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Developing pre-service teachers' adaptive expertise through STEM-CT integration in professional development and residency placements

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This paper focuses on how one innovative teacher education model, that included a unique residency model and the integration of computational thinking and digital teaching and learning in elementary classrooms, supported the development of adaptive expertise in pre-service teacher education programs. The theoretical frame applied in this study is adaptive expertise through the lens of sociocultural theory, and it employs tenets of ethnographic research procedure as methodology. Data demonstrated that the model provided pre-service teachers with a rigorous setting that allowed for practice of routine expertise as well as adaptive expertise. Additionally, analysis pointed to balancing efficiency and innovation and mentor-mentee collaboration as key components of the development of adaptive expertise in pre-service teachers.

KEYWORDS

adaptive expertise, pre-service teachers, qualitative research, professional development, integration, teacher education, elementary education, project/problem based learning

Introduction

Rittel and Webber (1973) posited that humanity will increasingly face what they deem "wicked problems" which they defined as elaborate, complicated and ever-changing difficulties with potential to impact us at political, cultural, societal, and economic levels (Ferguson et al., 2018). Educational systems are viewed as a panacea for such problems and are often accused by policy makers, news pundits, and community members of falling short in the achievement of high benchmarks related to effectiveness and failing to produce high quality teachers (Tyack and Cuban, 2000; Anthony et al., 2015). Currently there is an unprecedented focus on the overhaul and modification of teacher preparation programs in the United States as a means to increase student achievement and international academic standing (Darling-Hammond and McCloskey, 2008). In this paper, the authors posit that adaptive expertise, coined in 1986 by Japanese cognitive psychologists Hatano and Inagaki, is a promising framework for teacher education programs that hope to cultivate innovative, dynamic, and creative teachers who positively impact students, schools, and communities (Hammerness et al., 2005; Anthony et al., 2015; Baldinger and Munson, 2020). While research demonstrates the promise of the application of adaptive expertise in teacher education environments (Anthony et al., 2015; Baldinger and Munson, 2020; et al., 2005), a deeper understanding of how to develop adaptive expertise in

pre-service teachers (PSTs) could be a springboard for designing educational contexts that encourage and support it (Bohle Carbonell et al., 2014; Baldinger and Munson, 2020).

This paper focuses on how one innovative teacher education model, that included a unique residency model and the integration of computational thinking (CT) and digital teaching and learning (DTL) in elementary classrooms, supported the development of adaptive expertise in PST education programs. Furthermore, the authors deliberate on how to design teacher preparation programs that go beyond basic routine learning and teaching to create spaces where PSTs can be innovative and experiment alongside their mentor teachers as a means of fostering creative classroom environments. This model, while couched in the integration of science, technology, engineering, mathematics (STEM), CT, and DTL in elementary classrooms provides an example of creating partnerships and learning opportunities that foster PSTs' adaptive expertise beyond the traditional teacher preparation program, and is intended for an audience of educational researchers, higher education faculty, administrators, and other stakeholders in education.

Literature review

Characteristics of adaptive expertise and distinguishing between routine and adaptive expertise in general contexts

Understanding the difference between routine and adaptive expertise is key in supporting the development of adaptive expertise. Hatano and Oura (2003) described adaptive expertise as one's capacity to apply what is learned in resourceful and pliable ways. This contrasts with routine expertise which requires fast completion of activities correctly but without deep comprehension (Verschaffel et al., 2009). While both kinds of expertise involve domain knowledge and performance in familiar settings that a novice does not possess, the two types of expertise diverge when individuals are confronted with novel situations (Hatano and Inagaki, 1986). Those with routine expertise will often flounder under the pressure of new demands while those with adaptive expertise will reclaim momentum quickly because of a flexible approach to knowledge acquisition (Bohle Carbonell et al., 2014). Although adaptive expertise is rooted in routine expertise, adaptive expertise practices continuously develop while routine practices stagnate. Adaptive expertise also includes the selection of appropriate strategies and the ability to move fluidly between different strategies, processes which are scaffolded through metacognitive processes that support control and awareness (Verschaffel et al., 2009). Nevertheless, it is important to note that adaptive expertise and routine expertise can develop in tandem. Timperley (2013) reminds us that the two are not mutually exclusive, rather that they can occur simultaneously in an individual's trajectory as they begin to acknowledge the necessity of both.

Moreover, adaptive expertise encompasses the ability to apply multiple perspectives when problem solving and the capacity to organize knowledge (Bohle Carbonell et al., 2014). Bell and Kozlowski (2008) observed the impactful nature of analogical problem solving related to adaptive expertise, which requires the transfer of skills from a context that differs on the surface but has similar deeper characteristics. Likewise, in an extensive literature review, Schraub et al. (2011) found: (1) a moderate correlation between self-efficacy and adaptive expertise; (2) positive and significant correlation between adaptive expertise and past experiences with novel situations and interacting with those who think differently than you; (3) positive correlation between adaptive expertise and openness to new situations; (4) moderately positive correlation between autonomy and adaptive expertise; and (5) learning climate can have an impact on cognitive skills and problem solving abilities related to expertise. In sum, those with adaptive expertise are more efficient and effective in solving novel problems than their peers with routine expertise, an increasingly valuable distinction in today's changing workplace.

Teaching and adaptive expertise

Work environments are becoming more and more complex which require higher levels of expertise (Howard, 1995; Tannenbaum, 2001; Molloy and Noe, 2009; Bohle Carbonell et al., 2014). Professionals must be able to demonstrate expertise across several work environments, not just one arena (Pink, 2006). Furthermore, they must show willingness to acclimate to shifts within their domains of expertise and adapt to unpredictable problems that might arise (Van der Heijden, 2002). This ability supports changes in work requirements, complex situations, and unprecedented issues that may arise (Allworth and Hesketh, 1999; Griffin and Hesketh, 2003; Chen et al., 2005; Joung et al., 2006; Blickle et al., 2011). Classrooms are an example of a complex and dynamic work environment that requires high levels of expertise and the ability to solve multifaceted dilemmas. Researchers note the complex nature of teaching and argue that adaptive expertise may be a viable means of addressing the "problem of complexity" presented by teaching (Hammerness et al., 2005; Lampert, 2010; Lampert et al., 2013; Baldinger and Munson, 2020).

Teachers who possess routine expertise sustain a basic level of performance but do not continue learning and developing (Chi, 2011). In the dynamic and complicated arena of teaching, teachers need to be both fluent in the undertaking of routines (Anthony et al., 2015) and able to innovate when needed (Lampert, 2010). Flexibility is central to the development of adaptive expertise of teachers (Zook-Howell et al., 2020); however, it is important to conceptualize adaptive expertise as more than just flexibility in classroom decision-making (Verschaffel et al., 2009).

In addition to flexibility, teachers with strong tendencies toward adaptive expertise show propensity toward innovation, ongoing learning, and creativity, as well as the desire to seek out challenges (Barnett and Koslowski, 2002; Hatano and Oura, 2003; Crawford et al., 2005; Martin et al., 2006, 2007; Mylopoulos and Scardamalia, 2008; Varpio et al., 2009). The capacity to adjust to rapid changes in the classroom is also key. One must be able to apply expertise in unprecedented ways. Teachers without this capability often return to the novice performance level which occurs even before the development of routine expertise (Hatano and Inagaki, 1986; Holyoak, 1991). According to Soslau et al. (2018):

> Adaptive teachers strategically move away from planned curriculum components to better support the contextual needs of their pupils, question familiar solutions to problems by noticing unique features, and recognise the need to refine, change and try

> out different decisions while paying close attention to the impact on their pupils. (p. 70).

However, the path to seamless adaptation in the classroom is a multi-layered and demanding one (Darling-Hammond, 2005; Corno, 2008; Allen et al., 2013; Bohle Carbonell et al., 2014; Männikkö and Husu, 2019), which requires instruction that acknowledges the power of differentiation (Fairbanks et al., 2009), ongoing knowledge building and refinement of how to apply that knowledge (Von Esch and Kavanagh, 2017), and a deep reflective practice particularly in the areas of flexibility and innovation (Bransford et al., 1999). Perhaps the most challenging requirement of complex adaptive teaching is the unlearning of prior beliefs and routines (Männikkö and Husu, 2019). Männikkö and Husu (2019) argue that those entrenched in routine expertise solely link knowledge to prior experiences, while teachers with adaptive expertise approach novel situations with both prior knowledge and an openness to new phenomena. Additionally, educators who possess adaptive expertise create learning activities that encourage errors, exploration, and a variety of innovative tasks that lead to a flexible knowledge base (Bohle Carbonell et al., 2014; Männikkö and Husu, 2019).

Finally, Soslau et al. (2018) distinguishes the development of adaptive teaching expertise from acquiring expertise in a particular area of content. She notes that content adaptive experts are focused on sophisticated comprehension of a disciplinary content area and are not necessarily concerned with teaching others. In contrast, "adaptive *teaching* experts are pedagogical experts that engage in a process of self-assessing and strategically adjusting their decision making before, during, and after teaching episodes" (p. 768, emphasis added). This may include differentiation based on the needs of individual students, moving away from ineffective components of planned curriculum, and paying attention to contextual needs.

Pre-service teachers and adaptive expertise

While adaptive expertise has been established as a necessary element in the development of highly effective teachers (Hatano and Oura, 2003; Sawyer, 2006; Ball and Hill, 2008; Cochran-Smith and Feiman-Meser, 2008; Grossman, 2008), less research is available on how to help PSTs and novice teachers cultivate adaptive expertise. Scholars have noted the lack of significant research in this arena has hindered the evolution and expansion of reforms at the teacher education level that support adaptive expertise development in PSTs (Guyton and McIntyre, 1990; Cochran-Smith and Zeichner, 2005; Sawyer, 2006).

Existing research on PSTs and adaptive expertise points to a myriad of reasons that PSTs and novice teachers may struggle in their growth with adaptive expertise. One barrier is PSTs regress to teaching in the ways they were taught (Bloome, 1987; Soslau et al., 2018), and Feiman-Nemser and Buchmann (1986) dub this the "unquestioned familiarity pitfall." Soslau et al. (2018) connects the notion of unquestioned familiarity with PSTs performance in field-based settings, arguing that PSTs traditionally just replicate what they see their mentor teachers doing. They explain:

> While the cooperating teacher may be modeling highly effective decision making, the student teacher is often not privy to the cooperating teachers' internal rationale. This impedes the development of adaptive teaching expertise because the student teacher fails to make their own decisions based on any type of justification related to their pupils' emotional or academic needs nor does the student teacher understand or know about the cooperating teacher's internal and invisible decision-making processes. (p. 770).

Additionally, PSTs often fail to recognize the binary objective of classroom practice, moving seamlessly between learning how to teach and helping students learn (Soslau et al., 2018). While novice teachers and PSTs often struggle with finding this balance, teachers who possess adaptive expertise are continuously adapting and moving between these two areas of dual purpose as a means of attending to student needs and achieving optimal learning environments. PSTs may engage in shallow decision making because they tend to be unaware of the complexities of classroom interactions and contexts, are uncomfortable veering from scripts or curriculum, and as a result, may neglect the needs of students in the moment. In contrast, adaptive teaching experts adapt curriculum and make instructional decisions based on changing and dynamic student needs (Eilam and Poyas, 2006; Soslau et al., 2018).

How do we support adaptive expertise in teacher education?

While much adaptive expertise research in educational contexts has been focused on practicing teachers, some research demonstrates that teacher education programs are fertile ground for developing adaptive expertise in novice teachers, but more study is needed (Hammerness et al., 2005; Lampert, 2010; Lampert et al., 2013; Baldinger and Munson, 2020). Ball and Forzani (2009) note that traditionally teacher education programs have focused heavily on what they deem the "efficiency axis" which often manifest as formulaic routines. Baldinger and Munson (2020) give the Initiate-Response-Evaluate (IRE) questioning model (teacher initiates a question, the student responds, and the teacher evaluates with little room for thought provoking expansion) as one example of a formulaic routine and argue that routines must be balanced with innovation. They note that PSTs need to be simultaneously acquiring general routines that can efficiently deal with common situations in their domain and they need to confront and develop adaptations to non-routine situations. Schwartz et al. (2005) created a model to illustrate this (see Figure 1), demonstrating that the optimal place for PSTs to exist is in simultaneous progression between innovation and efficiency. This progression is particularly key when automatized routines or scripted curricula are in play (Schwartz et al., 2005). For this progression to occur in teacher education programs, where efficiency may be entrenched, PSTs need modeling, scaffolding, and opportunities to decipher when innovations are most beneficial (Baldinger and Munson, 2020).

Theoretical framework

The theoretical frame applied in this study is adaptive expertise through the lens of sociocultural theory (Vygotsky, 1978). Because the

teacher education model presented in this research is inherently social in nature (i.e., professional development (PD) interactions, PST and mentor partnerships), adaptive expertise is framed socially in line with Schwartz et al.'s (2005) notion that such interactions can promote innovation. Likewise, Sfard (2008) notes that "interaction opens up learning processes that are only available in cooperation with others; communication is thinking, not just thinking made visible, but an act of cognition itself" (p. 3). In this manner, opportunities for dialogic interactions between teacher professionals through a sociocultural frame can support their acquisition of adaptive expertise (Horn, 2010; Anthony et al., 2015; Janssen et al., 2015; Kavanagh et al., 2019).

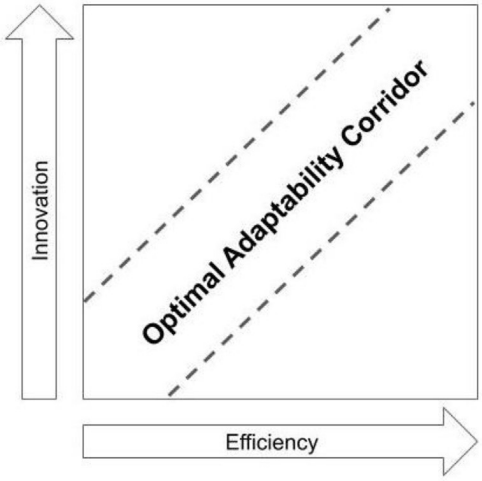

FIGURE 1
Optimal adaptability corridor. Reprinted from Schwartz et al. (2005).

Project model

The iSLICEE project model (Table 1) integrated STEM and LIteracy with Computation in Elementary Education to implement the following design: (1) created a model that enables K-5 pre-service teachers to integrate STEM and English Language Arts (ELA) with Computation (C) in a pre-baccalaureate teacher preparation program, (2) developed and implemented the iSLICEE curriculum by collaborating with PSTs, in-service mentor teachers, and faculty members of an institute of higher education during the student teaching residency period occurring in local partner schools, and (3) enabled mentor teachers and PSTs to implement the iSLICEE curriculum in partner schools.

Notably, PSTs and mentor teachers worked through a year-long residency model which began with summer PD. iSLICEE PSTs were required to participate in a one-week PD solely for them and an additional one-week summer PD with university faculty and their mentor teachers. The first PD focused on acclimating PSTs to the iSLICEE program and familiarizing them with an array of grant-supported technological tools for digital teaching and learning as well as instruction on CT. Each iSLICEE classroom received a set of iPads and Apple pencils, Apple TV, assorted robots (e.g., BlueBots, Ozobots, and Dash robots), and Google Home. PSTs learned how to set up and use each of the technologies to support their mentor teachers in the upcoming school year during their residency placements. PSTs also worked with several online tools including Google Sites, Seesaw, Scratch, and Flipgrid. The PD also provided PSTs opportunities to build connections and relationships with their peers in the iSLICEE cohort. These PSTs became resources for one another during the next week of the program (see below) and during their year-long residency placements for student teaching.

A second PD week included PSTs and their mentors and provided more intensive content instruction in the areas of STEM-CT

TABLE 1 Project model.

iSLICEE Project	The iSLICE Working Plan		
Visions	**Strategies**	**Activities**	**Outputs**
1. integrate STEM, Literacy with Computation in elementary teacher preparation program 2. iSLICEE curriculum collaboratively developed and tested by mentor teachers, student teachers, and professors 3. mentor teachers and new teachers implement iSLICEE curriculum in high-needs schools	integrating computational thinking in STEM and ELA + Digital learning and teaching + ELA, Math, Science Standards	STEM and Literacy courses @ university 1-wk student fellow PD involved current and previous fellows 1-wk PD involved mentor teachers, fellows & professors Classroom practices and implementation: student teaching	**Teacher Intruction** 1. STEM-Lit-C integration 2. best instructional practices 3. CT knowledge 4. technology skills **Student learning environment** 1. STEM-Lit-C integration 2. digital technology enhanced STEM & Literacy learning environments

integration and DTL. Sessions were primarily led by higher education faculty; however, PSTs also led sessions in which they shared what they had learned in the previous week. Example topics of PD sessions included coding in ELA, designing engineering solutions with robots, teaching the elements of CT with games, coding in Scratch, and practical tips for managing classroom technology. In Years 2 and 3 of the program, returning mentor teachers and select PSTs from prior years, who returned as graduate assistants, shared successful strategies and activities from their classrooms such as using BeeBots to teach storytelling to 1st grade students and Ozobots to teach a 3rd grade math standard about polygons. In the later part of the week, PSTs and mentor teachers created units of study to implement in their K-5 classes during the upcoming school year. The units created by the PST and mentor partners included: (a) CT in STEM and/or ELA; (b) advanced digital learning and teaching in elementary education; and (c) Practice Standards promoted in Next Generation Science Standards (NGSS Lead States, 2013), Common Core English Languages Arts (ELA), and Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). PSTs and mentor teachers presented their units of study and shared ideas during the PD and across a web-based platform.

Context and participants

The iSLICEE project was implemented in seven high-need rural local education agencies (LEAs) located in three geographic counties in rural Southern Appalachian Highlands. Participants in this study included PSTs from a public university in the southeastern United States of America who were majoring in elementary education. There were 49 total participants including 45 females and 4 males. Forty-seven of the participants identified as white, one participant identified as Hispanic, and one participant identified as Asian.

The teacher preparation program in which the participants were enrolled is a four-year, eight semester program that includes general education courses and courses on teaching pedagogy. Upon graduation, PSTs are certified and licensed in Elementary Education. All PSTs in the program complete a one-year residency model. In this model, PSTs are placed in a kindergarten – fifth grade classroom in a cooperating district at the beginning of the school year. In the fall semester, PSTs complete 15 credits of course work including courses that focus on content pedagogy in elementary classrooms (ELA, Science, Math, Social Studies, and Clinical Field). They also complete 135 h in their mentor teacher's classroom in the fall and are in their mentor teacher's classroom full time in the spring. PSTs are required to successfully complete all coursework and field hour requirements and receive passing scores on Praxis exams (tests that measures knowledge and skills needed to become a teacher; required to receive a license in Elementary Education) and edTPA (performance-based, subject specific assessment used by many teacher preparation programs in the United States to measure PSTs skills and readiness for classroom instruction; required for licensure).

iSLICEE fellow cohort selection process and requirements

In spring of their junior year, PSTs can apply to become a candidate of the iSLICEE Cohort. The Project Director and Co-Directors meet with all Juniors, approximately 60–80 people each year, and share information about the program including application procedures, purpose and mission, and requirements. Interested PSTs submit an application which faculty then review. A segment of those who submitted applications are then selected to be interviewed by the project director. The annual group of iSLICEE candidates were chosen based on the application and interview process with group sizes ranging from 11 to 16. The Project Director and Co-Directors suggest a placement plan to each PST for their participating iSLICEE mentor teacher. Faculty consider personality dynamics, strengths and weaknesses, geographical location of the school, and grade level requests when placing PSTs with mentor teachers.

Methodology

Design

The following research questions informed the study:

1. How do PSTs in iSLICEE negotiate routine and adaptive expertise?
2. What aspects of iSLICEE encourage the development of adaptive expertise in PSTs?

This study employed tenets of ethnographic research procedures (Hatch, 2002). In keeping with ethnographic procedure, the perspective of the individuals of a particular culture is described in an attempt to understand their daily experiences through the examination of observations, interviews, and artifact collection (Hatch, 2002). Focus group interviews were the primary data source applied, a methodology that engages participants with specific attributes in group discussion under the guidance of a moderator (Krueger and Casey, 2009). In addition, artifacts including lesson plans and observations of PD informed researchers' understanding and served to triangulate data (Patton, 2014). Observations included: PSTs engaging with DTL and CT resources; PSTs planning for and leading PD sessions for mentor teachers and university faculty on DTL and CT; PSTs co-planning with their mentor teachers to create and present a lesson plan integrated with a content area subject and DTL and CT. Focus group interviews were recorded, transcribed, and analyzed using thematic analysis which aimed to identify, describe, and report prevailing themes within a given data set (Boyatzis, 1998; Braun and Clarke, 2006).

Data collection

Participants met in a classroom at the university along with two faculty facilitators. Chairs were arranged in a circle to encourage communication amongst participants. The facilitators also sat in the circle but generally avoided participating in the conversation. Rather, the facilitators' role was to pose questions to participants to promote discussion and to encourage dialogue if the conversation became stagnant. Facilitators had a list of potential interview questions on hand and used these questions particularly to engage conversation at the beginning of the focus group. This method was based on the method of semi-structured interviews in which the researcher has specific questions to ask but is open to the idea of

following unforeseen leads that arise during the interview (Glesne, 2011). The facilitators engaged in depth-probing by pursuing various points of interest with phrases such as "tell me more" or "can you explain further." "The intent of such interviewing is to capture the unseen that was, is, will be, or should be; how respondents think or feel about something; and how they explain or account for something" (Glesne, 2011, p. 134). This avenue empowers the researcher to perceive phenomena in deep and multi-faceted ways. It also allowed for what Glesne (2011) calls "a distance reducing experience" (p. 134). The interview questions focused on PSTs' perceptions of the following: background and previous learning related to DTL and CT, iSLICEE PDs attended, mentor teacher pairings and interactions, lesson planning and carrying out of lessons, integration of CT and DTL in content areas, and their own knowledge acquisition related to CT and DTL. Interviews were conducted yearly. The interviews were recorded with a hand-held recorder and transcribed by the researchers. Rather than having an outside source do the transcribing, the research team believes, as does Bailey (2008), that transcribing provides more in-depth interaction with the data through systematic and attentive repeated listening.

Data analysis

Bernard (2018) notes that analysis is "the search for patterns in data and for ideas that help explain why those patterns are there in the first place" (p. 355). Thematic pattern analysis was used so that the "analysis and interpretation of [the] study's findings…reflect[ed] the constructs, concepts, language, models, and theories that structured the study in the first place" (Merriam, 1998, p. 48). Researchers engaged in three cycles of coding to divide, group, and reorganize data in meaningful ways (Grbich, 2013). In the first cycle exploratory coding methods were applied to examine data through an open-ended lens (Saldaña, 2021). This preparation supported the second cycle of coding by providing preliminary insights into the data. Saldaña (2021) noted that second cycle methods include "such analytic skills as classifying, prioritizing, integrating, synthesizing, abstracting, conceptualizing, and theory building" (p. 88). Descriptive coding was applied in the second cycle of coding to assign labels and/or summarizations to the data. The third cycle of coding, focused coding, supported the process of thematic organization by probing the data for first and second cycle codes that occurred frequently or were determined to be meaningful.

Researchers engaged in analytic memoing through each cycle of coding to question assumptions and consider how thinking processes and determinations informed the analysis of data. Analytic memo writing and coding support and inform each other through "a reciprocal relationship between the development of a coding system and the evolution of understanding a phenomenon" (Weston et al., 2001, p. 397).

Coding cycles resulted in approximately forty codes which were then grouped into approximately 10 categories. Individual researchers coded all data individually, met to discuss initial codes, organize and collapse codes, and identify themes. Overarching themes were agreed upon after engagement by researchers in multiple rounds of reanalysis of data and interrater reliability was established (O'Connor and Joffe, 2020).

Results and discussion

Finding 1: routine expertise and challenging work environments

In line with scholars that call for challenging work environments as an avenue for building expertise (Howard, 1995; Tannenbaum, 2001; Molloy and Noe, 2009; Bohle Carbonell et al., 2014), data demonstrated that the iSLICEE model provided PSTs with a rigorous setting that allowed for practice of routine expertise as well as encouragement of exploration, creativity, and innovation which is the presupposition of adaptive expertise (Hatano and Oura, 2003). PSTs described the demanding environment as eye-opening, sometimes disconcerting, but ultimately positive in terms of growth mindset and creative exploration. CT was unfamiliar to most with PSTs noting "I had never heard those two words" and "It's not a concept I grasp yet." Nonetheless, PSTs expressed excitement to participate in a PD that encouraged them to step "outside of our boxes." One PST explained that the challenging environment pushed her toward increased creativity, "seeing that creativeness come out, I think, will definitely change the way I think."; while another noted, "Two weeks ago I thought I was a really creative person. Now? I'm thinking I have a lot more [creativity] to explore in me." Because much of the DTL strategies that were presented to PSTs were novel, and they had little or no experience using them, PSTs had to begin by developing routine expertise with the technological tools, such as Bee Bots, Scratch Jr., Flipgrid, etc., during the summer PD. Suni explained, "The robots such as Dash and Blue Bots were all completely new things to me. I've never even heard about them until all of this." Männikkö and Husu (2019) note that the development of routine expertise is a necessary step in the acquisition of teaching and learning strategies and a building block to adaptive expertise. Likewise, data from this study demonstrated that procedural explanations and routine practice with technological tools were imperative in the proper utilization of the tools. PSTs described their initial discomfort with some of the new technology with comments such as "I know how to use my iphone. That is about it." Sophia explained, "I'd say mine (experience with technology) was relatively minimal. I mean, we have technology in the house. You can usually play around and sort of figure things out, but to use it for teaching and in the classroom is totally different. You've got to know different skills and also you have to know it enough to be able to explain it to the kids." During the initial PD week, PSTs were given opportunities to experiment, play, and just "figure out how to work everything." Data demonstrated that routinized application of technological tools was a necessary step in PSTs' consideration of creative use of the tools in a classroom setting. Research demonstrates that individuals often gain proficiency in routine expertise and never leave (Hatano and Oura, 2003). For those that do begin to demonstrate adaptive expertise in addition to routine expertise, it generally occurs after several years of experience in the classroom. However, our data showed evidence that several of the PSTs began to dabble in the realm of adaptive expertise while building routinized expertise of technology use. The case of Belinda is one example. During the PST PD week faculty members demonstrated how to use one technology, Lego Story Visualizer, a student friendly app which allows users to upload photographs and create a comic strip story (Billen et al., 2021). Faculty members shared routine expertise as they gave procedural instructions on using the app including how to upload photographs, choose a background, add captions and more. As PSTs became savvier with the

LEGO app, faculty encouraged PSTs to think in originative ways as they considered how to use the app organically and purposefully, following the PD mantra of "not just technology for technology's sake." After becoming comfortable with how to use LEGO Story Visualizer, Belinda co-planned an integrated ELA lesson with her mentor teacher that focused on the standard "Recount stories; determine the central message, lesson, or moral and explain how it is conveyed through key details in the text." Utilizing the book Harry Potter and the Sorcerer's Stone (Rowling, 1998), students read, discussed, and applied the text as they built scenes using LEGOS, uploaded photos of their builds into the app, and created comic strips to demonstrate their understanding. Along with her mentor teacher, Belinda presented the lesson at the following summer's PD, noting that the innovation and richness of the lesson contributed to high student engagement and motivation.

One key characteristic of adaptive expertise is the ability to apply teaching design and curriculum in strategic and purposeful ways, which involves flexibility, dynamic thinking and decision making that consider the needs of students (Bohle Carbonell et al., 2014). Data demonstrated that PSTs were excited about the development of their creativity and innovation (evidence of adaptive expertise) in relationship to their teaching. Juan noted, "I feel better about myself as a teacher that I am doing the right thing, and I feel more confident, being able to be innovative and doing things for my students to benefit them." Further, Hayden explained, "You aren't just streamlining learning. I was able to differentiate my learning and my teaching a lot using the technology and the robotics and different instructional strategies." Experimentation with adaptive expertise was demonstrated as PSTs reported moving past simply considering how to use the technological tools in the lesson to contemplation of how the technology might be most appropriately applied to support the content being taught. For instance, Rose explained how she moved from merely integrating technology for technology's sake, just "making sure I get it in there" to a more strategic implementation. Another PST reported, "Often, I would spend a lot of time trying to fit a particular piece of technology into a lesson just because I was determined to use it. But as time went on, I became less overwhelmed and my experience with technology kind of helped me more effectively integrate that technology into a lesson where it did support the content and the curriculum for a particular lesson."

While adaptive expertise is often regarded as a skill reserved for more veteran teachers, data demonstrated that PSTs began to wrestle with concepts related to adaptive expertise such as purposeful content and technology integration while concurrently building necessary routine expertise related to teaching, learning, and technology use such as technology tool utilization, scheduling, and standards implementation. This confirms the work of Timperley (2013) who noted that routine and adaptive expertise often develop in tandem. Additionally, in routine expertise, PSTs often replicate what they observe their mentors doing (Soslau et al., 2018); however, in the current project, PSTs had similar or slightly more knowledge of how to use the technologies than their mentors minimizing the opportunity for PSTs to emulate the actions of their mentors when using the new technologies.

Preconceived notions of play versus "learning"

In our data we observed that PSTs reported being concerned about whether the innovations they conceived of, developed in conjunction with their mentor teacher, and/or carried out in the elementary classroom setting were "real learning" or simply "play." At its root, this desire seemed to develop from the core belief that technology should be purposeful and directly connected to required classroom content. PSTs discussed their desire for digital teaching and learning to enhance content, rather than just to take up time and space in a meaningless way. In this manner, PSTs experimented with both routine expertise (i.e., as they learn the basics of technology use, standards, application, and implementation), while also considering technology use from an adaptive expertise perspective (i.e., reflecting on deep and integrative uses of technology and its possibilities for learning and growth). Simultaneously, PSTs grappled with their own institutionalized and ingrained ways of knowing and ways they have been schooled personally as they worked to make determinations about the nuances between "real learning" and "play." In this sense "real learning" was positioned and denoted positively in opposition to play which was referenced in a negative light. Abby noted,

> I felt like a lot of it [what they implemented in the elementary classroom] is enhancing their learning. Are they playing? And so, I feel like through the program and throughout my placement, being able to integrate that technology- I feel like I really truly understood at the end of it, what it means and what the difference is [between play and real learning]. I think that is just something I grew in because when I started out, I felt like that was a very fine line, so that was something I struggled with. I feel like at the end of the day, I did have a good grasp on being able to tell the difference between the two.

Abby described her growth during the program as she moved from someone who saw "real learning" as quiet students working diligently and completing work that can be measured and held in the hand (e.g., worksheets, quizzes) and play as the opposite of this (students engaging in tasks that are harder to quantify) to a more nuanced view of what real learning may require and involve. As she engaged in PD and collaboration with her mentor, Abby reported that she began to separate the notion of "play" from "technology for technology's sake" and instead considered how she might redefine play and add it to her repertoire of ways to promote "real learning" with her elementary students. We argue that forming a new definition of play was a higher-level adaptive skill, which may not often be addressed before later years of in-service teaching.

Balancing efficiency versus innovation

Adaptive expertise supports teacher's balance between efficiency and innovation and is a requirement for teachers to respond to the changing realities of teaching practice. As a result of participating in this model, PSTs were presented with the advanced tasks of learning both the routinized elements of the school day (many of which cannot be disregarded) while simultaneously experimenting with innovation. For example, PSTs noted the pressures of standardized testing, teacher evaluation, and the requirement to show direct and relative connections to state standards. Time was a constant pressure point, and, in interview data, PSTs referenced it as a barrier to the iSLICEE model of innovation. Nonetheless, data demonstrated that PSTs began to view possibilities of balancing both; that rather than choosing

between efficiency and innovation, they might find ways to incorporate both. For example, Lexie reflected on how easy it was to get lost in just the requirements of the teacher education program and the basics of lesson planning which she noted did not drive her creative impulses. However, she explained that the iSLICEE experience pushed her past the basics and toward creativity. She said, "I also took more chances with technology. I got more creative just because I felt more comfortable." These self-reported data indicate that easing discomfort with routinized expectations such as standards integration and lesson planning could open a space for creativity and innovation when paired with the appropriate supports.

Finding 2: collaboration with mentors and mentor characteristics are key contributors to developing adaptive expertise in PSTs

Collaboration with mentors

Data analysis pointed to collaboration as a key contributor to the development of adaptive expertise. As stated previously, the iSLICEE model relies heavily on district, school, and mentor teacher partnerships as a means of supporting iSLICEE cohort PSTs. PSTs were paired with an iSLICEE mentor teacher, who attended the PD sessions and co-created lesson plans related to integrated content, technology, and computation. Soslau et al. (2018) notes that collaboration may be a scaffold for the development of adaptive expertise. Likewise, data analysis demonstrated that support from a mentor when grappling with difficult work such as technology and computation in elementary settings, inspired PSTs to continue problem solving rather than give up. Valeria described how collaboration helped develop and advance her problem-solving skills thus:

So, technology does not always do what we want, or expect it to do, so just being able to collaborate with others in iSLICEE to see what worked, what did not work in their classroom really helped me increase problem solving skills. In the aspect of, oh, I'm just going to use technology in my classroom just more like, how am I going to enhance that learning. I think I'm more confident in that now just having that experience in my placement.

Bennie also described the partnership as pivotal to her growth:

> I think partnering with my mentor was a very empowering experience. Our partnership was a lot of like she would pitch an idea, and then I would kind of bring it to reality. So, it involved a lot of discussions and idea pitches and trial and error. And then going back and evaluating what we did, what we could have done better. So that's what made it so powerful for me. We would often work on projects and ideas way in advance in order to make sure that the integration technology not only enhanced the lesson, but then keeping the learning for the students as a central focus as far as what's going to benefit them.

Mentor characteristics

While data cannot confirm whether mentor teachers who are higher on the adaptive expertise spectrum are naturally drawn to programs such as iSLICEE, the PSTs described their mentors in ways that align with adaptive expertise. PSTs characterized mentor teachers as "innovative," "open-minded," "exploratory," and "passionate" and considered how these traits encouraged a similar stance from them. Georgie explained,

> I was very fortunate with my relationship with my mentor teacher because she was so open minded with everything. She did not see me as okay let me teach you this, it was, how can we learn together. And for every part integrating, we sat down together, and she was like, okay, I came up with this. What do you think about this, and we would kind of you know, feed off each other. And I really feel like that helped me grow, especially in my confidence, just because I felt like I had a part in the teaching. It wasn't just me there observing and learning from her, we worked on it and helped each other through the process. So, I think that model is very 50/50 in the classroom.

Similarly, data indicated that the relationship development that occurred during the PD between PSTs and mentors in combination with the tendencies of participating mentors to share, collaborate, and make internal processes visible, resulted in increased motivation and contentment in terms of classroom placement as well as a breeding ground for experimentation with adaptive expertise.

On the other hand, data showed that any missing links in the project model hindered the success, development, and motivation of PSTs in terms of their confidence in innovation and creativity related to adaptive expertise. For example, because of a logistical issue, Izzy's field placement was switched in September and her new mentor did not attend the summer PD. As a result, Izzy did not experience the supportive environment that many of the other PSTs described:

> So pretty much the whole time in my placement, I would only use the technology whenever I was getting observed and when I was teaching the whole lesson myself. But it was difficult because I felt like I had to take risks completely on my own, and I did not have a lot of support. My mentor did not have any interest in using technology in her own lessons and was very traditional like pen to paper. I think a lot of that comes from having the open mindset to change, but then I know that her not being a part of the summer professional development had something to do with that too.

From this perspective, the early relationship building and experimentation and planning with technological tools was key to creating environments that support adaptive expertise development in PSTs. Data also demonstrated that PSTs perceptions of the disposition of their mentor was important in creating contexts that supported adaptive expertise in PSTs.

Conclusion and implications

The results of this study build on previous research related to the promise of adaptive expertise and address a gap in the literature in terms of adaptive expertise and PSTs. While some have questioned the ability of PSTs to begin developing adaptive expertise so early on in their teaching practice, data showed promise for inspiring the use of adaptive expertise in teacher education. To achieve this goal, the following insights must be considered: (1) careful study of and comparison of a teacher education program's balance of efficiency and

innovation; (2) providing PSTs with an innovation or problem with which to grapple; (3) purposeful pairing of PSTs with mentor teachers who demonstrate adaptive expertise; and (4) concrete and specific times for collaboration between PSTs and mentor teachers.

First, teacher education programs should explore the balance or lack thereof between efficiency and innovation. For example, in the teacher education program studied, researchers found that prior to iSLICEE the program was high on efficiency and low on innovation. Many structural and state and university requirements such as accreditation, edTPA lesson plans, and graduation requirements call for high efficiency and are necessary in PSTs training and success. However, this study demonstrates that these necessary elements can be balanced with more time for innovation. In this way, PSTs can gain necessary routinized expertise while simultaneously growing in adaptive expertise. Adaptive expertise can be catalyzed by providing PSTs opportunities for innovation. Making space for open and creative work where students are presented with a challenge or a genuine question in education that we do not know answers to can be a good exercise to move them toward adaptive expertise. iSLICEE opened up space for innovation by asking mentor teachers and PSTs to integrate STEM and CT into their classrooms which pushed them to move closer to adaptive expertise as they navigated that challenge.

Research indicates that pairing PSTs with high-quality mentors is a key element in the confidence and success of PSTs (Hawkman et al., 2018). This study validates and builds on that notion by demonstrating that the openness of mentors to innovation and exploration positively impacts the development of adaptive expertise in PSTs. Likewise, the characteristics of mentor teachers varies; qualities of mentors such as "innovative," "open-minded," "exploratory," and "passionate" are more likely to encourage the development of adaptive expertise in PSTs. Furthermore, the additional collaboration time provided prior to the start of the school year through PD was powerful in relationship building. This has implications for the structure and organization of student teaching placements. Typically, PSTs and mentors do not have a shared challenge to address or time to work together and build a relationship through summer PD. Teaching at times is viewed as a solitary activity, but in reality, the best teachers are also strong collaborators who invite others to brainstorm and develop ideas together. Research has demonstrated that field experiences are a good breeding ground for building adaptive expertise in novice teachers. We take this a step further by not only purposefully partnering mentors and PSTs, but also providing PD, resources, and ongoing faculty support. Future research efforts are needed to explore long term impacts on PSTs as they become in-service teachers to better understand how adaptive expertise in teacher education programs may support them as professionals in their future classrooms.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by East Tennessee State University IRB. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. LR: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Writing – original draft, Writing – review & editing. CT: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. NW: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. JP: Conceptualization, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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