NSF-Noyce Funded Project: Developing Secondary STEM Teacher Leaders Technological Pedagogical Content Knowledge via Monthly Workshops in Mechatronics

Dr. Ruthmae Sears

Ruthmae Sears, Ph.D., is a Professor at the University of South Florida for secondary mathematics education, and the Associate Director of Coalition for Science Literacy. She has a Joint appointment in The Department of Teaching and Learning within the College of Education, and the College of Arts and Sciences. Her research focuses on curriculum issues, change initiatives in K-20 STEM settings, the development of reasoning and proof skills, clinical experiences in secondary mathematics, and the integration of technology in mathematics.

Alfredo R Rodriguez-Vera, University of South Florida
Stephanie A Arthur, University of South Florida
Dr. Robert L Potter

Robert Potter is Senior Associate Dean for Academics and Professor of Chemistry in the College of Arts and Sciences at the University of South Florida (USF). He has been actively involved in promoting more effective STEM instruction K-16 for over 20 years

Alexandro Castellanos, University of South Florida
Brandy Jackson

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Aecern Learning

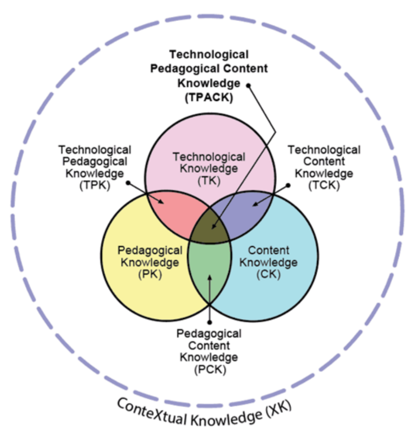
Overview

Mechatronics is an interdisciplinary field that combines mechanical, electrical, and computer engineering principles to develop systems and products [1]. Due to technological advancements and the national demand to expand the STEM workforce in the US, there is a pressing need to provide workshops that support STEM teachers' professional learning, enabling them to apply the knowledge they gain in their respective learning environments and develop future STEM professionals. Tauro et al. [2] suggest that offering professional development to teachers on integrating mechatronics into problem-based learning activities can positively impact students' learning outcomes. Given that teachers' technological pedagogical content knowledge (TPACK) relative to mechatronics applications alignment with mathematics and science [3], we sought to answer the following question: What are STEM teacher leaders' perspectives on a 9-month mechatronics workshop, and how do they perceive it has impacted their TPACK?

Theoretical Framework

The TPACK framework (Figure 1) considers teachers' knowledge of their subject matter, pedagogical considerations, and technology [4], [5]. This framework is particularly critical for disciplines such as mechatronics, which draws on knowledge of mechanical, electrical, and computer engineering principles. The practical application of mechatronics is essential in fields such as robotics and engineering design, where students must use digital tools to solve complex problems [6].

Figure 1 *The TPACK Framework and Its Knowledge Components* [7].



The TPACK framework provides a way to conceptualize how technology can be meaningfully incorporated into instruction while accounting for the contextual realities of teaching [5](Mishra, 2019). Technology knowledge (TK) refers to a teacher's understanding of digital tools and their capacity to select and apply these resources during lesson planning, instruction, and assessment to support students' demonstration of their understanding of the content addressed. Pedagogical knowledge (PK) focuses on the design and delivery of instruction for all learners. This domain includes knowledge of evidence-based teaching techniques, classroom management, learning differences, and various assessment practices (formative, summative, and evaluative). Content Knowledge (CK) addresses a teacher's depth of understanding of the content being taught, such as foundational principles and practices, connections across topics, and awareness of common student misconceptions. Teachers with strong CK can explain ideas clearly, anticipate misconceptions and learning difficulties, and scaffold instruction to support deeper learning.

Consideration of the context of technology use is also important. Mishra [5] updated the TPACK model to highlight this by renaming the outer circle to Contextual Knowledge (XK). Contextual Knowledge (XK) is represented in the framework through broken lines, which highlight the contextual realities that shape instructional practice. This domain captures the institutional, cultural, and structural factors that may constrain teachers' navigation and positions them as "intrapreneurs" (Mishra, 2019, p.77) [5] who understand their organizational environments and can leverage their influence to promote change The inclusion of XK was driven by the view that teachers must actively learn about their school's culture, students' needs, and resources available to support educational learning opportunities [5]. For instance, in rural or underfunded school districts, the digital divide may present infrastructural barriers that dictate which pedagogical strategies are feasible, regardless of a teacher's theoretical competence [8]. Without mastering this contextual knowledge, teachers struggle to apply their technical skills in real-world situations [9].

Methods

Using a mixed-methods research design, we sought to answer our guiding question. In the subsequent paragraphs, we describe the study context, participants, data collection, and analysis.

Context of the Study

The workshops were held at a community hub for STEAM learning and facilitated by interdisciplinary faculty from education, arts and sciences, and engineering from a southeastern research university, along with industry partners. The series consisted of monthly six-hour workshops from September 2024 to May 2025. Thus, they had 54 hours of contact time with the STEM teachers. These sessions gave STEM teachers hands-on mechatronics experience with clear links to their current practices. Workshop topics included foundational mechatronics, coding, sensors, microcontrollers, robotics, artificial intelligence, CAD, 3D printing, laser cutting, and sustainable technologies. Each workshop began with a leadership activity, followed by hands-on exploration of mechatronics applications (Sears et al., 2025). Participants then reflected on integrating these concepts in their classrooms, and concluded with final reflections [10].

Participants

The participants in the study were 10 STEM teachers, who were also graduate students pursuing a master's degree in education (M. Ed). Additionally, the participants were Master Teaching Fellows (MTFs) in a National Science Foundation (NSF)-funded Noyce project. The MTFs had at least three years of teaching experience. Thus, for this article, we interchangeably refer to them as participants, STEM Teachers, and MTFs.

Data Collection and Analysis

To examine STEM teachers' perspectives about the workshops, we employed a mixed-methods research design [11]. Data were collected through surveys at the end of each workshop, and personal reflections from September 2024 to May 2025. The survey asked participants to use Likert items to rate the extent to which the facilitators supported learning the workshop's stated goals and the extent to which they gained knowledge they can use in their jobs. Additionally, they were asked to provide responses to open-ended questions, in which they shared insights into aspects of the profession they found beneficial, explained how they will utilize the knowledge gained in their practice, identified topics they would like to learn more about, offered suggestions for enhancing the workshop, and provided suggestions and comments for the facilitators to reflect on. Additionally, during the December 2024 session, participants shared their holistic reflections on the workshops thus far, their perceived strengths and challenges, how they can apply the knowledge gained to their communities, and insights into their leadership activities.

The quantitative data were analyzed via frequencies and measures of central tendency (mean, median, and mode) [11]. The qualitative data were analyzed through the lens of the TPACK Framework [5] using a grounded theory approach, in which we sought to identify dominant themes [12], [13], [14].

Results

The findings suggest that STEM teachers found the monthly workshops insightful and that the content presented was applicable and valuable to their learning environments. In terms of technological knowledge, STEM teachers are familiar with Micro:Bit, Arduino, CAD programming, artificial intelligence, and 3D printing. The teachers acknowledged that they were generally unfamiliar with mechatronics-related content prior to the training and now have a better understanding after participating in the workshops. Regarding their pedagogical knowledge, the STEM teachers indicated that the hands-on activities they employed helped make meaningful connections between abstract STEM content and real-world applications in industry and everyday life. They also felt that developing their knowledge increased their confidence and willingness to include mechatronics-related tasks in their instruction. Furthermore, regarding their discipline-specific content knowledge as teachers of mathematics, science, or career and technical education (CTE) courses, they valued seeing how abstract content could be applied to everyday settings. The teachers also frequently reflected on contextual norms that can impact how they plan to use mechatronics applications. Thus, the STEM teachers perceived that the workshops helped to develop their TPACK. In the subsequent paragraphs, we provide examples of insights garnered from the MTFs on how the workshops contributed to their technological, pedagogical, and content knowledge, and on the intersectionality of TPACK.

Quantitative Findings

Survey data collected at the conclusion of each workshop provided insights into participants' perceptions of the effectiveness of the sessions. In particular, we evaluated the extent to which participants reported developing knowledge and skills relevant to their teaching responsibilities. As indicated in Table 1, the majority of participants agreed or strongly agreed that the workshops offered content that could be implemented in their practice, with four sessions achieving 100% positive agreement. The workshop topics that were excluded from the table did not include this survey item on the feedback form.

Table 1. Participants' Perceptions of Knowledge and Skills Gained for Implementation Within their Instructional Practice

Workshop Topic (Dates)	Number of Participants (*N*)	Percentage of participants who agreed or strongly agreed that they acquired knowledge and skills applicable to their instructional practice.
Sensors and Microcontrollers (Nov 2, 2024)	9	100%
Applications of CAD and Engineering Design (Jan 11, 2025)	9	100%

Sustainable Technology (February 1, 2025)	9	100%
Coding and Programming: Python (March 1, 2025	9	77.7%
Power Management (April 5, 2025)	8	100%

Technological Knowledge

Throughout the year, there was notable growth in the STEM teachers' knowledge of technological tools and in their willingness to use them in practice. For instance, in October 2024, an MTF noted, "It'll take some more sessions to develop a full idea, but I think I can introduce the 3D printing somehow with my students". However, by November 2, 2024, the feedback suggests that the hands-on experiences supported their learning, as indicated by the statement: "The hands-on learning experience with coding was where I learned the most". By December 7, 2024, the MTFs begin to demonstrate confidence in their technological knowledge of coding and robotics. For instance, an MTF indicated, "I have learned a lot about coding and robotics quickly and can help troubleshoot with the team" (December 7, 2024). Thus, there was a noticeable increase in the MTFs' technological knowledge to support the integration of mechatronics content into their practice.

Pedagogical Knowledge

The STEM teachers often sought to make explicit connections between the content addressed in the mechatronics workshops to support their students' learning and inform their instructional practices. For instance, during the October 5, 2024 meeting an MTF noted, "Today's workshop gave me ideas for how to design and develop some lesson plans" While another MTF indicated, "I feel more comfortable using AI to generate rubrics for projects (which I can then refine) using it to adapt assignments for students like translation, or changing the Lexile level for me" (October 5, 2024). Similar insights were shared across time, as indicated by a response by the MTF on March 1, 2025, that noted, **"**I loved being able to demonstrate activity completion and be more mindful of the input that I am putting into my teaching and how that can lead to certain outcomes with my students and my teaching". Thus, as the STEM teachers engaged with mechatronics applications during the workshop, they also reflected on ways to apply that knowledge to support students' learning outcomes.

Content Knowledge

The STEM teachers initially acknowledged that their knowledge of mechatronics concepts was limited and asked for additional support to develop their content knowledge. For instance, on October 24, 2024, an MTF noted, "I feel like at this point, I need more foundational pieces of Mechatronics. Basic engineering, coding, and computer systems. I do not have the knowledge of vocabulary usage or the concepts that we have seen or heard, and it feels very unattainable right now". Similarly, another MTF indicated, "I just want to see more examples of how to use Mechatronics in my pure math classroom and then create other programs and classes that extend from my math class" (October 24, 2024). Thus, the teachers were explicit about their knowledge gaps and expressed a desire to learn and address them. Over time, the STEM teachers noted that the hands-on experience at the workshop helped not only with their content knowledge but also with their confidence in applying mechatronics. For instance, an MTF noted on December 7, 2024, that they were also "Developing confidence to go hands-on with the items instead of just reading about them." While the feedback from April 7, 2025, indicated that "Working with knowledgeable individuals to detail what happens when programming input and output situations" made a difference. Thus, as they engaged in the workshop, their knowledge of mechatronics was strengthened.

Contextual Knowledge

Throughout the year, the teachers consistently reflected on how well they could apply the knowledge gained from the workshops in their contexts. For instance, an MTF noted that based on the training, they are planning on "Bringing new things to my department for us to try, and I am working on starting an after-school club for students to work with robots and code them" (December 7, 2024). Thus, this suggests that the MTF is exploring ways to share the ideas learned across their department and embed them in informal learning settings.

The STEM teachers also noted that they plan to use the Arduino kits that the district previously provided. For instance, an MTF noted, "We have Arduino kits from SpaceTrek that the district provided a few years ago. I would like to use these, and now is the perfect time." This suggests that teachers are also aware of resources they can access to further support their instructional efforts.

Intersection of Technological Pedagogical Content Knowledge (TPACK)

The STEM teachers also frequently commented that the workshop strengthened their overall TPACK. Notably, the teachers highlighted that they enjoyed "Learning how to perform the skills has been great (like soldering and coding) as well as how to integrate them into the curriculum" (February 1, 2025). Similarly, an MTF indicated that the workshops help to **"**Develop a better understanding of programming and develop classroom activities to develop students' understanding" (March 1, 2025). Thus, the STEM Teachers highlighted how the knowledge was helping with their TPACK.

Implications

The findings of this study have implications for supporting the professional learning of in-service STEM teachers, enabling them to promote meaningful learning opportunities in their learning environments while integrating mechatronics content. It also provides insights into the development of STEM teachers' TPACK across time. The results suggest that as teachers' knowledge develops through participation in professional development workshops, their confidence and willingness to apply mechatronics increased, which aligns with the literature [2]. Professional development and district curriculum developers can draw on the lessons learned to develop sustained, supported professional development that helps teachers understand new and unfamiliar content and builds their confidence and likelihood of using mechatronics in their future practices. Moreover, hands-on experiences can help strengthen teachers' TPACK in an engaging, authentic professional development environment. Furthermore, teachers' awareness of their contextual constraints (such as resource availability, alignment with standards, school culture and norms, and time limitations) helped ensure that the planned ideas are enacted as intended and supported within their school environment.

Future studies should examine how teachers ultimately use and apply the workshop knowledge in their secondary STEM classroom settings. Such studies can examine the nature of planning and subsequent enacted practices, and their ultimate effect on students' learning outcomes. Consideration should also be given to how technology and mechatronics applications are used to mediate learning experiences.

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