Understanding Professional Learning Practices of Engineering Educators: Insights From the SPARK-ENG Program

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To meet our institutional demands for enhancing engineering education, we developed a professional learning program to comprehensively support our engineering educators at our university. In this study, we investigated participants' authentic professional learning experiences that emerged from their engagement with the program through interpretive inquiry, framed by complexity theory. Data analysis revealed that the program enabled participants to experience four-layered learning practices that functioned as learning systems—an evolving learning process. This process empowered them to transition from knowledge recipients to active and authentic educators. Our program provides a valuable reference for creating supportive environments for engineering educators' professional learning.

Keywords: engineering educators, professional learning, active pedagogy, learning program, evolving learning process

INTRODUCTION

Rapid changes in scientific and technological interactions in society have posed significant demands for qualifying engineers (Gołuch et al., 2024). Evidence-based, student-centered pedagogies are now more crucial than ever (Ross et al., 2024). However, lecturing remains the predominant instructional approach in engineering education (Nelson & Brennan, 2018). Engineering faculty often struggle to employ active pedagogies and to create supportive environments that engage undergraduate engineering students (Nelson & Brennan, 2020), despite abundant research indicating that adopting more active pedagogical methods enhances student engagement and performance (Felder & Brent, 2016; Freeman et al., 2014). This may be due to educators not being sufficiently equipped to implement active pedagogies for preparing future engineers (Sukackė et al., 2022).

There has been a growing number of higher education professional development programs available for engineering educators. Still, these often emphasize general teaching strategies that are not specifically tailored to engineering disciplines and/or they frequently lack the characteristics shown to be effective for long-term pedagogical change, such as understanding students as learners, experiencing long-term impacts of pedagogical change, engaging in interdisciplinary collaboration, and accessing guidance from expert mentors (Chen et al., 2024). Also, these programs often do not encourage educators to research their own or others' teaching practices (Svendsen, 2020). To address these issues and meet institutional requests for enhancing engineering education, we developed a modular professional development program to support our engineering educators at a major Canadian university, and here report some findings as a result of the implementation of this program.

RESEARCH PURPOSE

We developed a 12-module professional learning program—Scholarship of Pedagogy and Application of Research Knowledge in Engineering (SPARK-ENG). The modules are categorized under 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* (SoTL) (Forming an Identity as an Educator, Professional Learning Communities, Researching Educational Practices in Engineering) (see Figure 1).

Experienced educational researchers from our university's Faculty of Education partnered with engineering educators from the Faculty of Engineering to develop these modules. Each module was grounded in established educational literature and research, focusing on active and student-centered pedagogies tailored specifically to engineering.

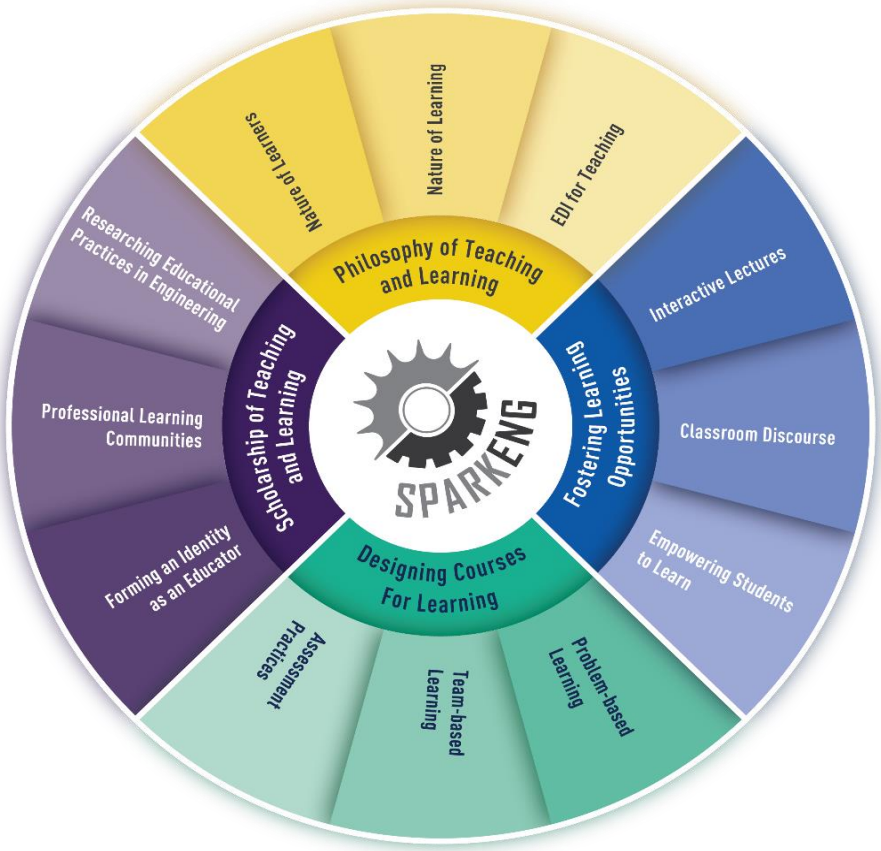
As each SPARK-ENG module was implemented, the engineering educator participants were encouraged to engage with the module content as a cohort. The timeline for each module was a total of four weeks. In the first week, the participants had the opportunity to consider a case study and two readings that would introduce them to a pedagogical concept or approach, and this was animated in a workshop led by an instructional coach, an expert in pedagogy and teaching. The second and third week of the month allowed participants to engage with other podcasts, videos, case studies or short readings that further supported the ideas presented in the first week. Meanwhile, the instructional coach organized classroom observations and one-on-one mentoring meetings to provide feedback on classroom practice for participants as they tried to implement what was learned from the module content. In the final week of the month participants would meet in person as a Community of Practice (CoP) to reflect and discuss the module content and its implementation and/or research.

Based on our pilot studies, we were confident that our program had positively impacted engineering educators' professional learning. In this study, we further investigated participants' authentic professional learning practices through their engagement with our program by addressing the following research questions:

(1) *How did engineering educators experience their professional learning through the SPARK-ENG program?*

(2) *What is the meaning of their relevant professional learning practices for engineering educators?*

FIGURE 1
THE MODULES AND FOUR THEMES OF SPARK-ENG



THEORETICAL FRAMEWORK

The Complexity of Teacher-Professional Learning

Teacher professional learning has been perceived as a complex system driven by recursive interactions among systems, which come together in unpredictable ways but also exhibit significant patterns (Davis & Renert, 2014; Davis & Sumara, 2005; Opfer & Pedder, 2011). A prominent feature of the complexity of teacher professional learning is its nested nature, with layers unfolding within layers (Davis & Renert, 2014). All nested layers of complex systems are learning systems that incorporate new information and processes, transforming themselves through their interactions with the world (Davis & Sumara, 2005). Thus, teacher professional learning typically occurs simultaneously through the actions of autonomous individuals (teachers as learners) and the interactions within collectives (such as cohorts of SPARK-ENG) (Davis & Sumara, 2005). The individual learners and the collectives mutually influence each other. “[T]here is individual knowledge made public, there are a bumping up of ideas, there emerges a shared project, and there is collective action on a task that produces the emergent learner, and products attributed to the group” (Davis & Simmt, 2016, p. 478). Thus, to understand teacher professional learning, it is essential to examine how personal knowledge and practices shape and are reshaped by individual and collective experiences (Opfer & Pedder, 2011). Viewing teacher learning as a complex system acknowledges its multifaceted processes, actions, interactions, and elements, as well as the challenges of predicting exact outcomes and the emergence of various outcomes (Mitchell, 2009). It also involves shifting the emphasis from "development" to "learning" and transitioning from an “atomistic” to a “holistic” perspective (Webster-

Wright, 2009, p. 713). In this study, we view engineering educators' professional learning as a complex system, emphasizing interpreting learning practices via interactions that emerge within various activities.

The Features of Teacher Professional Learning

Aligning with the nested model of teacher professional learning from complexity theory, Pedder et al. (2005) develop four key features of teacher professional learning: *embedded* within teaching practice and reflective processes; *extended* through engagement with various sources of knowledge; *expanded* through collaborative participation; and *deepened* through discussions about and appreciation of the value of learning [emphasis added] (p. 209). Others further reinforce these features. For instance, Timperley et al. (2007) highlight the importance of making professional learning contextually relevant. Darling-Hammond et al. (2017) emphasize the integration of professional development with teaching practice. Thompson et al. (2020) create a model that effectively embed professional learning within teaching practices, supporting sustained teaching enhancement. In addition, Klette and Smeby (2012) indicate the significance of diverse knowledge sources, such as external experts, peer collaboration, research literature, and the Internet, in developing effective professional learning. Hattie and Timperley (2007) and Vescio et al. (2008) reveal that collaborative professional development encourages teachers to share expertise, discuss experiences, and reflect on teaching practices, leading to deep professional learning. Hattie (2015) further highlights that teachers who recognize the value of professional learning are more likely to engage in professional growth.

Understanding Authentic Professional Learning

In this study, we also draw on the perspective of authentic professional learning to explore engineering educators' learning practices, focusing on their "lived experiences" as they strive to improve their teaching practices (Webster-Wright, 2009, p. 715). Researchers contend that educators actually learn through practical experience, that reflection plays a crucial role in learning that necessitates change, and that this learning is influenced by the context in which it occurs (Day, 1999; Gare et al., 2001; Lieberman & Miller, 2001, as cited in Webster-Wright, 2009). Webster-Wright (2009) further articulates the essence of authentic professional learning: "*Learning from experience*", "*Learning from reflective action*", and "*Learning mediated by context* [emphasis added]" (pp. 720-722). There is a need for further research that goes beyond the mere "development of professionals" to explore how the "experience of professional learning" is constructed and embedded within real-world professional practice (Webster-Wright, 2009, p. 712).

If we accept that professional knowledge is experiential, contextual, and embedded in practice; that learning evolves through practical experience and reflective action within contexts that may pose dilemmas; and that professional learning is situated, social, and constructed, then inquiries into authentic professional learning and its support should reflect these notions. However, many professional development programs do not adequately connect the theoretical understanding of professional learning and the actual practices used to support it (Webster-Wright, 2009). We advocate for a more interpretive and holistic inquiry that seeks to understand the genuine lived experiences of engineering educators engaged in professional learning practices, and to illustrate ways to support their professional growth.

METHODOLOGY

Participants

The SPARK-ENG program has been in place within the Faculty of Engineering for two years. Three cohorts of participants proceeded through the SPARK-ENG program. Participants in the cohorts included professors/instructors (referred to as educators in this study) from various engineering disciplines, including Chemical and Materials, Electrical, Mechanical, Civil, Environmental, and Biomedical Engineering. Each cohort participated in 11 or 12 CoP sessions over their involvement in the program. A total of 14 educators completed the program, but due to attrition (three participants leaving the university), this study focused on the 11 educators who remained.

Data Collection

To understand educators' professional learning practices, we interviewed participants throughout the program and at the end of each year of participation, collected their reflections, and recorded their CoP meetings. Both the interviews and the CoP recordings were transcribed, and participants reviewed the transcriptions for accuracy and any potential concerns. Participants were referred to as P1 to P11.

Data Analysis

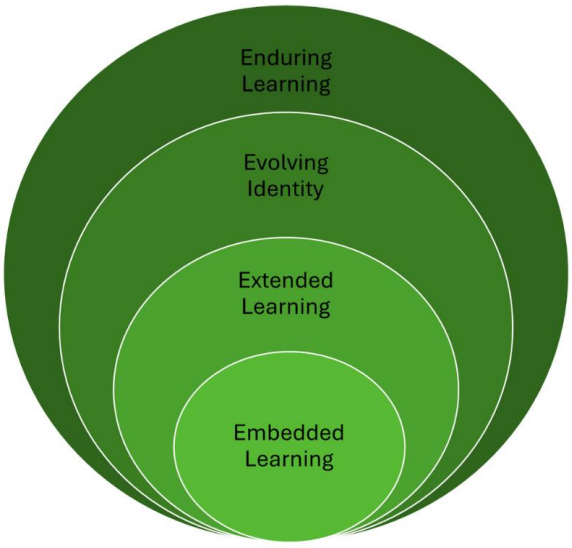
We adopted interpretive inquiry to analyze the data. Interpretive inquiry is conducted to develop an understanding that is more informed and sophisticated than the previously held one (Ellis, 1998; Guba & Lincoln, 1994). It enabled us to understand educators' professional learning practices as immediate and local, allowing for greater intensity and attention to the meaning-making in the social milieu (Smith, 1992).

During the implementation of our program, one of the authors attended the CoPs, conducted interviews, and took notes on emerging themes or topics from participants' learning processes. These notes were shared and discussed in our biweekly research meetings. This approach allowed us to identify emerging themes, recognize patterns, and orientate our inquiry.

Our inquiry underwent several interpretive cycles (see Figure 2) derived from Davis and Renert's (2014) nested ecosystems. In this study, we initially sought to understand how participants experienced their professional learning through the program, forming one layer of our inquiry: *Embedded Learning*. However, participants did not confine their learning to the provided opportunities; they extended it to explore additional practices, developing another layer of our inquiry: *Extended Learning*. These practices broadened and deepened participants' professional learning and enabled them to reshape their perceptions of being engineering educators and becoming SoTL (Scholarship of Teaching and Learning) researchers, leading to a third layer of our inquiry: *Evolving Identity*. The evolving identity motivated participants to seek sustainability in their professional learning, informing an additional layer of our inquiry: *Enduring Learning*. They valued continuous improvement, collaboration, and maintaining connections beyond the program. Certainly, the interpretive cycles remain open for further inquiry.

The interpretations of the findings were validated through multiple actions based on Zellermayer and Margolin's (2005) approach. Specifically, we triangulated data collection from CoPs, interviews, and reflections. Guided by complexity theory, our data analysis informed its application to engineering educators' professional learning. Additionally, we cross-checked interpretations among the program team researchers through regular discussions.

FIGURE 2
INTERPRETATIVE CYCLES



RESULTS

Within each layer of the interpretive cycle (embedded, extended, evolving, enduring), multiple consistent elements emerged, further illuminating the deep and rich experiences of the engineering educators who participated in the SPARK-ENG program. The evolving identity of the educators and the initiatives toward longer-term sustainability with regards to pedagogical learning were unexpected findings, but ones that may be significant in complex learning environments such as engineering education.

Embedded Learning

The SPARK-ENG program provided a comprehensive approach for educators to learn and implement pedagogical improvements, which consisted of module content specifically tailored to engineering education, featuring a toolbox within each module, regular CoP meetings, and instructional coaching. More importantly, participants effectively utilized these embedded learning opportunities, positively impacting their teaching practices.

Learning Through SPARK-ENG Module Content

The most significant and notable aspect of teacher professional development pertains to its content, particularly the specialized knowledge in teaching the subject and understanding how students learn within a specific subject area (Cull et al., 2018). SPARK-ENG was specifically designed to connect to engineering subjects and situate educators' pedagogical knowledge in the engineering context. Our participants appreciated the value of the program's learning materials (e.g., readings). Feedback about the module content was almost exclusively positive, as P1 shared, "the readings … are very effective." They also highlighted how their engagement with the module content significantly impacted their teaching practice. As P10 reflected:

> *All the SPARK-ENG program themes have been packed with many helpful strategies and approaches, some of which I have implemented in my class and some of which I plan to incorporate in my future classes.*

Collective Participation

An integral aspect of teacher-professional learning involves collective participation (van Veen et al., 2011). Collective participation allows teachers to discuss concepts, strategies, and challenges in their teaching practice, linking them to new learning opportunities (Evert & Stein, 2022; Loughland & Nguyen, 2020). This engagement often occurs through Professional Learning Communities (PLC) (Evert & Stein, 2022; van Veen et al., 2011) or CoPs (Mar et al., 2023). In our program, participants explored CoPs and PLCs as effective pathways for enhancing capacity in engineering education. They appreciated the CoPs as an opportunity for fostering a sense of community. As P5 shared:

> *What actions have changed for me…is, first of all, learning about PLC, professional learning community. I never heard this term before personally. … most importantly … it was for me the idea of the professional learning community … We as instructors and educators, we are not just one – it's not a one man show. You are one piece of a puzzle. We are part of a system. We are part of a community.*

Furthermore, participants valued the opportunity to discuss and refine teaching practices, discovering the benefits of CoPs. For instance, P2 remarked, "being able to…discuss teaching style and also look at ways to improve my teaching…every time I come in, I always take away something new…" This collective participation led to new insights and practices, as P1 noted, "being part of that community … like, … [using] whiteboards … I probably wouldn't have done that if I was just teaching by myself."

Learning via the Instructional Coach

Instructional coaches play multiple roles in professional development programs, and their involvement influences the quality of professional collaboration and creates a safe professional learning environment for participants (Carlisle & Berebitsky, 2011; Coburn & Russell, 2008; Elfarargy et al., 2022; Kho et al., 2019). In our program, the instructional coach played a crucial role by providing constructive feedback and helping participants develop instructional materials, fostering a supportive and effective learning environment. As P7 shared about the coach's role in providing constructive feedback on their teaching practices: "[The coach] went to my classroom … gave me the feedback … for how I actually could improve and what I already did well in the class." P6 pointed out that the coach helped them with course preparation:

> *[The coach] helped me put together my first multiple-choice questions for [online interactive platforms] and sort of discuss how to properly structure multiple choice questions. And I kept that in mind even more so when I was choosing the questions to include on my exams, so that they were … structured well and written properly.*

Extended Learning

SPARK-ENG emphasized the integration of practical, evidence-based, student-centered pedagogies and reflective practices into engineering educators' teaching practices. Participants gained confidence and effectiveness by applying insights from the program—such as interactive tools and assessment methods—and by collaborating with colleagues. Their engagement with educational literature and self-reflection fostered continuous improvement. Thus, participants took the initiative from the program to commit to more than we expected, extending their learning beyond the program's immediate scope.

Integrative Pedagogical Development

Quality professional learning allows educators to connect their learning with their teaching practices and engages them in inquiry about those practices (van Veen et al., 2011). In our program, participants emphasized the learning opportunities of integrating insights from the program into diverse teaching contexts. They honed their ability to learn through various teaching practices and gained newfound confidence and practical skills. For instance, they developed lesson materials that allowed for better student engagement with their course content, as P4 described their efforts toward a more student-centered pedagogy:

> *With the new course that I was teaching this past semester, I … develop[ed] better lecture material…. I want to help the students learn and I want to help them be enthusiastic, and the material should be fun…engaging and interesting. There was the communication exercise for [the course] and that was great. That was a LEGO exercise. … the prevention through design … clarifying ideas … [it helped to] make it flow properly for people who are learning the material for the first time.*

They also emphasized the value of integrating real-world problems and practical examples into their courses, as P10 indicated:

> *I put many real case examples close to the students' daily lives to the assignment. So I feel that's a good place to use Theme 3 kind of knowledge …. I think probably in the future I can add more into my class.*

Participants specifically highlighted how interactive learning methods, team-based learning, and peer learning positively impacted student engagement and learning outcomes. A compelling example was shared by P6:

> *I felt like I had a very good culture in my classroom this semester. And part of that, I think, is certainly because I was doing things like [online interactive platforms] this semester that I wasn't doing last semester. Whereas last semester, I felt like I didn't have as much engagement from the students … two-thirds of them who were in class most days. But I had much greater attendance this semester. I felt like I knew a lot more of the students better than I did last semester and had really good interactions with them.*

Participants also tried various ways to improve assessment in their teaching practice, such as using clear rubrics and structured support, which enhanced student performance. P4 offered a practical example:

> *I found being very specific with the marking rubrics really helps [my students] to determine what they need to provide in their report. [For instance, in one course,] I gave them … two group assignments, one individual assignment. I gave them specific rubrics for each one, and they did a very good job—way better than the time before when I taught the [same]course, [but] I didn't have rubrics.*

Learning from Colleagues to Enhance Pedagogy

Learning from colleagues is regarded as one of the significant and valuable sources of support for teachers' professional learning (McCormack et al., 2006). Our participants gained substantial insights from their colleagues to enhance their teaching practices. For instance, they were inspired by experienced educators who shared their studies on students' difficulties and their experiences adapting inclusive pedagogies that considered the diversity of student backgrounds and learning styles. As P7 reflected:

> *I would just use [an example] that we had for last class when [P1] talked about how to use different ways to explain the questions. We need [to] definitely consider [that] students will have different education backgrounds, cultural backgrounds, or they even have different brain functions that can identify or really even understand the problem. So, we need to provide different explanations that may enhance students that could understand the problem so they will be able to link to what they have learned in the class to really tackle the problem that we give to them.*

In some cases, participants who taught the same course worked together to promote teaching effectiveness beyond the program. This collaboration encouraged them to experiment with innovative pedagogies they might not have considered alone. It also alleviated the isolation often felt in solitary teaching roles, fostering a supportive community where colleagues could observe each other's classes and exchange insights to enhance their collective teaching effectiveness. As P1 reflected:

> *There were all the instructors [of one course], we were working quite closely together on our course over the last year. And I was thinking about how I did things in my teaching that I might not have tried if I was just teaching by myself. So, I think that. And then I enjoy being in a community. Teaching can so often be a lonely thing to do if you're just teaching one course by yourself.*

Moreover, participants demonstrated a willingness to adopt new techniques and tools, such as using online interactive platforms, based on positive feedback and results shared by their colleagues. As P1 indicated:

> *I think I would try some of the other things that other people have tried like, for example, the [online interactive platforms]. I think that was really – that sounds like it was really effective.*

As an extension of SPARK-ENG's encouragement for mutual support, participants advocated for co-teaching as an opportunity for more intensive and continuous pedagogical learning as they became more comfortable with learning from others. As P5 advocated:

> *I now focus a lot on telling my colleagues about the benefits of having co-teaching. … I think co-teaching is great if we do it right. We balance it. We do it 50 percent, 50 percent between two co-instructors, but also give us the opportunity to watch each other and observe and give recommendations.*

Cultivating a Sharing Culture for Teaching

A sharing culture is a professional learning environment where educators exchange ideas, resources, and expertise while improving teaching practice (Morgan, 2020). Teachers' knowledge sharing and their confidence in colleagues significantly impact teacher professional learning (Talebizadeh et al., 2021). Our program fostered a sharing culture among educators in the Faculty of Engineering for their teaching. For instance, participants valued sharing authentic practical experiences from their classrooms, beyond the sharing within CoPs. Such sharing allowed colleagues to learn from each other's approaches and perspectives on classroom management and student engagement. As P5 shared:

> *Sharing knowledge between instructors, that's something that I learned and implemented during the last year; I started to share things about my course with other instructors and see what you do in your course? What do you do in your program? And share ideas with them, but also gain ideas that they have implemented. That, for me, is very important.*

Participants also recognized the significance of coordination among educators teaching the same level courses, as it was crucial for effectively managing student workload. This went beyond the program's expectations. Awareness of the projects and assignments in these courses could help educators to avoid overwhelming students with overlapping or extra requirements. As P5 indicated:

> *I really started to pay attention to sharing examples to the instructors who teach at the same level. So, if I'm teaching 200 level and talking to instructors from 200 level is actually very important because we are talking about the same students. Some courses have two or three or four projects throughout the semester. Then I have to be careful with the loads that I am implementing in my course because now this whole load is still the same load on the same students. So, this is actually very important when we share those ideas among [the instructors at] the same level.*

Participants furthermore took great pride in sharing their experiences with others. They hoped that those interested would benefit from their sharing and apply them to their own courses. They believed that their experiences could have a significant positive impact. As P6 shared:

> *It's like, that's something that I've been proud to talk to people about and to share that information with. And hopefully, if they're interested, they can take advantage of that and apply it in their own course as well. That could make a huge difference.*

Embracing Literature to Promote Pedagogy

Engaging with literature is crucial for effective professional development (Desimone et al., 2002; Hattie, 2009). Reflecting on and integrating findings from literature can help teachers refine their pedagogies (Darling-Hammond & Richardson, 2009; Fullan, 2007). Our participants emphasized the value of researching existing ideas and methodologies in educational literature to improve their teaching practices. For instance, P5 appreciated ideas and experiences from literature and stressed the importance of continuously educating themselves:

> *Let's look at the ideas that we come up with or the ideas that we are hoping to implement, it's not necessary that it's new. It could be there in the literature. It could be published already. We learn from people who have over a hundred years of experience in teaching and learning. We are new in this community, so we have to be sure that we educate ourselves as we go, not just teach lessons and then become very static.*

However, navigating and comprehending complex educational literature could be challenging for engineering educators. For instance, initially they were skeptical about the necessity of delving into educational research, as P2 thought, "I personally was struggling with this. I was like, why do I need to learn about the literature in education?". Yet, they came to recognize the importance of building on existing educational literature and learning from the collective wisdom of experienced educators, as this approach can help them continually improve and avoid stagnation in their teaching practices, as P5 had shared:

> *Once you know the definition and once you know the methods that have been published in the literature, your way of delivering it becomes more effective, and students notice that and love it because they see it. They see that now you know what you are doing, student-centred learning activities. We have done it in the past without knowing the definition of student-centred learning activities.*

Reflective Thinking for Enhancing Teaching

Learning becomes more effective when it involves reflection and intentionality (Svendsen, 2020; Zach & Ophir, 2020). Teachers' awareness of their teaching practices can create more opportunities for improvement and change (Svendsen, 2020). Our participants acknowledged the importance of self-reflection for their teaching. For instance, they emphasized the need to be conscious of their own teaching methods and the impact on student learning outcomes, highlighting a shift from a previous lack of consideration and signaling a transformation in their perception of teaching. As P2 shared:

> *It's important to self-reflect as an instructor. I think that's one thing that really got to me, that it's important that you are conscious of your teaching style. And also conscious of how students are learning. That's not something that I, myself, and probably many others are aware of. They just deliver and they are not conscious of whether your teaching style should be adaptable or should be modified to sort of reflect or to sort of help the learning of students—I mean, with student learning. That is very important.*

Reflecting on their teaching, participants went beyond the prompts from our program that encouraged reflecting on the modules' learning materials. Rather, they independently initiated reflecting on lessons they had just implemented and the impact of their teaching on their students' learning.

Evolving Identity

Evolving as an educator and researcher in engineering education involved a dynamic interplay of personal upbringing, beliefs, learning experiences, teaching experiences, and engagement with SoTL. This evolution, marked by ongoing introspection, adaptation, and professional growth, illustrated a deepening understanding of their roles and identities in enhancing teaching effectiveness.

Being an Engineering Educator

Historically, university-level engineering educators have typically been selected based on their expertise in their fields, often without a formal background in educational theory (Eastman, 2017; Froyd & Lohmann, 2014). This practice may constrain the development of their educator identity in teaching practices (Lux et al., 2022). However, coursework, self-reflection, and professional learning experiences can contribute to the re/formation of educator identity (Gilmore et al., 2009). Our study showed that participants' educator identities developed through a complex interplay of personal upbringing, beliefs,

learning experiences, and teaching practices. These factors collectively re/shaped their educator identities and pedagogical approaches.

Participants initially did not fully engage with developing an educator identity, possibly because engineering education often prioritizes technical proficiency over personal identity development. As P1 reflected, "It's just not something that we tend to discuss very much in engineering. The language and vocabulary don't come that easily." Or it might be because the concept didn't resonate with them or they felt they had already formed their identity in some way, as P1 shared, "perhaps either I hadn't really thought about forming an identity as an educator, or that I have already formed an identity." However, as participants engaged in learning practices, they became more reflective and aware of their teaching motivations, which ultimately helped them redefine their identities as educators in engineering education, as P4 indicated:

> *I learned that my own personal perspectives and how I was brought up in my family and the education that I've had has shaped the way that I want to teach and the kind of career that I have. So, I suppose what might have changed after my experience, I guess just being a little more thoughtful and mindful about it. Like why I'm doing this and what perspective I come from and why. It helps me explain why I'm passionate about teaching.*

Participants illustrated how their upbringing shaped their teaching philosophies and practices such as inclusivity, as P9 shared:

> *I am a quick learner ... and like to make my voice heard. ...my mother reminding me to count to 10 to allow "others to answer". This has made me value the "Think-Pair-Share" structure in every class I teach, to remove the anxiety of answering quickly (and incorrectly) as well as to give other students an opportunity to learn and process.*

In addition, participants noted that their beliefs significantly influenced the development of their educator identities. For instance, those who valued experiential learning often emphasized hands-on, practical experiences, and real-world case studies in their teaching. As P2 reflected:

> *My identity specifically ... it would be experiential learning. That's the word that just came to me. So when you teach or when you deliver to students, you actually do it based on something that you know and something of – even true case studies. True case studies through hands-on sort of learning where students can follow through or work closely with you and really learn some of these topics.*

Along with other factors, participants showed that educator identity was also shaped by teaching experiences: a commitment to continuous improvement and adaptability, informed by practical experience and a deep understanding of student needs and learning processes. For instance, P8 revealed a significant evolution in their teaching philosophy and approach:

> *If I think about my career, like when I first started, it's just teaching, "I'm going to go through all these examples, and they're going to learn, because I went through all derivations of all of these examples." And by the end of the day, just exhausting. And slowly it kind of transitioned to breaking up my lessons a lot differently ... it wasn't busy work; it was a problem that I picked with a lot of intentionality behind it ... I knew, kind of knew, the ins and outs, and knew the misconceptions of the students. So, I know that they're going to have a struggle with this problem, and it allows me then to kind of address that and give them some sort of feedback, right?*

Becoming a SoTL Researcher

Becoming a SoTL researcher signifies a significant transition for engineering educators, as it expands their focus beyond the traditional knowledge, skills, and perspectives of engineering disciplines (Bielefeldt, 2015; Dewar et al., 2018). SoTL encourages educators to reflect on their teaching, apply research methods, and contribute to the broader educational community by sharing findings (Fanghanel, 2013; Auten & Twigg, 2015). Our program supported participants in developing their interests in SoTL through a focused module theme (the fourth module), insights shared by experienced SoTL researchers during CoP meetings, and collaboration among colleagues. However, participants initially encountered significant challenges, including transitioning from focusing on technical expertise to prioritizing learner engagement. As P9 reflected:

> *I think personally one of the big mountains is going from a very non-educational base, like my degree and my focus in my PhD and my research was all not to do with people at all. For me, it's almost in the background redoing my graduate studies … but focused now on education and that's the hurdle, is to get, how do I get up to speed on these things? Even if it's not formally all the way to the other end of the research spectrum … That for me, is the big leaping point.*

However, they developed a growing interest in SoTL and valued the application of research methods to understand and improve teaching effectiveness. As P6 indicated:

> *I never have been interested in reading and doing research at all. [But] as long as it helps me in my teaching or helps me succeed with the material then absolutely, I'm interested. [For example,] I'm trying to think how I would adapt that to the risk management course that we teach.*

Participants also expressed a willingness to contribute to the field of SoTL by converting their classroom experiences and innovations into research publications. As P6 indicated:

> *I do want to get into trying to turn some of the things that I've been trying in my classroom into research output as well. It'd be great to be able to start to write some of this up and share it with others and publish it and branch out a little bit that way. So I definitely want to get involved that way as well.*

More importantly, participants highlighted the essence of SoTL lies in conducting inquiries into teaching and learning practices and sharing the findings—a process that not only informs educators' own practices but also benefits others in the field of engineering education. As P1 expressed:

> *I mean the essence of it is really doing some kind of inquiry and sharing it. So, beyond your own, it's to inform your practice, but you're also hopefully benefiting others by sharing it, is the essence of what it's about. … Learning more about how to take some of the things that we've been doing and how to use it as a research study and find ways that we can sort of share our results or quantify our results and quantify how well things have gone and share that with others, I think, this has been really useful.*

Enduring Learning

Enduring learning in professional learning hinges on more than just short-term sessions; it flourishes through sustained engagement and a deep passion for learning. Participants in our program valued ongoing interaction and sought regular follow-ups, workshops, and structured discussions even after the program concluded. Their commitment reflected a dedication to ongoing pedagogical improvement while managing

their teaching practices. This ongoing engagement underscored the significance of a passion for learning in fostering long-term development and achieving lasting improvements in teaching practices.

Aspiration for Sustainable Professional Learning

One aspect frequently highlighted in discussions about effective teacher-professional learning is its duration and sustainability (van Veen et al., 2011). Intellectual and pedagogical changes need to be sufficiently long-lasting (Desimone, 2009). This suggests that single-session or short-term interventions may be less effective compared to long-term interventions supported by follow-up sessions, continuous collaboration, and consistent facilitation of teacher learning (van Veen et al., 2011). However, teacher's work pressure is a common issue associated with professional learning, often resulting in insufficient time allocated for professional learning activities. Thus, it is necessary for teachers to acquire self-regulatory inquiry capabilities to ensure ongoing professional learning, which becomes especially crucial once learning programs or projects conclude (Svendsen, 2020).

Our program, as detailed in the Research Purpose section, had a reasonable duration and time allocation, providing the essential elements for effective implementation, as reflected by P5:

> *I think my overall experience with the program was great. I was very passionate about this program from the early beginning. I didn't miss one single workshop or one single meeting. I communicated all my ideas … It was two years. It was very effective for me, and it has changed a lot of my perspectives about teaching and learning.*

As our program approached its conclusion, participants expressed a desire to continue meeting periodically. Despite concerns about their availability due to busy schedules, they remained enthusiastic about staying engaged. As P2 expressed:

> *I feel like maybe as alumni, it would be nice to continue to sit together or meet, maybe not too often, because I know many of us, I mean, we are really busy. But from time to time … I think it would be good to continue to sit down and meet and discuss our teaching styles and sort of improvements we can make just once in a while.*

They proposed organizing structured meetings where they could discuss teaching, share insights, and potentially receive guidance from a coach or facilitator. This structured approach suggested participants' preference for productive and focused discussions over informal gatherings. As P2 suggested:

> *If we can have a coach or someone that leads or that guides such discussions, that would be good. … any sort of meeting or further discussion from time to time, I would certainly want to participate.*

Participants also suggested various activities, including attending workshops, joining mentoring sessions, sharing ideas and experiences, and contributing to CoP initiatives. These activities were intended to sustain engagement with professional learning and support, albeit with time pressures considered. As P1 suggested:

> *I think we should keep meeting but not very often. If we can have workshops … one opportunity for people to come together, probably just share one or two things, or we have someone that probably can provide some more insights from time [to time]—I mean, not very often, probably bimonthly or something like that, I think that will be great.*

Learning Passion

Learning passion is fundamental for sustaining professional development and achieving long-term professional growth. Educators who exhibit genuine enthusiasm for their field are more likely to engage in

continuous professional development and reflective practice (Hargreaves, 2003), improving individual teaching practices, and cultivating a culture of shared knowledge and innovation within the educational community (Ryan & Deci, 2000). It can also inspire peers, creating an environment that promotes continuous improvement and collaborative growth (Fullan, 2007).

Participants in the study exhibited a genuine enthusiasm for learning and teaching and this passion was evident in their eagerness to improve their teaching practices, adopt new strategies, and stay actively engaged in their professional community. For instance, participants recognized that effective teaching requires continuous effort and refinement and acknowledged that even small changes could lead to significant improvements and foster their professional growth. As P2 reflected:

> *I think my teaching style has improved quite well. Not radically, not astronomically. But at least in a few ways, I think I can see that it has improved. And I think more importantly, it has just shown that it is important for us to keep developing our pedagogy. To keep developing our teaching styles. I think that's what is even more important, just to create that awareness that it's important to keep improving, to keep introducing new skills or new styles that would improve the teaching and learning process.*

Furthermore, participants saw teaching as an ongoing journey requiring regular updates and enhancements to pedagogical practices. As P5 expressed:

> *Research could have an end … But teaching doesn't. Teaching really doesn't. You have to do this job…it's a continuous process. We have to keep improving it over the years.*

Participants specifically expressed a desire to innovate and inspire their students. This enthusiasm drove them to continuously seek improvement in their teaching practices. As P9 noted:

> *I want to be innovative. I want to be motivating. I want students to be changed after taking a class with me. I think my experiences have given me a unique view and unique opportunity to engage with students on a different level than some of my colleagues, and I want to be available to my students to walk with them on this journey.*

More powerfully, participants' engagement with diverse learning practices and their passion for learning empowered them with the capability and confidence to be on their own. As P4 reflected:

> *[They] helped me … But now … I can do it better. Now I have a process for doing that. [They do not] need to help me every time now… and now I can do it on my own, or I can do most of it on my own.*

DISCUSSION

The data analysis identified four layers of professional learning practices that emerged from participants' engagement with the SPARK-ENG program. *Embedded Learning* was supported through the program's tailored content for the engineering field, collaborative participation, and the instructional coach's facilitation. *Extended Learning* involved integrating practical, evidence-based, student-centred pedagogies and reflective thinking into teaching practices, driving continuous professional growth beyond the program. *Evolving Identity* was re/shaped through participants' ongoing reflection on personal, educational, and professional experiences and their engagement with SoTL, leading to a more intentional articulation of their teaching philosophies and motivation. *Enduring Learning* was sustained by participants' learning passion for professional growth, evidenced by their commitment to continuous improvement, ongoing collaboration, and the integration of new pedagogical strategies. The four-layer learning practices felicitously captured the dynamic and interconnected nature of learning processes

through the SPARK-ENG program, where multifaceted interconnectivity enhanced interactions among layers and encompassed both individual and collective learning experiences, creating a holistic and integrated professional learning process for engineering educators.

Specifically, *Embedded Learning* significantly enhanced various aspects of *Extended Learning*. For instance, as a crucial element to *Embedded Learning*, Collective Participation exposed educators to collaborative environments, fostering a culture of sharing and considerations of what a student-centered learning environment might entail. P2 emphasized that collective participation offered constructive feedback, helping them better understand and address students' learning challenges. The instructional coach, another element of Embedded Learning, further enhanced *Extended Learning*. The instructional coach provided targeted feedback and strategies, particularly in refining classroom questioning techniques and developing effective lesson materials, transforming initial ideas into practical teaching tools, and enhancing both student engagement and learning outcomes, as P6 experienced. Additionally, the coach facilitated co-instructors' collaboration, as illustrated by P4's experience in their course teaching. This robust support ensured educators had an extensive pathway for effectively integrating student-centered pedagogical strategies into their teaching practices.

Embedded Learning and *Evolving Identity* mutually influenced each other. For instance, the influence of Collective Participation within *Embedded Learning* extended to helping educators develop their identities in *Evolving Identity*. Participation in CoPs or PLCs fostered a sense of belonging and a culture of sharing. This collaborative learning environment helped participants, like P5, see themselves as integral parts of an educational community—"one piece of a puzzle". This experience reflected an evolving identity that valued collaboration and underscored the connection between educator identity and collective professional growth. Besides, participants' *Evolving Identity* impacted their insights into the pedagogies derived from the program's module content within *Embedded Learning*, such as P9's "Think-Pair-Share" pedagogical approach, influenced by their upbring experiences.

Likewise, *Extended Learning* and *Evolving Identity* also had a reciprocal impact on one another. For instance, Integrative Pedagogical Development within *Extended Learning* and Being an Engineering Educator within *Evolving Identity* shaped each other. As P1 indicated, as an educator, they needed to relearn material for teaching new courses and this evolving teaching practice, in turn, strengthened their identity as an educator. Reflective Thinking for Enhancing Teaching within *Extended Learning* was crucial in re/shaping *Evolving Identity*. As P2 emphasized, reflective thinking allowed them, as an educator, to critically assess their teaching styles and effectiveness, which in turn reinforced their identity as an educator.

Furthermore, becoming a SoTL Researcher within *Evolving Identity* promoted the sustainability of *Enduring Learning* by transforming educators into lifelong learners. For example, P9 transitioned from a disciplinary research background to engaging with educational literature and acknowledged that SoTL was not a one-time effort but an ongoing professional learning process.

The SPARK-ENG program's multi-layered learning systems illustrated the intricate interplay between various elements and their evolving and expanding nature. This highlighted the experiences of engineering educators in enacting professional learning practices to promote pedagogical shifts through continuous professional growth. In other words, SPARK-ENG empowered the participants to transition from being knowledge recipients to "active learners and producers of knowledge" (Aubusson et al., 2009, p. 234). In essence, participants perceived teaching improvement as an ongoing journey rather than a finite task, as Rodriguez-Gomez et al. (2024) suggested.

Achieving the above understanding helps us to reveal the meaning of the relevant professional learning practices for engineering educators. Learning about pedagogies to improve teaching practices is a primary goal of many professional development programs in engineering education (Chen et al., 2024; Ross et al., 2024); our program is no exception. Our program incorporated active, student-centered pedagogies into professional learning through content-driven module reviews, collective participation, and instructional coaching. It specifically tailored learning content for engineering educators, providing a robust foundation for understanding and applying pedagogical strategies within the engineering context. This approach went beyond merely grasping pedagogical theories; it involved contextualizing learning to address the specific demands of engineering education. Participants further extended this learning through their practical

application of evidence-based pedagogies and reflective practices, which are essential for engineering educators (Sukackė et al., 2022; Borrego & Henderson, 2014). It included adopting interactive learning methods, improving assessment practices, enhancing questioning techniques, developing lesson material, and collaborating co-instructors. Additionally, participants developed a deeper understanding of how to enhance their teaching practices by learning from their own and others' experiences, fostering a culture of sharing, and engaging with educational literature. This "knowing how" was cultivated through direct application of program insights and collaborative learning environments.

Participants' learning processes were also deeply personal and evolved through their upbringing, beliefs, learning experiences, professional journeys, and engagement with SoTL. These unique learning paths allowed participants to incorporate their philosophies and experiences into their teaching practices, leading to distinctive approaches to improving their teaching practices. As educators reflected on their identities and teaching philosophies, they became more intentional in tailoring their methods to align with both their personal values and the needs of their students.

Building on these transformative learning experiences, participants recognized that learning is most impactful when embedded in a long-term, sustainable process rather than consisting of isolated events, as Karlberg-Granlund and Pastuhov (2024) suggested. They preferred ongoing follow-up, structured meetings, and collaborative activities, underscoring their understanding that meaningful learning requires persistence and regular engagement. Far from being recipients of knowledge, they actively refined their teaching practices, explored innovative pedagogical strategies, and contributed to their educational communities. This active engagement was further evidenced by their eagerness to continue learning even after the program concluded.

CONCLUSION

Our learning program offered a time-space opportunity for engineering educators to learn through the emergence and interactive dynamics of individual participants and the collective in which they were involved. These outcomes were achieved through "a transition in one's stance toward knowledge, agency, and collegiality" (Zellermayer & Margolin, 2005, p. 1278). Adopting complexity theory as a conceptual framework allowed us to recognize the significance of our program in providing participants with a space to explore emergent learning opportunities. It also gave us the language to interpret the professional learning practices of engineering educators engaging with our program. It provided a methodological approach that focused on emergent critical practices as the centerpiece of our analysis, shaping our data analysis.

The analysis of engineering educators' authentic professional learning practices revealed a pattern of four layers of learning systems, where the layers of *Embedded Learning* and *Extended Learning* comprehensively demonstrated the key features of teacher professional learning from the perspective of complexity theory and the essence of authentic professional learning. More importantly, the results extended beyond these features to illustrate how engineering educators were empowered through *Evolving Identity* and *Enduring Learning*, achieving "self-formation" —a process of coming to know themselves and their roles in the engineering education they care about (Jardine et al., 2015, p. 3). Furthermore, the four layers of learning systems evolved as a whole, providing a holistic perspective on engineering educators' professional learning. The evolving nature of the learning systems showcases participants' creativity through authentic professional learning practices that extend beyond the programmed learning opportunities. This underscores the core concept of complexity—emergence—where the observed professional learning practices arose from "the dynamics of the relations between different parts of the learning context" (Zellermayer & Margolin, 2005, p. 1279).

This layered approach allowed engineering educators to have opportunities to "zoom in" on their authentic learning practices and "zoom out" to view their learning within a broader theoretical/empirical context and holistic perspective (Zellermayer & Margolin, 2005, p. 1302). Furthermore, we are going to emphasize that relying solely on individual engineering educators to drive change, without comprehensive support such as that provided by our program, may not be effective, as Fink et al. (2005) suggested. Our program offers a valuable reference for creating supportive environments for engineering educators'

professional learning. The four layers of learning systems can serve as a conceptual framework for guiding or understanding educators' authentic professional practices.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the University of Alberta's Faculty of Education, Faculty of Engineering, and Centre for Mathematics, Science, and Technology Education for funding the program development and research project.

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