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Integration of The M In STEM Curricular Units Among Pre-Service Teachers Through A Phenomenological Approach

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ABSTRACT

Regardless of policymakers and educationists continuously hailing the importance of science, technology, engineering, and mathematics (STEM) and its correlation with developing countries' economic prosperity, all stakeholders have lamented poor mathematics participation in STEM fields. The need to conduct the current research has thus arisen. This is because K-12, or school mathematics (STEM), continuously attracts relatively tiny groups of culturally and linguistically different learners who are persistently involved in almost every human endeavor. Rested upon both the disproportionate representation and configuration of mathematics and coupled with the contestations, the current study examines an alternative approach to mathematics learning together with experiences associated with STEM participation. Consequently, this phenomenological investigation aims to explore and describe the lived experiences related to improving the integration of mathematics in STEM curricular units among pre-service teachers. Data was collected from six (6) STEM pre-service teachers until data saturation was reached. The data collection process was carried out through in-depth semi-structured interviews and analysed through a thematic approach in the search for dominant themes. The findings and thus the question from previous studies, what does integration of STEM and mathematics really mean would require mathematics practices through the integration of STEM right through elementary classrooms, using model-eliciting activities as well as responsive, professional development for mathematics teachers. The consensus is to make explicit connections between science, engineering, and technology while maintaining a relationship with mathematics and engaging context through instruction. Keenly, such an approach also bridges the gap between secondary and higher STEM education, facilitating the process of designing integrated STEM learning, which ought to be anchored on experiential or evidence-based models.

Keywords Career, cognition, narrative research, mathematics integration, phenomenology, STEM.

1 INTRODUCTION

Several concerns regarding the state of school mathematics (M) and science, technology, engineering, and mathematics (STEM) education as a collective in South Africa have consistently been raised (Graven, 2014, 2015; Macrae, 1994; Pausigere & Graven, 2014, Robertson, Graven, 2015). For example, Graven (2014) highlighted the link between poverty, inequality, and school mathematics performance in South Africa's post-apartheid context. A decade before Graven (2014), Macrae (1994) lamented the legacy of apartheid on mathematics education in South Africa, particularly among African or Black students. Such worrying opinions warranted Pausigere and Graven (2014) to suggest that learning metaphors and learning stories of learners and teachers in the numeracy community of practice could improve the predicament of South African school mathematics education. Collectively, what could be ascertained from the previous studies, as Robertson and Graven (2015) articulate, is to explore South African mathematics learners' experiences.

Additionally, more established research is needed to unpack pre-service teachers' conceptions of STEM education, the integration of school mathematics in STEM units, and student achievement gains among pre-service teachers. Unpacking and resolving such unknowns will seek to shed more light on the link between poverty, inequality, and mathematics performance in South Africa's post-apartheid context. In response, the current study investigates the integration of the M in STEM curricular units among pre-service teachers.

Beyond South Africa, different perspectives and through quasi-experiment in the past, too, Childress (1996) already started asking whether integrating technology, science, and mathematics improves technological problem-solving. More than 20 years later, such a question led Crotty Guzey, Roehrig, Glancy, Ring-Whalen, and Moore (2017) to interrogate the approaches to integrating engineering in STEM units and student achievement gains. On the other hand, Cunningham and Carlsen (2014) investigated teaching engineering practices and beliefs associated with understanding the challenges linked to physical science teachers integrating engineering and physics. Similarly, Rinke, Gladstone-Brown, Kinlaw, and Cappiello (2016) alluded that it is equally important to understand how teachers' conceptions of integrated STEM education are reflected in curriculum writing. While relatively new research, the inference from Childress (1996), Crotty et al. (2017), Carlsen (2014), and Dare, Ellis, and Roehrig (2014, 2018) regarding the integration of the Mathematics in STEM curricular units suggest growing traction. For example, in 2001, the United States National Science Foundation (NSF) introduced STEM. The discipline STEM was fundamentally referred "to the career fields which require knowledge and skills to be integrated into their field…" with the motive being integral or better fit "… with the learning style of … students…" (Azman & Maat, 2019, p. 965). What is also known is that STEM education has often been considered a meta-discipline, meaning the "creation of a discipline based on the integration of other disciplinary knowledge into a new 'whole.' This interdisciplinary bridging among discrete disciplines is now treated as an entity known as STEM" (Morrison, 2006, p. 23). The previous studies have also provided a relative basis for understanding various architecture and configurations of STEM, improving STEM participation (Azman & Maat, 2019; Crotty et al., 2017). For instance, Azman and Maat (2019) recently conducted a systematic review of teachers' perceptions and challenges towards STEM integrations. While there are several questions unanswered, one critical insight was the proposal regarding re-examining the state of mathematics representation and, thus, integration in STEM (Azman & Maat, 2019; Crotty et al., 2017; Roehrig, Wang, Moore & Park, 2012). One motive for such has, in part, been due to the work of Roehrig et al. (2012). A decade ago, Roehrig et al. (2012, p. 7) questioned the need for "… adding the E…" in examining the influence of K-12 engineering standards on the implementation of STEM. In addition, Crotty et al. (2017) recently reviewed the approaches to integrating engineering in STEM units and student achievement gains. The conclusion is that regardless of policymakers, researchers, and educationists continuously hailing the importance of STEM and its correlation with developing countries' economic prosperity, all stakeholders alike have lamented over poor mathematics representation and, thus, participation in STEM. In response, various ongoing studies have used qualitative approaches in examining the relative influence of STEM on learning and teaching. Fundamentally, most research so far used methods including but not limited to ethnographies, case studies, and sometimes autobiographies, which form the narrative research. Disappointedly, researchers have noted that mathematics has received little to no interrogation through a phenomenological approach (Roehrig et al., 2012). The limited attention is particularly true when examining the phenomenon of mathematics learning together with experiences associated with STEM participation. The need to add to a rich repository of knowledge on STEM has thus arisen because mathematics continuously attracts relatively tiny groups of culturally and linguistically different learners and hence the current research.

2 BACKGROUND

Mathematics remains the most underrepresented in STEM disciplines (National Academies of Sciences, Engineering, and Medicine, 2018). However, it has been argued that mathematics learners are persistently involved in almost every human endeavour (De Meester, De Cock, Langie & Dehaene, 2021; National Academies of Sciences, Engineering & Medicine, 2018). Rested upon the ongoing underrepresentation and exacerbated by the growing need, particularly in the fourth industrial revolution technologies, the current study examines alternative approaches for mathematics learning and experiences associated with STEM participation. Understanding pre-service teachers' experiences and mathematics integration in STEM and non-STEM fields is likely to improve mathematics participation and, therefore, STEM, improving academic performance and promoting STEM and non-STEM participation. Accordingly, this phenomenological study aims to concurrently explore and describe the lived experiences of pre-service teachers and their views of integrating mathematics in STEM curricular units. Faced with such contestations, the current background, and thus theoretical framework, for the most part, are built on the work of De Meester et al. (2020) via the examination of how to bridge the gap in various levels of STEM disciplinary knowledge, such as but not limited to secondary school right through to higher education institutions. De Meester, Knipprath, Thielemans, De Cock, Langie, and Dehaene's (2015) position of integrated STEM also served as a focal point to examine De Meester, De Cock, Langie, and Dehaene's (2021) view on integrated STEM curriculum units. The work of De Meester et al. (2021) subsequently provided a foundation to examine challenges faced by STEM teachers when confronted with the notion of integration, which consequently paved the way to interrogate implementations of STEM curricular units through a phenomenological approach. To fully address the research objectives, an additional focal point was the need to explore the methods of integrating Mathematics into STEM curriculum units through a phenomenological stance. While not an exhaustive list, the current research developed on work such as but not limited to affordances and constraints of STEM integration for science and mathematics (Rinke et al., 2016) and discipline-based interpretation through computational modeling and building cognition (Chandrasekharan & Nersessian, 2015; Farris, Dickes & Sengupta, 2016). Other grounds for evaluation included Dickes, Sengupta, Farris, and Basu's (2016) view on the development of mechanical reasoning, as well as Nersessian's (2012) and Sengupta, Dickes, and Farris's (2018) position on modeling practices for conceptual innovation through ethnographic study, which also laid the background for the shift toward a phenomenology of computational reasoning in STEM and thus mathematics.

2.1 Research Objectives

From the synopsis so far, two key objectives have evolved and thus been proposed, which are examining:

RO1: Pre-service teachers' conceptions of STEM education.

RO2: The integration of mathematics into STEM units and student achievement gains among pre-service teachers.

3 CONCEPTIONS OF STEM EDUCATION

While different debates have been raised regarding the need to improve the cognition and adequate integration of mathematics in various curricula, the problem has far more been aggravated in terms of its underrepresentation in STEM (Baker & Galanti, 2017; Dare et al., 2018; De Meester et al., 2021; De Meester et al., 2020; Guzey, Moore & Harwell, 2016; Ingvarson, Meiers & Beavis, 2005; Krajcik, McNeill & Reiser, 2008). While not peculiar to developed nations such as the United States (US), a little over two decades now, several barriers to STEM education, particularly in the US, have been attributed to public schools (Lantz, 2009, p. 4), sadly, aiding these *barriers* are evolving *misconceptions*. These misconceptions, as Lantz (2009, p.4) recounts, include:

"STEM education is just another "fad" in education and will soon go away; colleges will not accept credits for high school courses called STEM; technology means additional computers and hardware for schools and students; technology means the ability to use and apply word processing, spreadsheets, and PowerPoint; all inquiry is open-ended; hands-on learning and inquiry are the same things; STEM education does not include laboratory work or the scientific method; all STEM-educated students will be forced to choose technical fields because they do not have a liberal arts foundation."

In addition to the ongoing misconception pointed out by Lantz (2009, p.4), critiques have singled out mathematics by indicating that;

"Mathematics education is not part of science education, and STEM education addresses only workforce issues; technology education and engineering are disparate and troublesome; technology education teachers cannot teach science or mathematics; engineers cannot teach science and math; technology and engineering are additional courses to be prepared and layered as are science and mathematics courses; [and lastly] STEM education consists only of the two bookends-science and mathematics. "

These misconceptions imply that unless the misconceptions are effectively examined and rectified, form and function in terms of implementation and integration of STEM worldwide, particularly in developing countries, remain ill-structured and vague.

In response, so far, the call is to place far more attention on integrating STEM disciplines (Baker & Galanti, 2017; Dare et al., 2018). Several past and ongoing studies examine this phenomenon. For instance, as a departure from the current research, in recent times, through the use of an evidence-based model, De Meester et al. (2021) examined the process of designing integrated STEM learning material and found positive relation with programmes for teacher training when such a progarmme is based on integrated STEM education. A variation of the current study but thrust on understanding science among in-service teachers' implementation of integrated STEM has also been examined (Dare et al., 2018). Through phenomenological multiple case studies, Dare et al. (2018) established a close link with curricular units and understanding of in-service teachers' implementation of integrated STEM curriculum. Informed by the misconceptions and barriers and through a case study, De Meester et al. (2020) showed a need to decrease the gap in various learning levels regarding STEM curriculum.

Contrary, through the case study, while De Meester et al. (2020) and Knipprath et al. (2015) advocated for the integration of STEM disciplines, far less attention has been reported on the contribution of an individual component of STEM, more so with mathematics than the other components.

However, though Mathematics is one of the critical components influencing STEM professional development, as Ingvarson et al. (2005) highlight, little to no evidence exists to establish how mathematics as a universal language of STEM discipline influences STEM programmes on teachers' knowledge, practice, student outcomes, and efficacy. In the past, the focus has also been directed to everyday problem-solving in engineering (Jonassen, Strobel & Lee, 2006). Thus, one key reason to re-examine the dual role of mathematics in STEM, as Krajcik et al. (2008) alludes to, is that mathematics possesses universal evolving learning goals, which could be tailored to the design model of any aspect of STEM. These universal learning goals are essential for developing curriculum materials that align with national standards and incorporate project-based pedagogy.

The inference so far is that regardless of the ongoing focus on the implementation and integration of STEM curricula, many more areas remain rife for research (Baker & Galanti, 2017; Dare et al., 2018; De Meester et al., 2021; Easterbrooks & Stephenson, 2006; English, 2016). For instance, although De Meester et al. (2021) argued that STEM teachers are far more likely prepared to implement STEM education, researchers are yet to establish how STEM performance and design are accounted for through mathematics. Additionally, studies still need to examine the mathematics-teaching process when teachers design STEM learning materials (De Meester et al., 2021).

The inference is that STEM education will likely be improved by depth through the mathematics design process and how such design processes influence STEM learning materials. One way to achieve this is through an inductive, data-driven algorithm. In simple terms, an inductive, data-driven algorithm allows for a new set of input of a group of procedural rules, which is later revised against the backdrop of available examples. Such a mathematical inclined inductive, data-driven algorithm could be used to apply and build models that describe teachers' process of designing STEM learning materials. For example, while researchers have evidenced that integrating K-12 level STEM disciplines provides learners the opportunity to experience learning in real-world, multidisciplinary contexts, the same is not known as to how the integration of mathematics does to STEM and its ripple effects on STEM fields (Dare et al., 2018). Furthermore, more reported research is needed regarding how teachers, for example, integrate mathematics phenomena in STEM instruction, given the pervasiveness of mathematics language (Dare et al., 2018).

Consequently, contrary to the misconceptions and barriers, the phenomenon must be explored further. Additionally, unlike the studies on in-service teachers, the current phenomena need further exploration by understanding STEM pre-service teachers' experiences in implementing mathematics as part of the integrated STEM curricular units. The present study delineates previous studies using classroom experience data and interviews. These two approaches illustrate different variations of integrated STEM instruction through mathematics while simultaneously understanding pre-service teachers' challenges and successes with such approaches. A parallel work by Baker and Galanti (2017) has already revealed that integrating STEM at elementary levels through model-eliciting activities improves professional development for mathematics coaches and teachers. In other research, an examination of twenty literacy, science, and mathematics practices in educating students who are deaf or hard of hearing revealed an improvement (Easterbrooks & Stephenson, 2006).

Thus, the need has arisen to re-examine the perspectives on STEM integration in K-12 education (English, 2016) and what the integration of science and mathematics really means among pre-service teachers (Davison, Miller & Metheny, 1995).

3.1 Approaches and integration of mathematics in STEM curriculum and student achievement

While several approaches have been used in the past in an attempt to integrate mathematics adequately into STEM and thus improve overall student achievement, the evidence is scarce and varies considerably (Blikstein & Wilensky, 2009; Dickes et al., 2016; Rinke et al., 2016; Sengupta et al., 2018; Wagh, Cook-Whitt & Wilensky, 2017). Thus far, the research examines the affordances and constraints of explicit STEM preparation for elementary teachers' preparation (Rinke et al., 2016). Through phenomenology, Sengupta et al. (2018) recently investigated computational thinking in K-12 STEM and concluded that computational thinking in the STEM discipline forms the basis for teaching and learning. Using the constructionist approach, Blikstein and Wilensky (2009) examined the learning environment for materials science using agent-based modeling. As with the work of Blikstein and Wilensky (2009), the conclusion reached by Chandrasekharan and Nersessian (2015) is the need to improve cognition using the construction of computational representations for scientific discovery. In the past, the ethnographic approach has also been used in examining neural engineering to model practices in conceptual innovation (Nersessian, 2012). Using bridging analogies and anchoring intuitions, Clement (1993) has shown that dealing with students' preconceptions in physics could be resolved. On the other hand, Danish (2014) applied an activity theory lens to design instruction for learning about a honeybee system's structures, behaviour, and function.

Collectively, what is concluded and supported by Dickes et al. (2016) is that such approaches tend to develop mechanistic reasoning and multi-level explanations in STEM. They also build discipline interpretation and perspectival computational thinking for learning STEM (Farris et al., 2016). This means there is a tendency to develop an understanding of conceptions and conceptual growth in interaction. *As opposed to the misconceptions and barriers stated in the beginning,* such approaches also claim that it enables learning through design and teaching by exploring social and collaborative aspects of constructionism. The call for such studies has prompted the need to examine the alignment between students playing computational models and goals of inquiry (Wagh et al., 2017). What could be established from the studies, too, is the need to bridge the gap between secondary and higher STEM education by examining trans-disciplinary representational and epistemic practices and shifts.

4. THEORETICAL STANCE PHENOMENOLOGY OF MATHEMATICS AND STEM INTEGRATION AND COGNITION

Informed by the background through the research objectives, phenomenological stance as a theoretical praxis is critical in advancing and improving the integration of mathematics in STEM curricular units among pre-service teachers. This is because, while fledgling misconceptions and barriers have branded mathematics as being predominately algorithmic and heuristic, fundamentally, the experience of mathematics learners is inherently heterogeneous (Sengupta et al., 2018). The heterogeneity includes but is not limited to the engagement and multi-pronged forms and genres of representations beyond algorithmic and computation, which also includes understanding informed translation and interpretation. Note that the Husserlian approach articulates the ongoing study through interviews. Generally, discussions fall within the Husserlian approach to data construction. While the current research is not specifically on the Husserlian approach, some limited attention is provided to the procedure regarding the interview process. This assisted in honing the findings and how they emerged. Following Husserlian phenomenology, it is argued that experiences tend to be directed toward "intends" through specific concepts, thoughts, ideas, or images, which constitute the meaning or content of any particular experience (Husserl, 2001, 1969). Thus, based on Husserl (2001, 1969), the data collection approach was anchored on the objective, consequently, on phenomenology. Essentially, what that means, as noted by Creely (2016, p. 45), is the need to understand "things from within," which is the Husserlian phenomenological approach to conducting research and inquiring about learning. Further explanation of stages regarding the phenomenological cannons is seen in the Husserlian approach to interviews section.

Nevertheless, in stark contrast with what is known about mathematics in terms of algorithmic thinking and computational abstractions to determine the correct answer, the phenomenological stance, as a theoretical praxis, requires several alternative thinking processes. First, even though several studies have been conducted using various approaches, as demonstrated in the background, there is a call for an epistemological shift (Sengupta et al., 2018). The claim refrains from viewing STEM or mathematics as mastery or overcoming computational logic and symbolic forms to viewing STEM and thus mathematics as a more complex form of experience of various phenomena instead of viewing STEM as rehashing, re-producing a set of axiomatic computational abstractions. Such epistemological perspective or conceptualisation could have led to the minimal use and application of mathematics. Therefore, the proposition is to adopt a view that accounts for discursive, perspectival embodied experiences. That experience accounts for the service and production of computational abstractions and a paradigmatic shift toward a phenomenological approach (Sengupta et al., 2018).

Altogether, the implication is that computational thinking in STEM is good. Accordingly, in mathematics, Sengupta et al. (2018) argue for an epistemological shift from viewing STEM and mathematics, particularly as computational logic and symbolic forms, to viewing the complex structure of experience, which will avoid the risk of seeing our experiences as technocentric. Nevertheless, beyond the early studies, the evidence is that the *epistemology* of both mathematics and STEM cognition has yet to receive much attention. Meanwhile, understanding the *epistemology* of mathematics and STEM cognition has received little attention. In the interim, understanding the *epistemology* of both mathematical and STEM cognition is critical because it allows examining the beliefs and assumptions related to the nature of knowledge for STEM-related disciplines. By implication, mathematical thinking and practices are central to *knowing* and *doing* STEM disciplines. Correspondingly, a phenomenological perspective is needed to understand the uncertainty and subjectivity inherent in the experience of mathematics cognition and hence STEM.

Several vital points or implications should be considered for employing a phenomenological perspective from the discussion. One key reason is that mathematics practices or algorithms are not only developed over a prolonged period but could even be an individual's lifetime. Such a long-lived experience is a consequence of the nuance and complexity of lifelong learning, not only peculiar to mathematics but experiencing different learning generally, suggesting that various phenomena tend to require other forms of algorithmic approaches and hence integration. Consequently, the argument that ease of conceptual difficulty comes with time is closely associated with lifelong experience of various phenomena. As a result, pedagogical approaches based on lived experiences supersede mechanistic approaches alone. In fact, the corresponding body of experimental studies has supported the process of the phenomenological method, as explained shortly. For instance, Francis, Khan, and Davis (2016) suggested enactivism to explore spatial reasoning and coding in terms of *digital experiences in mathematics education*. Comparably, Grover and Pea (2013b) used a discourse-intensive pedagogy and an Android App inventor to introduce computational concepts to middle school students.

Similarly, Kafai and Burke (2013) suggested that in K-12 programming, moving from computational thinking to computational participation is vital for cognition. Effectively, and as Lehrer, Schauble, and Lucas (2008) affirm, the development of the epistemology of inquiry to *cognitive development* is key regarding the integration of mathematics into STEM. In reaction to Lehrer et al. (2008), a parallel study by Sengupta et al. (2018) suggested a move to the phenomenology of computational thinking as a foundation for teaching and learning mathematics or STEM and hence the need for the current research.

5 METHODS

The current section is devoted to the method used in unpacking the current objectives. In another study, Barroso’s (2020) phenomenological approach was used to examine the learning situations of STEM students in pre-calculus. Some conclusions included a lack of comprehension and an inability to learn alternative solutions. The inference is that through the phenomenological approach, STEM students' learning situations in mathematics largely depend on factors such as comprehension and learning alternative solutions. However, unlike the previous study, the current study intends to examine how to improve the cognition and integration of mathematics in STEM curricular units among pre-service teachers through a phenomenological approach. Therefore, a qualitative approach, as opposed to a quantitative informed by phenomenological design, was used to unpack the research objectives. While Hytner (1999) suggested various guidelines for the phenomenological analysis, particularly with interview data and in qualitative research, phenomenological research design generally provides the opportunity to concentrate on identified phenomena related to lived experiences of the respondents as described in the following subsection (c.f. data analysis for details) (Groenewald, 2004; Hycner, 1999).

5.1 Husserlian approach to interviews

Four stages were followed during the interview process. The first included the ontological description, which involved textual analysis requiring content identification and labeling for specific experiences through interacting with participants about their learning experiences. The second stage was phenomenological 'reduction' involving the search for foundational meanings. That is, participants' experiences, together with intentions, are then identified and interpreted. The third stage was hermeneutical analysis. While a vast analytical tool, strictly for this study though, it was for understanding meaning, the process of knowing and learning. The fourth and final stage was synthesis, which involved assembling the results generated through participants based on the initial three stages (viz; ontological description, phenomenological reduction, and hermeneutical analysis).

5.2 Sampling and ethics

Based on the research objectives, a purposive sample was adopted. Crossman (2018) explains that purposive sampling is usually characterised as a non-probability sampling technique, which primarily concentrates on the features of the sample (6 respondents for the current study) and the research objectives. In the present study, the sample criteria or features used were informed by specific criteria in selecting the participants. For instance, one sample criterion was based on pre-service teachers in their fourth year pursuing a Bachelor of Education with a specialisation in mathematics. In effect, it was required that the respondents are mathematically inclined students. In addition, specialising in mathematics meant they also have experience of and exposure to one of the components of STEM so that they are at least able to interrogate one or multiple of the components of STEM disciplines. However, some features which were not considered were independent of whether respondents were high or low-performing students. As such, that feature did not influence the respondents' opinions. The saturation of data determined the sample size (6).

Oral ethics was assured, including privacy, confidentiality, and anonymity. Thus, confidentiality, privacy, and anonymity were at all times observed. In addition to the ethical process, ethical approval was sought and granted by the Nelson Mandela University research ethics committee, thus adhering to the norms and practices inherent to ensuring participants were protected. This also included: To ensure credibility, the participants were known to the researcher as the researcher worked with the participants. Thus, it was easy for the researcher to have continuous conversations with them concerning the study, which assisted in the accuracy of the data.

Additionally, validity through trustworthiness or transferability of the data, which refers to whether data and findings would yield similar results in a similar setting, was addressed. In this instance, the researcher clearly described the data analysis to ensure that the findings could be transferred to other places. To ensure dependability, which refers to the research process ensuring that it is logical and documented, the participants received feedback from the narratives they wrote. The practice was also conducted to ensure the consistency of the data.

5.3 Data Collection

Informed of the research objectives, one data collection method was used. This was audio (via Ms. Teams) recordings of the structured interview. There were two months of the session from February to March, which included four sessions each week with the participants incorporated into their mathematics lesson. In this respect, the interaction was guided by questions focussing on lived experiences related to pre-service teachers' understanding of improving the cognition and integration of mathematics and its integration with STEM curricula. Cumulatively, interviewees were interviewed on six different schedules (twice in February and four times in March). An additional session was devoted to ensuring that relevant points were all clarified. Additionally, it clarified ambiguities in responses.

5.4 Data analysis

Using the guidelines of Hytner (1999) and Husserlian's approach to interviews from phenomenological data analysis, several steps were adhered to, including the phases or processes. In this process, the researcher listened to recorded audio repeatedly through bracketing and phenomenological reduction. Additionally, a method of delineating units of meaning was applied. In this process, specific themes or lists of units of significant meaning were identified through each respondent. The process also allowed for the scrutinisation and thus allowed for redundant units to be eliminated (Groenewald, 2004). In effect, the most relevant points of the interview are used. The last three processes included clustering units of meaning for the formation of themes, summarising each interview, and, lastly, unique/ composite summary themes for the interview. While clustering units of importance for building themes, an attempt was made to cluster the most relevant subject matter based on different emerging themes.

Meanwhile, summarising each interview phase was used to validate and simultaneously check and modify emerging themes. First, the general and unique themes phase is meant for all interviews and composite summaries. An attempt was made to look specifically for common themes. Finally, the researcher clustered the common themes based on the research aims.

6 RESULTS

As a recall, the current research examines two key objectives supported by the background and theoretical disposition. For ease of reference, the two objectives included the examination of both pre-service teachers' conceptions of STEM education and the integration of mathematics in STEM units and student achievement gains. The first theme under investigation was; pre-service teachers' conceptions of STEM education. *A respondent called Afrika* (*pseudonymised)* indicated the need to;

"...tailor the professional development design and support an evolving participant vision of STEM integration."

In support of *Afrika, Kenyatta* added that.

"opportunities to engage with mathematics as learners [pre-service teachers] should reflect mathematics with problem-based learning and draw from mathematics design features to modify existing curricular tasks to allow participants to think more broadly about mathematics content within STEM integration."

Though Dare et al. (2018) and Cunningham and Carlsen (2014) raised concerns regarding understanding the challenges STEM teachers face when integrating other components such as engineering and physics, an additional unanswered question from Childress (1996) and from a participant called *Lam*

"was whether integrating such components alone do improve problem-solving."

Such a question is vital because, as Krajcik et al. (2008) noted, developing curriculum materials that align with STEM or mathematics and incorporate project-based pedagogy contributes significantly to national standards. A respondent called *Nia* suggestion is for understanding STEM teachers' implementations of integrated curricular units through lived experiences or modeling (phenomenological) "…*approach using mathematics as an anchor*." Additionally, as Francis et al. (2016) allude, it provides an opportunity for other forms of cognition, such as but not limited to spatial reasoning and coding, particularly relevant to digital experiences in mathematics education. Additionally, Zap (a respondent) added that;

"the need for ongoing support as they considered the challenges of curricular pacing and administrative expectation" is critical in integrating mathematics with the STEM curriculum.

Alternatively, Zania highlights the need to

"... share and built[d] STEM integration capacity with a specific focus on mathematics content which advances professional development, encourages STEM instructional leadership and promotes mathematical readiness for STEM citizenship and careers."

In addition to Zania, Frika (pseudonym) alluded to that

"the degree of STEM integration that occurs in instruction may be related to the mathematical ability to make explicit connections between the disciplines."

Accordingly, it is possible to develop discipline interpretation using computational modelling (Farris et al., 2016).

7 DISCUSSION

In the current study, and through phenomenological stance, the intent was to understand how to improve the cognition and integration of mathematics in STEM curricular units among pre-service teachers. Several highlighted studies for the integration of STEM in K-12 and university mathematics have led to two critical themes, as explained further below.

7.1 Pre-service teachers' conceptions of STEM education

Primarily, the dominant view of mathematics as a calculations and data representations component of STEM makes it challenging develop reasonable and realistic conceptualisation of STEM integration (Blikstein & Wilensky, 2009; Dickes et al., 2016; Rinke et al., 2016; Sengupta et al., 2018; Wagh et al., 2017). In response, a claim has been made to situate participants' experiences on mathematics by re-engineering a new form of STEM integration by considering participant-driven, real-life contexts which focuses on making mathematics content explicit and existential by nature in support of Afrika's and Kenyatta's (participants) views.

Several inferences could be drawn from the data and the previous work (Barroso, 2020; Blikstein & Wilensky, 2009; Dickes et al., 2016; Rinke et al., 2016; Sengupta et al., 2018; Wagh et al., 2017). Given the importance of experiential learning, for instance, it could be inferred from Barroso (2020) and other participants (Afrika and Kenyatta) that a phenomenology approach to the learning situations of STEM disciplines holds prospects for pedagogical development as well as lifelong learning. This is because supporting the development of the epistemology of inquiry is vital for *cognitive development* (Lehrer et al., 2008; Sengupta et al., 2018; Wagh et al., 2017). Jointly and supported by Wagh et al. (2017), it is implied that such an approach not only bridges inquiry-based STEM and cognition but also enhances mathematics reasoning by exploring the alignment between students' cognition and computational models and goals of inquiry. As with the views of Danish (2014) and Nersessian (2012), it also encourages the ability to *model practices.* Through the phenomenology approach, it is possible to bridge analogies and intuitions, mainly dealing with students' preconceptions in mathematics and, thus, STEM (Clement, 1993). Such an approach provides the foundation for building cognition because the construction of computational representations is in discovery mode (Chandrasekharan & Nersessian, 2015). Resultantly, there is a need to consistently shift toward the phenomenology of computational thinking (Blikstein & Wilensky, 2009; Sengupta et al., 2018). Ultimately, just as Roehrig et al. (2012) asked whether adding the "E" is enough to investigate the impact of K-12 engineering standards on the implementation of STEM integration, it will be equally possible to estimate the effect of mathematics influence in STEM configuration. Accordingly, such a quest provides the foundation to integrate mathematics in STEM units and student success (Crotty et al., 2017). Anchored on Nersessian (2012) too, Rinke et al. (2016) suggest that characterising STEM teacher education within mathematics affords and limits the constraints of unambiguous STEM preparation in all stages of mathematics. This is achieved by addressing how teachers' conceptions of integrated STEM education are reflected in curriculum writing, as opined by Lam (respondent) and Ring-Whalen et al. (2016). Though Dare et al. (2018) and Cunningham and Carlsen (2014) raised concerns regarding understanding the challenges STEM teachers face when integrating other components such as engineering and physics, an additional unanswered question from Childress (1996) and a participant *Lam.* Built on Krajcik et al.'s (2008) position, Jonassen et al. (2006), together with Ingvarson et al. (2005) therefore raise the need to effectively explore the factors affecting the impact of professional development programs on STEM teachers' knowledge, practice, student outcomes as well as efficacy. If such an approach is undertaken, it will build STEM by developing design-based integration curricular materials and improving mathematics cognition (Guzey et al., 2016).

7.2 The approaches to integrating mathematics in STEM curriculum units

Previous studies questioned the "readiness to use mathematics as a vehicle for K-6 STEM integration, which maintains an important grounding in the teaching realities of grade-level standards and standardiz[s]ed test preparation" (Farris et al., 2016, p. 22). While it is essential to examine pre-service teachers' conceptions of STEM education, what is brought to light is overwhelming evidence highlighting the need to explore the integration of mathematics into STEM curriculum (Baker & Galanti, 2017; Dare et al., 2018; Dickes et al., 2016; English, 2016; Farris et al., 2016; Grover & Pea, 2013b; Kafai & Burke, 2013). Several conclusions from both literature as well as data could be drawn. For instance, with English (2016) and Dare et al. (2018), STEM education from K-12 needs to understand the perspectives on integration. The reason, as Dare et al. (2018) and a respondent (Nia) suggest, is for the understanding of STEM teachers' implementations of integrated curricular units through lived experiences or modelling (phenomenological) "*…approach using mathematics as an anchor*." Additionally, as Francis et al. (2016) allude, it provides an opportunity for other forms of cognition, such as but not limited to spatial reasoning and coding, particularly relevant in digital experiences in mathematics education, as Zap (a respondent) added. The implication is the need to use a discourse-intensive pedagogy to introduce computational concepts (Grover & Pea, 2013b). In turn, Kafai and Burke (2013) argued that such an approach enables a shift from computational thinking to computational participation, which is vital for developing mechanistic, experiential reasoning and multi-level explanations (Dickes et al., 2016).

8 CONCLUSION

Based on the objectives, one key conclusion and, thus, the question from previous studies reached is that; what integration of STEM and mathematics means would require not only ensuring teachers' responses to STEM but mathematics practices through the integration of STEM right through elementary classrooms using model-eliciting activities and responsive, professional development for mathematics teachers. The implication for pre-service teachers' experiences is the nature of integration. The consensus is to make explicit connections between science, engineering, and technology while maintaining a relationship with mathematics and engaging context through instruction. Keenly, such an approach also bridges the gap between secondary and higher STEM education and facilitates the process of designing integrated STEM learning, which ought to be anchored on an experiential or evidence-based model of phenomenology.

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