this case includes the disciplinary consideration by the participants of what an engineer is and what one does. For example, in this particular epistemological framework, engineers are typically considered to be “designers …[who require] skills with materials, ability to work collaboratively, and ability to become part of a community of practice” (Johri et al., 2014, p. 53). Descriptors of typically held beliefs about engineering (or what might be referred to as nature of engineering (NoE) knowledge) often include, for example, that engineering is solution-oriented, contextually responsive, empirically based, has a personal dimension, is influenced by societal and cultural factors, is interdisciplinary and is a social process (Antik-Meyer & Brown, 2019). Studying this unique community, made up of the participants and their understandings and beliefs about this particular context “necessarily requires attention to the relationships between individuals, [and] their own self-making in terms of their ability to actively engage with their environment” (Deglau & O’Sullivan, 2006).

In this pilot study we considered the uniquely situated context of engineering education as foundational to our understanding of how participants interacted with the module-based learning program (SPARK-ENG) and each other as part of a CoP. By tapping into participants’ (and our engineering research partners’) insights surrounding the learning that was experienced, including the types of PCK that were illuminated in the process, this study aimed to authentically examine how engineering educators experience pedagogical learning and change.

Method

Research methodology

A qualitative case study approach was employed in this research. A case study involves the study of a case, unit, or phenomenon with boundaries (Merriam, 1998). Merriam uses a ‘fencing in’ concept to bracket researchers’ choice of a case for their case study. She writes that the case is “a thing, a single entity, a unit around which there are boundaries. I can fence in what I am going to study” (Merriam, 1998, p. 27). Educational practice is a complex situation where the teacher, learners, and learning environments are consistently intersecting and influencing the process and products of teaching and learning. Thus, fencing the boundaries of the case is critical in this study. The boundaries of the case were the community of engineering faculty who learned, reflected, and developed their understandings of pedagogies of engineering teaching through the SPARK-ENG pilot modules. The current faculty contingent in the Faculty of Engineering has a low culture of talking about teaching. For most, research is valued overall. This stems from a history of little to no investment in educational activities or innovation, save a few disparate examples. More recently, since 2015, there has been a push to value education and invest in different pedagogical approaches, projects and funding proposals and there is an uptake and greater interest in teaching. Culture is changing, opening up a space for targeted pedagogical education for faculty members.

Procedure

During May and June 2021, we piloted two SPARK-ENG modules using a web course design program embedded into our university’s online course platform (eClass™). This web course design program and eClass™ platform provided flexibility in navigating diverse module contents and interactive functions among participants. The two pilot modules were: 1) Problem-based Learning (PBL) and 2) The Nature of Learners (NL). The two modules were selected because they represented the range of the type of topics that participants would experience throughout the SPARK-ENG program.

Each module was designed to be completed in three weeks, and it was anticipated that each module would take 8-9 hours in total. In the first two weeks, participants engaged with module content asynchronously at their own pace. Week 1 included module objectives, an engaging case study to reflect on their current teaching practices, and selected readings. Week 2 included a presentation of important ideas and research related to the module topic through written explanations, graphic organisers, and podcasts with experts, culminating in instructional strategies as suggestions and an opportunity to develop and upload their own teaching plans relevant to the module topic. After that, they met synchronously online for the CoP session in the third week. During the CoP session, they discussed their questions, wonders, and learning through the modules and their classroom experiences in relation to the module topics. The design of each module was the same, from including similar elements in the same structure and format. The parallel design was intentional to allow participants to anticipate the ways in which they would learn and interact.

We asked for contact information of both junior and experienced faculty members from the Faculty of Engineering at our university in order to aid in our understanding of learning about pedagogy across the career span. We received twenty-three faculty members’ contact information and explained to them the background of the SPARK-ENG program and research process via email. Seven faculty members volunteered to participate in the study, indicated in the Findings as P1 to P7. Their teaching experiences and backgrounds were diverse. Four participants were considered to be junior members whose teaching experiences spanned 0.5-2 years, indicated in the Findings as “<2.” Three participants were considered to be experienced members with various work and teaching experiences with more than 2 years of teaching experience, indicated in the Findings as “>2.”. Their professional sub-disciplines within engineering also varied (i.e., civil, chemical, computer, environmental, etc.).

The participants engaged in all the planned components of the pilot modules to simulate the implementation of the complete program. The PBL module was piloted in May 2021 and the NL module was piloted in June 2021 with three weeks allocated for each module completion. The order of the module implementation was based on the completion of the module development. That is, the PBL module was ready for implementation before the NL module – even though the PBL module would normally come after the NL module when completing the entire program. To understand how the participants experienced and reflected on their learning of pedagogies and teaching practice through the modules, data was collected during the two CoP meetings and then individual interviews and a group discussion via Zoom™ after the completion of both modules as follows:

1. Two video recordings of CoP sessions: At the end of each module, there was a one-hour interactive session of CoP where participants discussed the module content and shared their workplace learning activities. Each meeting lasted for an hour. These were recorded and analysed for qualities of engagement in modules and faculty members’ learning.
2. One video recording of a one-hour whole group discussion: This was conducted after both modules were completed, and audio recorded and transcribed. This provided a retrospective review of overall module feasibility and appropriateness along with further

evaluation of the module components by the participants. During the discussion, participants shared a range of their perceptions on teaching and learning.

3. Video recordings of individual, semi-structured interviews at the end of the pilot project with each participant. Within 2 weeks after the completion of the modules, six participants individually participated in a semi-structured interview. This was done to gain a deeper understanding of each faculty members' experiences and perspectives on teaching and learning through the modules. Interviews were typically about an hour in length.

All interactions were done and recorded via Zoom™. All Zoom™ recorded data were transcribed for analysis.

Data analysis

The data were subjected to qualitative thematic analysis (Braun & Clarke, 2006). Thematic analysis offers researchers flexible guidelines for the data coding process where the aim is to identify themes and patterns that explicate interpretive understandings of participants' experiences. Specifically, strategies of open, axial, and selective coding (Corbin & Strauss, 2008; Flick, 2006; Williams & Moser, 2019) were employed in the first phases of analysis to support the development of emerging themes, with attention to any shifts in participant awareness of and perspectives on student-centred teaching approaches that were consistently emphasised in the modular materials. Consistent with thematic coding approaches, the research team took multiple passes through the data. During the open coding process, researchers individually reviewed video and audio files of group discussions and individual interviews and identified key words as indicators of important concepts. These keywords and concepts were synthesised to suggest any emerging themes.

During axial coding, the researchers gathered to compare their ideas and interpretation from the open coding results. The research team discussed similarities and differences in codes and further developed the possible overall themes that best represented the data. Ideas were merged, revised, and categorised during this process. As part of selective coding, the themes were discussed and examined against the data again and specific data that explicitly demonstrated the themes were closely attended to with the aim of understanding how the specific contextual and situated data emerged and how these themes were representing the perspectives that the data represented in depth.

To develop the trustworthiness of the data analysis, and to understand this particular situated learning context and PCK issues that were unique to the engineering education milieu, or, alternatively, that were common with other learning contexts, the research team of education and engineering members conducted a cross-checking comparison. Three researchers from the Faculty of Education participated in open coding individually and gathered to thematise the key ideas. Two researchers from the Faculty of Engineering also followed the same process and later met with the education research team to compare and synthesise the results of coding key ideas and finalise the themes.

Results

Here we report on three themes that emerged from the data analysis, with particular attention to the situated context under study. The themes interpret participants' learning experiences in that they: explained their preference toward practical over conceptual module contents; understood pedagogy through their perceptions on what engineering and engineering education is; and emphasised the importance of engagement within the CoP. Each theme is supported by quotes that are representative of the data.

Preference toward practical PBL over theoretical NL

The participants were willing and receptive toward learning how to enhance teaching through the modules. They found both modules’ content important and valuable for them to reflect on and develop for their teaching. This was most clearly expressed by the professors with less teaching experience. For instance, a junior professor explained:

> The most beneficial thing is, for a new teacher like me, that these two modules actually give me some tools that I was not even aware of … So, when I design my course or teach in the future, I will keep considering these two strategies. (P1; <2)

While valuing new ideas and pedagogical approaches suggested in both modules, they demonstrated a clear preference toward the Problem-Based Learning (PBL) module compared to Nature of Learners (NL) module during the interviews. The participants explained that the PBL approach was practical, relevant, and effective and NL was theoretical and challenging to implement in their classrooms, even though both modules had practical examples with strategies to try in classes. The participants mentioned that:

> To be honest, the PBL module ... matched my expectations. I learned something very practical. (P3; <2)

> The PBL module, I find the contents very helpful. I already follow the seminar on problem-based learning … The NL, I didn't take much away from it to be honest. (P6; <2)

> The other one [NL], I learned the concept but still I feel it’s too theoretical right now. (P4; >2)

There was a certain degree of reluctance toward NL being conceptual and theoretical, thus not as helpful as PBL to enhance their teaching. Especially at the early stage of their career, the participants seemed to expect to learn tools, skills, and strategies that were straightforward for whole classroom implementation. We acknowledge that implementing the PBL module as a specific instructional strategy before the NL module as a general instructional approach may have set participants expectations for learning instructional strategies.

They further explained why they valued PBL more than NL. In the NL module, there were suggestions on how to get to know students’ diverse backgrounds, interests and needs to enhance student-centred teaching. Yet, for these participants, the suggestions seemed not implementable due to external barriers such as time constraints and large class sizes.

> Probably I can start with some graduate course because I’m not sure if I can do that in a very large-sized class, like 200 people, to know every student. (P1; <2)

> This [getting to know your students] is not going to work for a large class … My smallest undergrad class is 65 and my biggest is 120 or 130 this year. So the problem is as soon

> as the teaching term starts, then I teach three classes, then it's more or less survival mode. There's really no time. (P6; <2)
>
> Looking after different students actually is not easy, especially under the North American system. … I do not see any chance to implement such assistance because, for a typical class with 50 to 100 students, the professor has no chance to look after every aspect of the students. (P4; >2)

Considering their current teaching environments, the participants in this study expressed that the process of adapting ideas of the NL module was challenging for them. Although they acknowledged that knowing their learners as suggested in NL could allow for better instruction, most participants reported that they had little experience and saw few opportunities to do this with large undergraduate classes, and thus they considered the NL module to be more conceptual in terms of pedagogy and thus not as useful. Some participants had taught classes with over 200 students and had experienced the challenges of class interactions and assessment in this context. These participants were concerned that they would not have enough time to interact with individual students and to understand each of their needs, interests, and learning situations, even though the strategies suggested in the NL module did not suggest that instructors learn about each individual student.

Considering time constraints of increasing workload and large size classes, their preference toward what they saw as a more ‘practical’ approach was not surprising. The perception of practicality is often seen as important for educators’ acceptance of professional development initiatives (e.g., Carvalho-Filho et al., 2019; Darling-Hammond & McLaughlin, 1995). For example, when student-centred inquiry approaches were introduced in K-12 science classrooms, teachers also reported challenges of time limits and lack of resources and support for classroom implementation. K-12 teachers were also able to see the benefits of student-centred inquiry-based learning; however, until they were able to understand how to enact such pedagogies practically, they considered these strategies to be extremely challenging to implement in their specific classroom situations (Kim & Tan, 2011; Zion et al., 2007). These external constraints often determine educators’ pedagogical decision-making in classrooms and need to be considered as instructors at all levels struggle to adapt innovative teaching approaches in their classrooms.

These findings are congruent with other recent research that has shown that similar potential barriers to active learning strategies for engineering instructors have been identified (Litzinger et al., 2011; Nelson & Brennan, 2020). However, the participants did consistently state that they considered PBL to be more practically implementable in larger classes. This was expressed to be congruent with their expectations for pedagogical advice and was seen as practical and implementable. As such, PBL was seen as a helpful and effective way to develop their PCK.

Perceptions on engineering and engineering teaching

The participants’ legitimate concerns about time constraints and class sizes explain their preference and reluctance toward some module content, yet we also found that the participants’ perceptions of what constitutes engineering and engineering education affected their experiences and understandings on the two modules as a way to develop their pedagogies. That is, their understanding of effective teaching was based on what they believed engineering is and engineering education should be. One experienced participant described how they approached planning for a lesson:

> … what is the durable knowledge we can give? … So, we would always be looking at ‘what’s the durable information?’. … That is one of the principles. Another principle is [that] a lecture or a series of lectures should have a target skill. What is it I am trying to teach? What am I trying to achieve? Is it this concept? Is it this particular technique? (P2; >2)

During the interviews, the participants also were considering what they thought engineering teaching should be by reflecting on their own learning experiences as students:

> We were all students before. As engineering students, we prefer things more practical. We learn from things. That’s why we chose engineering as our major, right? We learn things to solve real-life problems. (P3; <2)

They explained that engineering students prefer practical approaches and that is why they chose engineering as a field. Engineering was seen as a practice of problem solving. In the same way, engineering teaching emphasises knowledge and techniques that can be used directly to solve problems. During the interviews, the participants emphasised that engineering was practical work and they needed to achieve knowledge and skills for problem solving and also meet students’ expectations as future engineers. Based on these perceptions, NL approaches were not seen to be as effective for engineering teaching. One professor further mentioned that one strategy suggested in NL would not be accepted by his students because that was not what they would expect in engineering classes. Thus, they viewed PBL, as an obvious link to their identities as problem solvers, was congruent with their conceptions of what engineering is and how working in engineering typically occurs. These ideas appeared to be more easily incorporated into their pedagogical considerations and valued in engineering classrooms.

The participants further expressed that some strategies and ideas in NL were seen to be not typical of traditional engineering education culture. This was illustrated by responses that saw ‘getting to know students’ approaches as outside of the typical teaching repertoire of undergraduate engineering education practice. They explained how they valued understanding their students, but only with respect to how this affected the students’ ability to grasp content knowledge and skills that they are teaching. One participant explained:

> I acknowledge it [students are diverse]. I’ve never done anything differently. I also don’t knock myself out trying to be the understanding prof who cuts slack everywhere and gets into the students’ personal affairs. I don’t want to touch that; I don’t want to get involved in that at all. That’s not my role. They’ve come to the university because I know something they don’t know. (P2; >2)

The participant acknowledged that the diversity of students exists, yet, addressing it was not part of the instructor’s role in engineering classrooms. The focus for teaching was on teaching the disciplinary knowledge of engineering.

However, some instructors did express concern for their students’ perspective. For example, one participant shared that “it is important … to understand the difference, understand what’s different in previous knowledge that they [student] have, and try to level that up” (P5; >2). This participant valued the importance of getting to know students’ background knowledge. The purpose expressed for doing so was to identify the difference and gaps between students' previous knowledge and the course ideas, therefore helping the instructor to better support students' knowledge construction. The instructor here was expressing interest in their students' perspective, was looking for ways to help them move forward in their learning, acknowledged that students' prior learning might be a consideration, and that they saw this as their role to try to bridge those gaps.

When the module contents were congruent with the participants' view of what they considered to be engineering knowledge and skills and how students could work toward becoming part of the engineering community, they valued them as effective module content for helping students to move forward in their learning. They often expressed this as they spoke of what types of PCK resonated with them:

> Problem-based learning helps to bridge the gap between classroom and the real world … I think this is critical for my teaching in general. We need to find out how can we help them realise that they not only need to understand the information that we're teaching but that they need to be able to apply the information that we are teaching. (P1; <2)

> So how do you make it come alive a little bit and show applications in the real world; and that was the thing that we wanted to hear, just tying it into the real world and making it alive for the students. So that is, that's what I was expecting in the readings [modules] and certainly got a lot of that kind of reinforcement for that kind of an approach. (P5; >2)

The participants' understandings of what engineering is – engineering as practice, problem solving, and connections to the real world – seemed to affect their expectations of what they needed to learn and develop to become effective instructors in engineering classrooms. During the interviews, they often remarked that engineering education needed to "bridge the gap between the classroom and the real world" (P5; >2) and to bring forth "application of knowledge in the real world" (P3; <2). They recognised that instructors should find a way to bring forth these approaches in undergraduate engineering classrooms, yet the suggestions introduced in NL did not seem to resonate with them as a pedagogical approach that might help them toward this end, despite acknowledging the value of learning some aspects of their students' perspective – namely their content familiarity or efficacy – for effective learning and teaching.

Even though the reluctance towards the suggestions introduced in the NL was evident among the participants, we were able to see some possibilities that participants, with more scaffolds and exposure to student-centred approaches, might adopt some of the presented student-centred suggestions in their future teaching practice. Some participants had realised that getting to know their students and being attentive to students' diverse needs would be helpful and meaningful for student learning, even though this was different from their traditional typical perceptions of what engineering is as a discipline and what engineering educators should do in their classes. For example, one participant echoed one section of the module content when stating:

> "A small amount of kindness and empathy goes a long way." I think that's true. Sometimes, you know, yes, we as engineers, we don't do that much, right? Because … [from the engineering perspective] you are kind of crazy … if you try to do things like that. But I've noticed that that can actually as well help. But it's something that we're not used to doing, right? (P5; >2)

This participant realised that getting to know their students was something that engineers or engineering educators did not usually do or were “not used to doing,” but that this approach held promise for helping the participant work with their students. We hope that with this awareness, participants might explore some of these possibilities for ‘getting to know students’ as an important aspect of student-centred approaches to develop students’ learning and reflect on their identities and roles as educators of engineers in the future.

Importance of engagement within the community of practice (CoP)

The participants appreciated their engagement in the CoP discussions surrounding their teaching. During the CoP discussion after individual completion of each module, the participants reflected on teaching and learning with colleagues and shared their experiences, insights, wonders, and struggles for classroom implications of the module contents. When they shared how they implemented certain pedagogical strategies in their own classrooms and how these worked (or not), they reported that they became more aware of the potential and feasibility of classroom implementation, which often encouraged them to accept these strategies as evidence-based, effective, and trustworthy teaching pedagogies for engineering classrooms.

For example, one professor shared that:

> … the CoP was the part that I liked the most, that you can really communicate with others. ... They view these specific problems at different angles. ... If we discuss with each other, I can learn from that. … And they can give [their] feedback, like they said we have already done that and it’s very, very effective. Those things … [are] hard to learn from the materials, … [they are] very personal experiences. … you hear that someone in your university, they use this and it’s very useful. That’s something you want to hear. (P7; <2)

The participants valued this communication, especially accounts from more experienced faculty members, and they often considered this information to be reliable or practical since they saw this actually experienced or observed in their context. These discussions helped them to expand the practical suggestions from the modules. As the participants were from the same Faculty, their teaching contexts were similar and they expressed that many challenges that they faced were also similar, such as large class sizes and an increasing diversity of the students in their classes. The participants considered that this sharing of PCK during the two CoP meetings was highly relevant to their teaching contexts. In fact, some participants described the exchange of ideas during the CoP meetings as the most valuable and helpful part of the SPARK-ENG experience with regard to enhancing their pedagogy. A typical participant observation after the CoP meeting was that the:

> ... CoP has the interaction, when you share your ideas with others, when you validate your thoughts with somebody else, I think that creates more value and gives us more tools to better improve our teaching. (P4; >2)

In addition to the exchange of ideas, there were new perspectives emerging from these group learning sessions. Participants expressed often that the CoP meetings provided them with opportunities to consider something they had not previously considered:

> I think one of the most valuable parts is the CoP, when you actually bounce your ideas. … In a CoP ... you start explaining what you think, but then you get some ideas and some thoughts from somebody else, and say oh, I never thought about that. (P5; >2)
>
> [The CoP] helped me to understand more actually. I also learned it from other profs' point of view, like their perspective and they gave some feedback I never thought of … And I always say when you go to PhD, when you go – your education degrees go higher and higher, your brain runs only in a small circle so – and in part that's arrogant, you don't open your mind to think from another angle. I think that [the CoP] also helped. (P3; <2)

Through the CoP engagements, the understanding and learning from the modules were often developed and synthesised by the group, allowing for some of the ideas in the modules to be operationalized by the participants and thus become more accepted as possible PCK strategies by those who were participating. They shared how certain strategies had been and could be practiced in engineering classrooms in their own faculty. They recognised that interactions with their colleagues in the CoP discussions helped them see how the module information could be situated and critically examined, with an aim toward pedagogical enhancement for all. Possibilities, challenges, and feasibility of classroom implementation were discussed and recognised through CoP discussions.

Discussion

Teacher perceptions on the nature of engineering

In this study, the university professors in engineering shared their understanding and experiences of learning about pedagogical aspects of engineering through the two pilot modules: Problem-Based Learning (PBL) and the Nature of Learners (NL). In their discussion and conversations through interviews, there were complex understandings of pedagogical content knowledge (PCK) toward student-centred teaching approaches. The priority with respect to developing new PCK was given to learning how to better teach engineering content knowledge and application of this content knowledge to students; thus, the practicality of PBL teaching strategies was emphasised and valued as new learning more than developing increased understanding about the diversity of learners' backgrounds, needs or expectations.

There are various influences that inform teachers' pedagogical decisions in classrooms. External factors such as time constraints, prescribed curriculum, classroom environments, etc. influence what and how to teach (Roehrig & Luft, 2004). In this study, the participants also highlighted their concerns around constraints of time and class sizes toward certain pedagogical approaches. Yet, we also found their beliefs about engineering and engineering education deeply influenced their understanding and decision making about what pedagogical approaches were valued. Research has shown that teachers' epistemic beliefs within disciplines deeply influences their teaching approaches. What teachers believe as the nature of their discipline can be a determining factor for pedagogical decisions. For instance, science teachers' beliefs and understanding of the nature of science affects their teaching practice (e.g., Tsai, 2002; Waters-Adams, 2006). Based on their epistemic beliefs on what counts as science, science teachers accept and/or reject certain pedagogical approaches such as considering the social and cultural aspects and applications of science as not being 'true' science (Pedretti et al., 2008). Recent studies have also shown that teacher practice and identity are closely linked and can change with exposure to new and more student-centred pedagogical strategies, if adequately supported (Kaasila et al., 2021; Keiler, 2018).

In this study, the participants’ perceptions and beliefs about engineering and engineering teaching influenced what to prioritise as effective teaching strategies and pedagogies throughout the modules. The participants often suggested that engineers learn by doing and/or problem-solving, thus they believed that their students would value similar ways of learning. One participant described how problem solving was often a default strategy relied upon by engineers:

> If someone comes with a problem, we [engineers] presume you want us to solve it. And – otherwise, why would you tell me you have a problem? (P3; <2)

This illustrates how this situated group of engineering educators viewed PCK during this learning process. Engineering educators in this study demonstrated that they valued the transmission of content knowledge and its application to ‘real-life’ scenarios and, although they stated that they were open to learning new approaches and skills, they saw little application of some of the student-centred pedagogical approaches that focused on the students themselves, rather than the instruction, even though examples of engineering or other higher education instructors doing this were provided in the NL module. In fact, it helps explain why the PBL module was highly valued by the participants due to the emphasis on problem solving, even though, as module designers, we saw the NL strategies as being more student-centred pedagogical approaches. Orienting ourselves to engineering educators’ view of PCK informs how we will revise these modules and frame future modules. As the NL module was the first module where the student-centring of instruction was being explicitly presented to the participants, it remains to be seen if those who complete the full suite of 12 modules might shift their PCK balance toward more concern with student-centred pedagogy, as they experience other modules that explicitly address these approaches, such as the Nature of Learning; Equity, Diversity and Inclusion and/or Metacognition modules in this SPARK-ENG program.

The participants’ preference for what they consider to be more practical strategies for engineering education is consistent with scholarship surrounding the nature of engineering (NoE), which considers questions surrounding what engineering is, what engineers do, and how they think (Pleasants & Olson, 2019). A distinguishing feature of engineering as a way of interacting with the world is a concern with the practical or functional design of technologies (Kroes, 2012). This practical focus of engineering as a way of thinking may have led participants to value the merits of what they considered to be practical and useful aspects of the modules in this program that enabled students to better learn the content and skills. The content of the NL module may not have been as well situated in their understanding of NoE and the goals of engineering education, so these approaches were not received as critical aspects of effective teaching. They mentioned the challenges of the PBL approach in large classes, yet they still valued it as a practical and effective approach in engineering teaching. This suggests that in order to develop student-centred pedagogies for engineering professors, professional learning programs need to provide opportunities for instructors to reflect on their perceptions and beliefs about the nature of engineering and the pedagogical suggestions as situated in their disciplinary culture and contexts. This emphasises the importance of incorporation of signature pedagogies in professional learning programs that address the characteristics of teaching and learning of specific disciplinary knowledge, skills, and cultural norms within professions (Shulman, 2005) in order to enhance the transformation of teaching practice.

Situating PCK in the community of engineering faculty

Given that each discipline and subject area acquires their own signature pedagogies, engineering education professional learning programs should acknowledge and leverage the unique nature of knowledge and teaching practice in this situated context. We noticed that the participants' interactions during CoP helped them situate certain pedagogical approaches in their own classroom situations. They shared and reflected on their thoughts and experiences of teaching and discussed the challenges and possibilities of certain pedagogical approaches. Certain approaches seemed at first to be impossible to implement, yet, when senior faculty members shared actual examples of classroom implementation within the constraints of current teaching environments, the others often viewed the possibilities of the approach to be evidence-based and feasible in their own contexts. Their learning of PCK was situated and developed in the culture of engineering classrooms through collective reflection and discussion through the CoP. In this regard, engineering professors' PCK could be situated, reflected, and developed in their collective community. In a true CoP, the strengths of all members of the community are leveraged through reciprocal learning processes. In this way, both the individuals and the learning community are perpetually redefined and co-evolving (Ebbers, 2015).

Yet, we also acknowledge a potential risk of norm building or confirmation bias on certain PCK as futile and ineffective based on collective assumptions and traditional conceptions of engineering teaching in a CoP. We noticed a certain level of agreement and confirmation surrounding NL not being effective in engineering contexts was emerging through the CoP discussion. Certain PCK could be collectively rejected without further consideration in a CoP because it is not considered by that particular group to be congruent with their beliefs about engineering education. In our case, the SPARK-ENG professional learning program is designed as an asynchronous self-paced online course except the CoP component, so the designers of the SPARK-ENG program might consider how ideas that emerged from CoPs could be re-framed and resituated for engineering education throughout the professional learning program.

The complexity surrounding promoting PCK that supports teaching the content knowledge while also considering students as the centre of the instructional endeavour still remains as a further area for inquiry. Understanding how different pedagogical approaches align with the learners' cognitive and social backgrounds has been shown to be helpful in developing student-centred teaching to improve learners' performance in post-secondary settings (Felder & Brent, 2005; Kassem, 2019). Understanding how engineering educators' conceptions of the NoE affect how they encounter and implement pedagogical change has been shown here to be a factor that might influence the design of effective professional learning programs that help faculty to develop new perspectives and to enable instructors to reflect and critically evaluate their use of teacher-centred pedagogies for engineering. To encourage new and more effective signature pedagogies for engineering education, understanding how NoE beliefs affect professors' conceptions of themselves as learners could be also critical. We propose that this small study has illustrated how, in order to develop effective and sustainable signature pedagogies in disciplinary subject areas, it may be important to create learning communities where professors confront and reflect upon their beliefs about their profession writ large, and use these epistemologically-based ideas as fertile ground for reflective practice as they consider pedagogical change.

Conclusion and Implications

The results of this qualitative study offer interesting insights into engineering educators’ experiences in a teaching professional learning program. In the two modules piloted, participants expressed a clear preference for the practicality and relevance of the PBL module over NL module as theoretical, even though both modules had practical examples with strategies to try in classes. In addition to external factors such as time constraints, large class sizes, we found engineering educators’ perceptions and beliefs about engineering as a discipline influenced what they prioritised as effective teaching strategies and pedagogies. Compared with the NL approach, PBL strategy aligned and situated better with engineering educators’ understanding of NoE and goals of engineering education and thus, was valued as effective and relevant pedagogies and prioritised with respect to developing new PCK. Even those who talked about the importance of knowing their learners talked about it in a more practical sense, such as understanding students’ prior engineering knowledge. Engineering educators in this study valued the CoP discussion because interactions with colleagues during the CoP sessions helped them situate student-centred pedagogical approaches in the culture of engineering and their own classroom situations. Through those interactions, engineering professors’ PCK was situated, reflected, and developed.

Informed by these findings, we have revised these two modules and framed future modules in the following two main ways. First, to better situate student-centred approaches in the culture of engineering, in each module we included more examples of implementing student-centred pedagogy in engineering classrooms, especially in various engineering sub-disciplines (e.g., civil engineering, mechanical engineering, chemical engineering). These specific engineering classroom examples are intended to help engineering educators view student-centred approaches introduced in each module to be evidence-based and feasible and see the possibilities for implementing and adapting these approaches in their own classrooms. Many of the examples highlight large class sizes. To further facilitate the implementation, we also included practical suggestions which we call ‘toolbox’ in each module. These suggestions are quick, practical, and realistic tools that faculty can use immediately in their classrooms to apply the module topic to their repertoire of teaching strategies.

Second, participants in this pilot study valued CoP discussions as the CoP provided them with the opportunities to collectively reflect on and develop their PCK through interacting with colleagues. Therefore, to further support engineering educators in professional learning and developing new PCK through the SPARK-ENG program, we added more opportunities for them to interact with each other. In addition to the synchronous CoP in the third week, in each module we have added two asynchronous discussion forums. These forums provide engineering professors with space to share for example their thoughts about the module materials, ideas about classroom implementation, and give each other feedback. Through these forums, we intend to create additional opportunities for interactions to support situated learning for PCK development in their domain-specific professional learning communities. We are also considering adding more synchronous in-person interactions, such as workshops led by instructional coaches, classroom teaching observations and feedback, and forming 'reading pairs' to share thoughts about the selected readings. As the program is finalised and begins implementation, we anticipate conducting a full program assessment to share faculty members' sustained learning and enhancement of their teaching approaches as they engage in all 12 modules.

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Conflict of Interest

The authors disclose that they have no actual or perceived conflicts of interest.

Ethics Approval

This study was approved by the Research Ethics Board 1 of the University of Alberta (protocol Pro00107339). Informed consent was obtained from all participants for involvement in the study.

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