STEM Professional Development of Teachers in Under-Resourced Contexts

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Abstract. Numerous studies have shown that the success of STEM education at the implementation stage largely depends on teacher preparedness. Within this conversation, positive results of STEM teacher preparation programmed appear to be primarily based on outcomes achieved in STEM-supported classrooms and entirely in resource-rich education settings, where access to resources is assumed mainly as given. STEM education can be costly to implement because it often necessitates a well-equipped infrastructure and access to numerous resources. Given the need to 1) foster higher-order thinking skills, educational literacy, and digital responsibility in 21st-century education, and 2) the scarcity of integrated STEM intervention-based research in these under-resourced settings, we argue that supporting teachers through well-designed professional development activities to prepare teachers to implement this approach within such settings is compelling. Therefore, this paper focuses on identifying STEM professional development strategies that may help teachers implement STEM despite their minimal access to resources.

Keywords: STEM education, Challenging Contexts, Resources, Teacher Professional Development

1 Introduction

The success of STEM education largely depends on the successful implementation in the classroom through integrated STEM. Integrated STEM involves identifying, applying, and integrating science, technology, engineering, and mathematics (STEM) concepts to understand multifaceted problems and devise novel solutions. Implementing this approach in the classroom is what is referred to as STEM integration.

An integrated STEM approach is considered very useful in addressing the root causes of the leaky pipe situation and low STEM literacy at the classroom level because this approach is anchored on the argument that the world's problems are complex and require integrating several subjects and applying diverse skills and concepts to solve them (English, 2017; Gardner & Tillotson, 2019; Honey et al., 2014; Kurup et al., 2017, 2019; Kelley & Knowles, 2016; Roehrig et al., 2021; Tan et al., 2019). Despite the importance of integrated STEM, most teachers do not believe they are competent or prepared to execute it in their classrooms(English, 2017, Kelley & Knowles, 2016, Margot & Kettler, 2019).

The importance of preparing teachers to implement STEM in their classrooms has been emphasized in numerous studies because teachers who do not feel competent or understand the value of STEM integration in the curriculum to their students and society will not implement it in their classrooms. Despite the usefulness of the integrated STEM approach, many studies highlight under-prepared teachers as a significant challenge to implementing it (Roehrig et al.,

ICONSEIR 2021, December 21, Medan, Indonesia

DOI 10.4108/eai.21-12-2021.2317337

2021; Stohlmann et al., 2012; Thibaut et al., 2018). For example, recent studies emphasize that only a small percentage of teachers feel adequately prepared or competent to incorporate the integrated STEM approach in their teaching (Du et al., 2019; Guzey et al., 2016; Tuttle et al., 2016). This is because they lack the essential expertise and skills to teach engineering content or practices, despite their appreciation of the necessity of integrated STEM (Anderson & Li, 2020; Du et al., 2019; Guzey et al., 2016; Tuttle et al., 2016).

Many recent studies emphasize that the lack of basic infrastructure, resources, and materials also serve as a significant barrier to the successful implementation of STEM in the classroom in several contexts (e.g., Arshad, 2021; Ejiwale, 2013; Goodpaster et al., 2012; Margot & Kettler; Park et al., 2017; Thomas & Falls, 2019; Stohlmann et al., 2012). For example, Chowdury et al. (2020) asserted that access to resources, infrastructure, and professional development was significant in implementing STEM education in Bangladesh.

However, the question of which strategies of integrated STEM can be appropriately implemented within K-12 classrooms in challenging or under-resourced environments (e.g., environments lacking access to a reliable network connection, electricity, lab equipment, and laptop computers or smartphones) remains ill-defined, although there has been an increase in research on integrated STEM professional development. For example, Makonye & Dlamini (2020) underscore the difficulties associated with implementing integrated STEM within Africa contexts because of the numerous economic challenges (e.g., electricity access, internet access, infrastructure) associated with them and the need to devise and identify effective classroom strategies for teachers to ensure African nations are not excluded from STEM advancements.

This is important because effective STEM teacher professional development programmes consider the problems teachers face in their differing teaching contexts (Makonye & Dlamini, 2020; Owens et al., 2018). Our argument also indicates the need for researchers to document effective ways to successfully prepare different teachers to implement integrated STEM initiatives in diverse school contexts.

2 The Value of STEM

The justifications for STEM inclusion in the classroom is centred around student learning, the rapidly growing demand for STEM workers, and the societal advantages. Firstly, Students who participate in integrated STEM learning have been found to outperform their peers who participate in traditional STEM learning, which consists of separate disciplines such as Science, Technology, Engineering, and Mathematics (Murphy et al., 2019; Nadelson et al., 2013; Thibaut et al., 2018).

These researchers argue that when teachers use an integrated STEM approach, students will participate in learning activities that facilitate inquiry, problem-solving, retention, and critical thinking. Furthermore, STEM integration has been shown to boost students' non-cognitive learning outcomes(e.g., STEM interest, motivation to learn STEM), potentially increasing the number of STEM graduates (Ring-Whalen et al., 2018; Sanders, 2009; Thibaut et al., 2018; Wang et al., 2011).

Secondly, workforce talent shortages partly fuel the incentive to integrate STEM (Ejiwale, 2013; Nadelson & Seifert, 2017). STEM in industry, research and society currently leans more towards the integrated end of the spectrum (Anderson & Li, 2020; Nadelson & Seifert, 2017; Xue & Larson, 2015). Integrated STEM learning has the potential to produce a competitive future workforce with 21st-century skills, according to previous studies (e.g., Asghar et al., 2012; Ejiwale, 2013; Mustafa et al., 2016; Ring et al., 2017).

Finally, Integrated STEM has enormous societal benefits. It establishes strong STEM literacy foundations, increases STEM diversity, equity, and inclusion, prepares the STEM workforce for the future and makes a country globally competitive (Bryan et al., 2021; Mustafa et al., 2016; Nadelson & Seifert, 2017). In addition to pursuing STEM careers, several studies suggest that ensuring STEM literacy in a population should be a top educational priority (e.g., Bybee, 2010; Kennedy & Odell, 2014; Zollman, 2012).

For example, Blom (2016) suggest that Sub-Saharan Africa requires more and better STEM skills and knowledge to enhance value-added and productivity in critical areas such as extractive industries, energy, transportation, and light manufacturing to undergo economic change (p.6). To realize the benefits of integrated STEM, well-prepared teachers are crucial for successfully implementing this initiative (Asghar et al., 2012; El-Deghaidy & Mansour, 2015).

3 Teacher Preparation to Implement STEM

Teachers are the primary drivers of educational reform; thus, it is critical to prepare them to implement STEM education and adopt relevant teaching approaches. Teachers' preparedness and context-based solutions to support them are required for the success of STEM education in the classroom. Teacher preparedness is critical because STEM requires teachers to have 1) specialized subject content knowledge, 2) exposure to various fields of science and mathematics, 3) experience with engineering and technology, and 4) familiarity with appropriate pedagogies (Akerson & Buck, 2020; Asghar et al., 2012; Thibaut et al., 2018). Sadly, most teachers may not have the knowledge, experience, and skills required to develop and implement lessons that show the synergies between subjects and root the learning in real-life situations (Asghar et al., 2012; Kurup et al., 2019; Shernoff et al., 2017; Song, 2019; Woo et al., 2019). Therefore, raising teacher quality is undeniably crucial for improving students' STEM learning environments and opportunities (Al Salami et al., 2017; Du et al., 2019; Honey et al., 2014).

Currently, education leaders have started implementing programs that have been associated with improvements in teacher practice because of the growing body of research on effective STEM professional development (Balyk et al., 2018; Brand, 2020; Du et al., 2019; Gardner et al., 2019; Kelley et al., 2020, 2021; Knowles et al., 2018). Existing studies on STEM-focused professional development agree that teachers who participate in such programs show a significant increase in knowledge, different aspects of instructional effectiveness, and awareness of the value of STEM integration (e.g., Aydin-Gunbatar et al., 2020; Balyk et al., 2018; Du et al., 2019; Kelley et al., 2020; Knowles et al., 2018; Kuehnert et al., 2019; Luft et al., 2020).

For example, a longitudinal case study conducted by Du et al. (2019) revealed that teachers who participated in STEM professional development showed: 1) considerable growth in lesson design, classroom implementation, and mathematics and science skills, 2) a noticeable shift from the traditional method of teaching to more student-centred approaches, 3) increased pedagogical skills, and 4) an increase in their value of STEM integration.

A systematic review conducted by Chai (2019) to investigate the impact of reform-based professional development in STEM also highlighted that most studies reported positive changes in teachers perceived relevance, implementation of science and engineering practices in the classroom, and connecting science to other subjects. Even though STEM professional development research is rising in developing nations, studies in under-resourced settings are few (Ismail, 2018; Kurup et al., 2019; Song & Zhou, 2020). This highlights the need for researchers to document practical approaches to prepare different teachers to successfully implement integrated STEM initiatives in various school settings (Kelley et al., 2021).

4 Preparing Teachers through Effective STEM Professional Development in under-resourced contexts

Although there are different perspectives on what constitutes an effective STEM professional development (English, 2016; Goodnough et al., 2014), some common features emerge from the literature that can be applied in under-resourced contexts. A review of several studies reveals that effective STEM teacher professional development: 1) focuses on student-centered instructional practices related to STEM integration (Asghar et al., 2012a; Dare & Ring-Whalen, 2021; Du et al., 2019; Gardner et al., 2019; Knowles et al., 2018; Schrader et al., 2015; Siew et al., 2015); 2) engages teachers as active learners (Brown & Bogiages, 2019; Bush et al., 2020; Du et al., 2019; Erdas Kartal et al., 2018; Faikhamta et al., 2020; Ring et al., 2017), 3) involves teachers in collaboration (Bush et al., 2020; Dare & Ring-Whalen, 2021; Du et al., 2019; K. Gardner et al., 2019b; Hsu & Yeh, 2019; Knowles et al., 2018), 4) include opportunities for feedback and reflection (Aydin-Gunbatar et al., 2020; Brown & Bogiages, 2019; Burrows et al., 2021; Bush et al., 2020; Dare et al., 2018; Ring et al., 2017), 5) provides follow-up support in the form of reflective coaching cycles, expert support, mentoring, and professional learning communities (Aydin-Gunbatar et al., 2020; Brenneman et al., 2019; Kartal et al., 2018; Gardner et al., 2019; Kelley et al., 2020; Schrader et al., 2015), and 6) are of sustained duration in terms of contact hours and intensity(Burrows et al., 2021b; Bush et al., 2020; Du et al., 2019; Gardner et al., 2019; Perez, 2018).

Teachers also commonly highlighted these elements as their STEM professional development needs that must be considered when designing STEM professional development (Affouneh et al., 2020; Goodnough et al., 2014; Owens et al., 2018). These elements, when utilized, result in changes in teachers' perception about their knowledge, design abilities, implementation abilities, assessment abilities, skills, value beliefs, and in the long run, classroom practices in STEM integration and do not require many resources (Avery & Reeve, 2013; Kurup et al., 2017; Song & Zhou, 2020; Thibaut et al., 2018; Woo et al., 2019)

4.1 Student-centred STEM pedagogy

Gardner and colleagues (2019) contended that the instructional design incorporated in STEM professional development programs should be student-centred, experiential, and open-ended to ensure teachers implement the integrated STEM approach in their lessons. Since integration is the main issue of contention, teachers need to be exposed to strategies to carry out the integrated STEM approach in their classrooms.

Several studies of integrated STEM professional development literature reveals Inquiry-Based Learning, Project-Based Learning, Problem-Based Learning, and Engineering Design in a cooperative learning environment as the primary instructional approaches used to aid teachers in implementing integrated STEM in their classrooms (Asghar et al., 2012; Bush et al., 2020; Dare & Ring-Whalen, 2021; Du et al., 2019; Kelley et al., 2020; Knowles et al., 2018; Nadelson et al., 2012; Ring et al., 2017a; Schrader et al., 2015).

Experiencing project-based and inquiry-based integrated STEM activities ground the teaching and learning of STEM content in an authentic context, highlight the relationships between the STEM disciplines, and increase teachers value, competence, and skills in STEM integration (Aydin-Gunbatar et al., 2020; Guzey et al., 2020, Nadelson et al., 2013). Although all the approaches are relevant, only two (i.e. project-based learning and inquiry-based learning) will be employed in this paper because of their applicability to the study context as an initial step of introducing integrated STEM in under-resourced contexts.

The effectiveness of inquiry-based learning approaches as an integrated STEM instructional practice in secondary schools supports the inclusion of this method in teachers' professional development (Kurup et al., 2019; Nadelson & Seifert, 2017; Thibaut et al., 2018). Furthermore, existing studies show that this pedagogical approach equips teachers with the skills (e.g., planning experiments, using technology, designing products) and knowledge needed to engage students in authentic STEM activities, scientific inquiry, argumentation, and engineering practices and increase their awareness of STEM careers (Burrows et al., 2021b; Guzey et al., 2020; Knowles et al., 2018; Nadelson et al., 2012, 2013).

For example, a study conducted by Aydin-Gunbatar et al. (2020) revealed that engaging science teachers in inquiry-based STEM activities during professional development significantly improved their knowledge about the implementation of assessment in their integrated STEM lessons. Professional development in scientific inquiry is possibly even more crucial because it is underscored as the current curricula rationale for when teachers encounter unfamiliar content such as those often linked with STEM teaching and learning in many places with little access to resources (Chabalengula & Mumba, 2012; Gardner et al., 2018; Makonye & Dlamini, 2020; Mohammed et al., 2020; Ssempala, 2017).

Professional development designed with the underpinnings of Project-Based Learning will help science teachers gain the competence and value they need to implement STEM elements in lessons (Kelley et al., 2020; Nadelson et al., 2012; Schrader et al., 2015). Teachers who participated in STEM project-based learning workshops improved their understanding of the concept of integration, gained new experience for STEM integration in the classroom, designed lessons in authentic contexts across STEM disciplines, became more creative and innovative in the school, gained first-hand experience in design challenges and valued the interdisciplinary nature of STEM projects, and became more aware of STEM careers according to existing research (Aydin-Gunbatar et al., 2020; Knowles et al., 2018; Margot & Kettler, 2019; Schrader et al., 2015; Siew et al., 2015).

Incorporating this approach is significant to this study because Siew et al. (2015) revealed that science teachers perceived that the teaching approach helped enhance their integrated STEM teaching competence and value beliefs despite the limited resources in their schools. Similarly, Capraro et al. (2016) contend that this approach works well in rural, under-resourced, and diverse settings. Teachers must have opportunities to immerse themselves in and explore learning in the integrated STEM strategies to understand how to use this new approach in the classroom (Brown & Bogiages, 2019).

4.2 Active Learning

Active participation in STEM activities is one of the essential sources of teacher learning (Aydin-Gunbatar et al., 2020). This is because during active learning, teachers are involved in the different types of learning activities and learning environments they would engage their students in (Aydin-Gunbatar et al., 2020; Darling-Hammond et al., 2017). To gain the competence to implement integrated STEM pedagogical strategies, teachers must experience first-hand through fully engaging in the integrated STEM practices as part of their preparation (Brown & Bogiages, 2019).

For example, engaging teachers in the use of Burke's (2014) 6E instructional model (engage, explore, explain, engineer, enrich, and evaluate) is useful because it helps them improve their design and technological inquiry skills (Akerson & Buck, 2020; Anderson & Li, 2020; Lin et al., 2021). Active learning opportunities, a hallmark of adult learning theory, allow teachers to transform their teaching rather than just layering new strategies on the old ones (Darling-Hammond et al., 2017; Trotter, 2006). As a result, experiencing integrated STEM activities as if they were students would provide useful knowledge regarding potential challenges that learners might encounter or possible suggestions that they might come up with to plan and implement the integrated STEM activities in the classroom (Aydin-Gunbatar et al., 2020).

4.3 Collaboration

Bringing teachers from similar grade levels, schools, or departments to collaborate on professional development goals is another important aspect of STEM professional development. This intentional interaction enables educators to meaningfully reflect on and discuss the essential themes of professional development(Bush et al., 2020; Du et al., 2019; Knowles et al., 2018).

A study by Owens et al. (2018) and Asghar et al.(2012) on effective STEM professional development revealed that secondary school teachers believed an ideal program would leverage teachers' collective experiences and provide opportunities for discussions with colleagues similarly engaged in efforts to enhance their practice. The social constructivist theory (Dewey, 1969; Vygotsky, 1978) builds on cognitive constructivism by proposing that when people collaborate, they develop more complex and advanced conceptual constructs (Hodson & Hodson, 1998; Vygotsky, 1978).

As a result, STEM professional development experiences should be built around the idea of professional collaboration, which will help shape and deepen teachers' knowledge, skills, understanding, and value of integrating STEM into the classroom (Hsu & Yeh, 2019; Kelley et al., 2020; Knowles et al., 2018; Ring et al., 2017).

4.4 Feedback and Reflection

Reflection and feedback, both critical components of adult learning theory, are two other powerful tools in effective STEM professional development(Dare & Ring-Whalen, 2021; Kelley et al., 2020; Knowles et al., 2018; Margot & Kettler, 2019). High-quality STEM professional learning often includes time for teachers to reflect on their practice, get feedback, and make improvements as a result of that reflection and feedback (Bush et al., 2020; Dare & Ring-Whalen, 2021; Darling-Hammond et al., 2017; Kartal et al., 2018; Gardner et al., 2019). Teachers can use reflection to get deeper insights into their understandings of integrated STEM teaching and learning (Aydin-Gunbatar et al., 2020; Darling-Hammond et al., 2017; Kartal et al., 2018). Teacher reflection is critical because it helps teachers articulate their value beliefs, experience, and knowledge, which develops and enhances their teaching competence (Aydin-Gunbatar et al., 2020; Brown & Bogiages, 2019; Darling-Hammond et al., 2017; Kartal et al., 2018).

4.5 Duration

Exceptional STEM professional development programmes are structured to provide teachers adequate time to practise using their new knowledge and instructional approaches(Gardner et al., 2019; Luft et al., 2020). Effective professional development gives teachers enough time to gain knowledge and skills, practice, and implement new strategies that help them change their practice. Although the length of STEM professional development varies according to studies(Burrows et al., 2021; Du et al., 2019; Gardner et al., 2019; Shernoff et al., 2017), scholars suggest that the time must be sufficient to support teachers' value, competency, and pedagogical changes(Aydin-Gunbatar et al., 2020; Kartal et al., 2018).

According to various studies (e.g., Anderson & Tully, 2020; Darling-Hammond et al., 2020; Desimone, 2009; Du et al., 2019; Perez, 2018), professional development programs with more than twenty hours of immersive workshop contact time result in changes in teaching competence, values, and practice. Furthermore, engaging and supporting teachers for a total of eighty hours or more for an academic year or semester increases the likelihood that teachers will use the pedagogical strategies taught (Anderson & Tully, 2020; Darling-Hammond et al., 2020; Desimone, 2009; Du et al., 2019; Perez, 2018). Shrader(2015) also suggests that blended learning approaches may provide an ideal context for integrated STEM professional development in contexts with limited contact time available to teachers.

4.6 Follow-up Support

The purpose of follow-up support is to ensure that learned strategies or skills are retained and applied effectively (Owens et al., 2018; Perez, 2018). Research suggests that teachers face additional challenges when integrating STEM lessons into their classrooms because they rarely get enough practical experience from workshops(Al Salami et al., 2017; Anderson & Tully, 2020; Brenneman et al., 2019; Chai, 2019; Perez, 2018).

Consequently, long-term interventions embedded with follow-up support, such as follow-up interventions and ongoing facilitation of teacher learning, are considered more effective than one-time, short-term interventions (Gardner et al., 2019; Conradty & Bogner, 2020). Integrated STEM professional development must address this by providing ongoing support and follow-up in the form of coaching or expert scaffolding as teachers implement new integrated STEM strategies (Gardner et al., 2019; Owens et al., 2018; Schrader et al., 2015).

Follow-up through coaching and expert support can foster the implementation of the instructional strategies, reinforce knowledge already learned, and help boost teachers' perceived teaching competence (Brenneman et al., 2019; Cotabish et al., 2011; Perez, 2018). It is also equally crucial that extra help from experts is given to teachers in schools with limited resources to implement what they have learned successfully (Brenneman et al., 2019; Du et al., 2019; Schrader et al., 2015).

This is because after an intensive professional development program, some studies (e.g., Brenneman et al., 2019; Du et al., 2019) highlight that teacher show an increased need for material resources and funding, which is absent in resource-constrained environments(Brenneman et al., 2019). Therefore, a practical integrated STEM professional development embeds teacher education in the context of classroom practice and models what classroom teaching and learning should look like, including the use of a constructivist facilitation approach (Bush et al., 2020; Owens et al., 2018; Srikoom et al., 2018). This follow-up support through coaching, mentoring, and expert support model effective practice and provide feedback and suggestions for overcoming the challenges associated with program implementation in resource-constrained environments(Brenneman et al., 2019).

A review of STEM professional development research reveals that follow-up support is offered to teachers in the form of periodic school visits, in-class observations, discussion of issues and challenges with teachers, provision of feedback, evaluative comments, co-planning, and answering questions from teachers, which lasts between three to six weeks per cycle (Al Salami et al., 2017; Anderson & Tully, 2020; Brenneman et al., 2019; Chai, 2019; Richmond et al., 2017).

In these studies, during each cycle of follow-up support, mentors, coaches and teachers: 1) work together to plan how the group learning experiences from the workshop could be integrated into the existing lesson, 2) schedule observation of one or more of the lesson implementations, 3) reflect on what went well and what could be improved based on evidence from the lesson, and 4) Set improvement goals and a plan to implement them in a future lesson (Al Salami et al., 2017; Anderson & Tully, 2020; Brenneman et al., 2019; Chai, 2019; Richmond et al., 2017). The changes in teacher practice depend on and are deepened by such extended support (Owens et al., 2018; Schrader, 2019; Du et al., 2019).

4 Conclusion

The primary argument of this paper is that a well-designed teacher professional development intervention may help prepare teachers to implement in the classroom, empowering them to stimulate their students' motivations and interests toward STEM. Consequently, six practical elements and strategies applicable to under-resourced contexts should be incorporated in any intervention to enhance the different components of teacher's preparedness in terms of their STEM integration skills, attitudes, beliefs, competence.

Acknowledgement

The author would like to thank all who contributed to making this paper possible. Hopefully, this paper will begin a discourse on effective ways of implementing STEM in under-resourced settings.

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