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ORIGINAL PAPER

Connecting mathematics to STEM education: interdisciplinary teaching and learning facilitation

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Abstract
In interdisciplinary Science, Technology, Engineering and Mathematics (STEM) education, empirical evidence is required that points to the educational contribution of mathematics. Specifically, researchers are not clear how mathematics weaves itself through the STEM education meta-discourse. This article contributes to pedagogical practices in educational institutions where STEM has been newly introduced - What are the perceptions and experiences of South African teachers on interdisciplinary STEM education, and how do mathematics and interdisciplinary STEM discourses leverage each other at schools of specialisation (SoS) in South Africa? Participant teachers were drawn from ten SoS in South Africa. SoS are STEM-dense schools in South Africa's Gauteng Province, the country's industrial and commercial hub. Interview data was collected on teachers' experiences and practices to explore the affordances of Mathematics and other STEM disciplines to influencing curriculum advancement. Situated cognition, mathematics as explorations and flow theory informed this qualitative study. In the findings, technology was regarded as raising learner motivation and mathematical achievement. Important to the study is that participants have a high regard for mathematics' role in interdisciplinary STEM education. In the study, teachers had no autonomy to pursue the STEM agenda, as they were bound to adhere to a prescribed curriculum, which hardly refers to implementation of interdisciplinary STEM education. Various recommendations are proffered, such as maintaining the positive perceptions participants have on the role of mathematics in STEM curricula. The research calls for equality and equity of all the STEM disciplines, as one STEM curricula cannot succeed without the other.

Keywords STEM integration · Thinking mathematics · Flow theory

1 Introduction

Around the world, STEM education is promoted by governments to create a scientifically, mathematically, and technologically literate society. The main goal is to prepare young people to take up STEM careers in the near future (e.g. Department of Education and Skills, Ireland, 2017). While research on STEM education is fast advancing, the field still lacks a scientific evidence-base that informs theory, policy, and practice (Maass et al., 2019). This research explores practice on STEM teachers views on how Mathematics advances the learning of STEM disciplines, and how these disciplines affect the learning of Mathematics in turn. The research was conducted at schools of specialisation (SoS), which are STEM-dense schools in Gauteng.

1.1 STEM education is an imperative in South Africa and Schools of Specialisation (SoS)

South Africa's history of apartheid has resulted in some communities being oppressed in all aspects of their lives, where, as a result, they have been denied opportunities that include being able to develop skills necessary to be formally employed in lucrative STEM careers. The centuries of colonisation have taken a toll on African indigenous knowledge systems (Eglash et al., 2020). A decolonial perspective and material agency is needed in order to enable scientific epistemic access for the benefit of all. The mono-disciplinary

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approach of teaching STEM subjects is common. While the South African Curriculum and Policy Statement (CAPS) argues for subject integration during teaching, this intervention remains at the policy level alone. This contrasts with the Netherlands STEM curriculum initiative, in which an interdisciplinary course Nature, Life, Technology curriculum (NLT) is taught by an interdisciplinary team of teachers (Den Braber et al., 2019, p. 168). This course serves to supplement the existing mono-disciplines. Modelling is the main activity in NLT, alongside design and research. NLT aims for students to experience and understand interdisciplinary coherence in the STEM subjects, where mathematics is regarded as a tool and language of science.

Recently, South Africa established schools of specialisation (SoS). Only selected talented learners register in these schools. Government intends to establish how SoS can best function, with the hope of cascading the successes across the nation. These SoS specialise in STEM. The aim is to ignite a new level of hunger for learning about STEM, focusing on learner preparation for STEM careers. Project-based learning is a common feature. Corporate organisations, such as SASOL, a local company that makes oil from coal, frequently fund high-performing learners, irrespective of their social status. Any SoS focuses on the economic activity of its locality. For example, in Pretoria, the SoS focus on the automotive industry, as large car assembly plants for Nissan, Ford, BMW and others are located in the Roslyn area north of Pretoria. Experts visit schools to share their expertise, as well as to support and motivate learners in their STEM careers.

One of the common online learning organisations utilised by SoS is Siyavula. It is an educational technology company, which has online learning tools for Mathematics, Science and other subjects, and is aligned to the South Africa school curriculum. Teachers and students can access tutorial material and practice exercises that can provide immediate feedback to learners.

1.2 Research problem

The role of mathematics in STEM education is not clear to many researchers. Den Braber et al., 2019), in their study on the NLT curriculum, found that "students often don't recognise mathematics in the course or that they consider the level of mathematics in the course as too low, not interesting… and Mathematics teachers seem to feel that there is no need for their mathematical expertise" (p.167). Such findings call for the need to conduct further research into the role of Mathematics in STEM education. In a systematic review of the role of Mathematics in Science education, Just and Siller (2022) concluded that Mathematics was regarded as a minor matter in the eyes of science educators. Mathematics was not considered central to problem engaging and problem-solving (Niss & Højgaard, 2019, p.5). Instead, that role was attributed to science, technology or engineering. This is a challenge for mathematics researchers in their quest for an equitable position for Mathematics in the STEM system.

Of particular importance to this research is the emancipatory role of mathematics (Lewis & Lynn, 2018). For Gutstein (2012), mathematics is a weapon in the struggle of historically underprivileged groups for their progression into STEM careers. Learners from historically oppressed African groups in South Africa often learn mathematics through rote methods. This inhibits their progression into STEM careers. Given the generally misunderstood role of Mathematics in STEM and its power for enhancing equitable society, this research explores how mathematics weaves through the STEM ecology of South African schools.

1.3 Research questions

What are the perceptions and experiences of South African teachers on interdisciplinary STEM education?

How does Mathematics and interdisciplinary STEM discourse leverage each other at schools of specialisation (SoS) in South Africa?

2 Theoretical framework

One of the reasons that interdisciplinary STEM education has come to prominence is the realisation of the limitations of mono-disciplinary approaches (Yu et al., 2023) amongst STEM subjects. Earlier, it was assumed that acquiring distinct competences in these disciplines enabled learners to apply these in problem-solving situations. The inherent hurdles of knowledge transplant and transfer have been raised by situated cognition (SC) learning theory (Lave & Wenger, 1991).

In SC, learning is defined as *participation* in a community of practice. Learning is characterised by actively *participating* in a practice rather than by the *acquisition* of knowledge alone. Learning occurs through the process of legitimate peripheral participation (LPP), where learners start off as apprentices or newcomers, working together with mentors in the practice. Brown et al. (1989) argue that knowledge learnt separately from practice is both incomplete, and inappropriate. Brown et al. (1989) note the obvious but central aspect to this research, namely that one's ownership of a tool does not imply one's capability to use it. Another example these authors provide is the case of someone learning a new language from a dictionary, where in practice, that person's use of that language is likely to be absurd, for example overlooking grammar and collocation, such as in the construction 'Me and my parents correlate'. For Brown et al. (1989), the best way to learn a language is phenomenologically, through immersion; by living with the speakers of the language. Not only is the learning of that language more natural, but one's vocabulary grows exponentially more than from merely consulting a dictionary. This reference clearly illustrates the shortfalls of a de-contextualised and separate knowing of STEM subjects, such as from textbooks, under the assumption that this knowledge can later be appropriated to the solution of authentic problems outside the confines of a school. Burton et al. (2020) as well as Kaiser et al. (2011) argue for authentic learning, where knowledge and application fuse, as in mathematical modelling in learning other STEM subjects. The view that learning as participation is useful in this study as students solve problems that are a key characteristic of STEM education. Hufferd-Ackles, Fuson and Sherin (2004), corroborating SC, argue that reform Mathematics teaching is established through "a community in which individuals assist one another's learning of mathematics by engaging in meaningful mathematical discourse" (p.81). In this community, learners and their teachers are equal participants in knowledge creation.

To Liljedahl (2021), "thinking is what we do when we do not know what to do" (p.4). Liljedahl (2021) researches thinking classroom, versus mimicking behaviour. Thinking classrooms are resonant with Sfard's exploration routines, whereas mimicking behaviour is akin to ritual. The ideas Sfard (2007) presents on mathematics as a routine fit in well with flow theory, as well as with Liljedahl's declarations. To Sfard, Mathematics is seen to involve rituals wherever learners are thoughtlessly parroting what they have been taught. In thinking mathematics, on the other hand, learners experience dilemmas and impasses in trying to solve the problem. Students explore different strategies to solve the problem (Polya, 2004). In this way, learner struggles and efforts are focused on learning and on real growth, rather than on simply pleasing a teacher. Real mathematics learning starts with explorations and ends with ritual, and not vice-versa. In STEM, the aim is to solve an authentic task using multidisciplinary mathematics, scientific technology, and engineering knowledge.

One of the most important ideas for discovery and invention is encapsulated by flow theory (Csikszentmihalyi, 1997). Flow theory explains the level of learner engagement in the tasks they embark upon and concerns motivation and successful engagement in problem-solving. Nakamura and Csikszentmihalyi (2009) explain that:

> Flow research and theory relate to intrinsically motivated people to understand autotelic activity… exemplified by an artist who when the painting is going on well persists single mindedly… disregarding hunger, tiredness, or other discomforts… autotelic activity is rewarding in and of itself (p.195).

In autotelic activity, students undertake an activity out of enjoyment. Once learners engage in thinking mathematics, and it becomes motivating in itself, and it is then that interdisciplinary STEM problem-solving becomes productive. Liljedahl explains that at first, learners are used to mimicking behaviour, and resist thinking. They want the teacher to *tell* them what to do, adopting mimicking behaviour (MB). If the teacher concentrates on initiation in order to elicit thinking (Lobato et al., 2005), students gradually learn to think in increasingly robust ways as they experience productive struggle (Livy et al., 2018).

Situated cognition, mathematical explorations, thinking classrooms, and flow theory affect this research, as they lend insight to learning in interdisciplinary STEM education.

3 Methodology

This study is interpretivist in the sense that it seeks to explore STEM teachers' experiences in interdisciplinary STEM education in South Africa, in which mathematics learning takes place. The qualitative approach used is appropriate because it seeks to obtain information on the phenomenon of STEM education in South Africa. An empirical study to explore the practices of STEM integration with respect to mathematics learning in South African schools is used through case studies of two SoS schools. This provides a snap survey, by means of which to gather a better understanding of the practical role of Mathematics in STEM integration in SoS in South Africa.

The observer influences observations and the observed influence the observer. In subjective research, the aim is to nature comprehension and raise awareness (Denzin et al., 2006). Denzin et al. (2006) explain how qualitative research emphasises the subjective construction of reality, the subjective relationship between the researcher and the researched, and the contexts that not only influence the inquiry, but also the interpretation and analysis of the research. For McMillan and Schumacher (2011), qualitative techniques collect and report data primarily in the form of words, rather than numbers. In this research, the interviews with teachers relate to their subjective perceptions and experiences in STEM teaching and learning situations. The lived experiences of teachers are explored in order to abstract deeper meanings informing the study (Latchman, 2010). The qualitative researchers aim to obtain thick descriptions (Yin, 1992).

3.1 Sampling

Purposive sampling was utilised in order to select participant teachers. This sampling was appropriate, as we sought to generate understanding (Glaser, 1967). The sample were ten high school Mathematics, Science and Technology teachers teaching at South African schools of specialisation (SoS), four of whom were women. Their ages ranged from twenty-five to fifty-one years of age. Their qualifications ranged from Bachelor of Education, Bachelor of Science with Postgraduate Certificate in Education, as well as Master's in Education. All the teachers were specialists in teaching at least one of the STEM subjects.

3.2 Interviews

The interviewers were the authors of this article. This method helped to gather participant teachers' demographic data, their teaching experiences, and practices of STEM education, with particular emphasis placed on the role of mathematics in the given curriculum. Researchers explained to the participants the aims of the research as well as its significance. Participants were encouraged to ask questions where they were unsure. Semi-structured interviews were conducted with participant teachers. Probing and eliciting was undertaken for further explanations on issues of interest in the study. The personal interviews helped participants to be more comfortable with themselves. This helped them to respond more freely based on their experiences and perceptions (Cheng, 2007). This in turn helped to gain more credible data.

3.3 Data analysis methodology

First, the experiences of the SoS teachers on the role of mathematics in STEM education is presented from the two schools. In the data analysis, we refer to the three frameworks in this study of situated learning (Lave & Wenger, 1991), flow theory, as well as the ritual-exploration dyad (Sfard, 2016), together with Liljedahl (2021)'s thinking classrooms versus the mimicking behaviour.

For situated cognition and flow theory we analysed whether the STEM tasks under consideration are situated in a context, whether theoretical or concrete. Is the task meaningful and motivating to the learner? In particular, what role does mathematics plays in STEM and does it help to investigate and solve the STEM problem?

With regards to Sfard (2016) regarding explorations versus ritual, we analysed whether the task of interest through STEM has opportunities of learning mathematics, rather than just mimicking answers without, a meaningful sense of how these were reached.

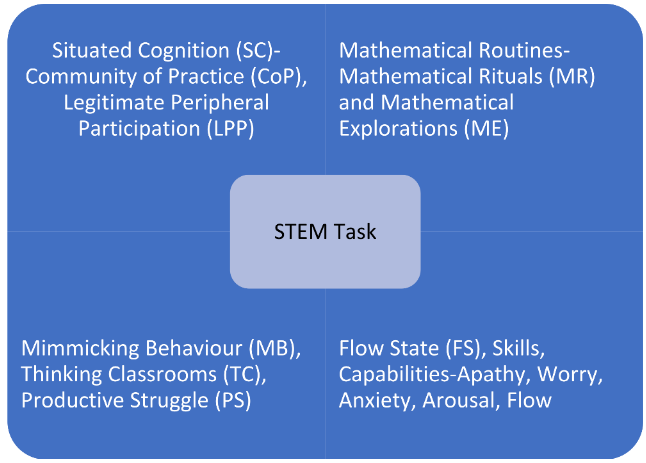


Fig. 1 Data analytical codes for teacher interviews on STEM tasks

Table 1 Codes for analysing interdisciplinary STEM process in teaching and learning

1. Utilisation of technology to enhance mathematics teaching and learning (TTLM)
2. Utilisation of mathematics in teaching and learning technology (MTLT)
3. Utilisation of mathematics in teaching and learning science (MTLS)
4. Utilisation of science in teaching and learning mathematics (STLM)
5. Interdisciplinary mathematics, science, and technology in teaching and learning (ITL)
6. Utilisation of technology to enhance management of the class (TMAN)

In analysing interview data, the codes in Fig. 1, were used prior to discussion.

3.4 Credibility and trustworthiness

The study was conducted both professionally and scrupulously. Data was collected from South African schools running interdisciplinary STEM curricula. Two elements used to consider to establish the study's credibility and trustworthiness are the identification of the unit of analysis, and data saturation. Tran et al. (2017) describe *data saturation* as "data collection and analysis continue to the point when [sic] additional input from new participants no longer changes the researchers' understanding of the concept" (p.75). To these authors, the u*nit of analysis* is "the atomic unit on which the search for themes is conducted" (p.75). In this study, the unit of analysis varies regarding teachers' perceptions and experiences of how mathematics teaching and learning affects and is affected in interdisciplinary STEM education. In data collection, data saturation is achieved by deep probing to elicit participants meanings. Data was analysed both deductively and inductively

(Azungah, 2018). Deductive analysis used predetermined codes from the analytical framework (see Fig. 1). Inductive analysis added analysis saturation by including important codes and themes otherwise not picked up by the analytical framework. Through the constant comparison method, codes and themes in the data began to emerge in order to build grounded theory (Glaser,1967). This helped to address the validity and reliability of the study.

All protocols including institutional ethical clearances and participants' informed consent were secured.

4 Results

4.1 Interview with participant teachers

At the beginning of the interviews, participants were warmly welcomed. They were assured that their professionalism was highly appreciated. We informed them that there would be no wrong or right answers expected, and that we simply wanted to learn from them in order to write an article for an academic journal, which they would be able to access once published.

This analysis is based on participants interview transcripts exploring the two research questions. The specific findings of the two research questions are addressed in the conclusion. Coding is based on participants' responses to the role of mathematics in interdisciplinary STEM education based on their teaching experiences.

The transcripts are cited verbatim, and present a snapshot of the general responses and coding throughout the sample. Chart 1 shows frequencies of the codes (Codes sourced from Subsection 3.3).

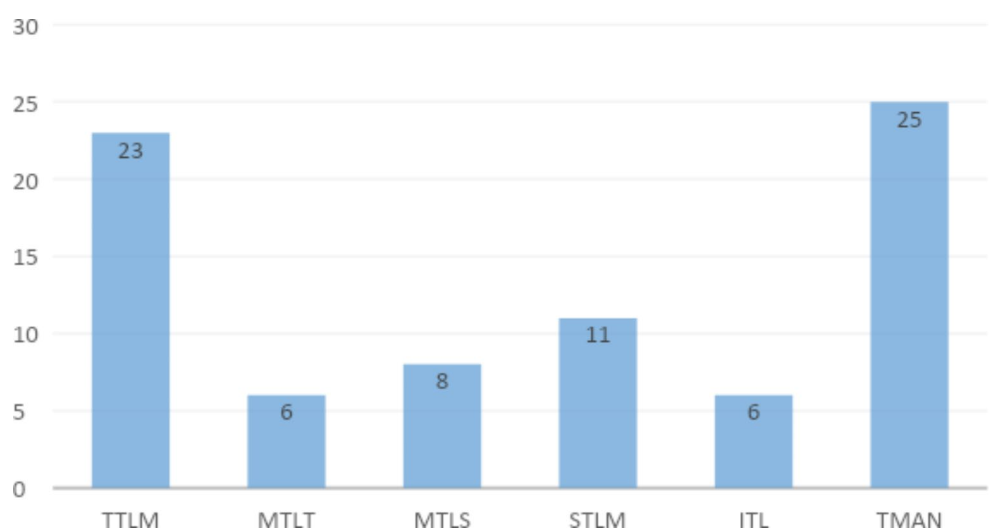
4.1.1 Utilisation of technology to enhance management of the class (TMAN)

Analysis of this data (Chart 1) shows that, to a great extent, STEM teachers use technology for the management of teaching and learning (TMAN) and for organising and controlling the teaching and learning environment, mainly sharing curriculum materials, implementing and assessing the curriculum. This is a generic use of technology not specific to STEM. For example, Mlambo responded "*I have been using ICT in my lessons… we use platforms like Siyavula… one can set assignments for learners and check their progress. It has a self-marking integrated feedback system to the learners and teachers, it's a useful tool in terms of helping you to understand your learners better where they are struggling, and what they are doing… it makes teaching and learning easier and fun… success is in class.*" The use of technology for the management of the learning processes is important as it lends rare insight into students' thought processes and behaviours. In particular, teachers can, at a glance, determine what concepts are easy or difficult for learners, as well as identify their errors and determine their misconceptions. This adds to the growth of teachers' knowledge of students and therein has the potential to transform their teaching practices. Mambo reports that the use of technology tends to grab learners' attention and generally increases success.

4.1.2 Utilisation of technology to enhance mathematics teaching and learning (TTLM)

From the interviews, the second most frequent code that remains related to the first was TTLM. Use of technology enhances thinking classrooms (Liljedahl, 2021), as well as mathematical explorations. In South Africa, this is done through a learning platform called *Siyavula*, dedicated to teaching and learning high school Mathematics and Science.

Chart 1 Bar chart showing codes on interdisciplinary processes on the role of Mathematics in respondents' STEM classes



Technology also offers learners multiple representations of examples, procedures and processes, and is moreover available to use at any hour of the day. Further to this, the capability of video stops and playbacks and other explanations that allow content to be reviewed serve as a form of semiotic mediation in a teachers' absence.

4.1.3 Utilisation of science in teaching and learning mathematics (STLM)

The third most frequent code was STLM. Lambert commented in this regard that "*…because they are aware of what this is and probably, they've been enjoying this topic about speed or bacteria in Life Sciences. Now they are more interested to know about it when it comes to the mathematics part, when they are asked about the rate of growth of that bacteria population."* This shows that science contexts whet the students' appetite for knowledge as they lend important context to mathematical problem-solving. This is what Stein et al. (1996) refer to as 'doing mathematics', in which mathematics learning is embedded in realistic and theoretical contexts with concrete outcomes/consequences.

4.1.4 Use of mathematics in teaching and learning technology (MTLS)

MTLS occurs when, for instance, function and calculus models explain scientific phenomena. Furthermore, the use of statistics and probability help to investigate scientific hypotheses to establish scientific principles, and to make predictions. For this, one may consider how mathematical ideas predicted the exponential spread of Covid-19, which prompted governments to impose lockdowns and other controls pertinement to containment. This clearly demonstrates the role of mathematics in STEM contexts.

4.1.5 Utilisation of mathematics in teaching and learning technology (MTLT)

MTLT was one of the least frequent uses of mathematics, but nonetheless important. Lambert stated that mathematics is used "*…when doing coding and robotics, it has to do with a lot of mathematics with a lot of measurements… if you were to code a robot, if you wanted it to move, you'd have to setup coordinate, you'd have to give it measurement in terms of the displacement vector it could travel… it must have appropriate mathematical parameters, or else it won't do what you want it to do."* As he describes, programming a robot to navigate space requires the knowledge of coordinate geometry and transformations.

4.1.6 Interdisciplinary mathematics, science and technology in teaching and learning (ITL)

One of the least frequent codes was ITL. For example, Mabunda stated, "*Oh yeah, there is also your branch of physics called applied mathematics… all those Newton's laws, projectiles and so on, which is an intersection of physics and mathematics, yeah… imagine a learner who's struggling with regards to the topic motion… and they get taught in Mathematics, they get taught in Physics the same thing you understand. Now they're getting a two… they're getting more information about the same thing in two different subjects… that would help them to get more time on practicing these topics and understanding them."* An important observation is that it is the same teacher who taught both Mathematics and Physics. He helps to make the link for learners to realise that these topics are closely linked and resting on the same ideas, even though they are studied as different subjects. The advantage of the same students being taught Mathematics and Science by the same teacher is rare. While this is optimal for Mathematics and Physics, this circumstance is becoming increasingly rare for Mathematics and Chemistry or Mathematics and Life Sciences. This is not to say there is no mathematics involved in these other subjects. For example, the topic of genetics in Life Sciences lends itself to a richness of mathematical topics such as permutations, combinations, and probability, when it comes to determining the characteristics of the offspring whose parents have certain genes. This raises the issue of co-teaching and the idea of a community of practice in STEM teaching. In this case, two or more specialist teachers work together to teach a common topic to learners from different subject perspectives, where all the subjects are considered equal, and mathematics, for example, is not understood as merely subservient to science.

Another example of ITL was *data handling.* One participant recounted: *"I actually was able to take them into the Technical Department… to find a measuring scale for them so that they can see this in real life… measuring the weight of each and every learner in the class and use the data in a statistics lesson."* This is an example of the interdisciplinary integration of mathematics in learning technology, and using technology to expand mathematical understanding. In this way, teachers and learners were cross-pollinating departmental boundaries in the school in the form of learning visits.

In the interviews, we noticed learners conceiving of and undertaking projects in SoS. For example; Lambert said "... *our students designed a health-scanning machine that won second prize in a world competition. You go in as a person. You don't have to be really a patient, but it really assists if you are a patient; you'd go in there, then it gonna scan your* *body. It's gonna scan all your vitals, everything and then create a report then sent to a certain platform accessible by your doctor and yourself. It's gonna measure high blood, if you have whatever weight that you have, it's gonna measure your height... it's gonna measure your sugar levels. Everything that is in your vitals it's gonna give it...".*

Situated cognition (Lave & Wenger, 1991) is beneficial when learners work in community of inquiry to solve authentic problems – in this case a health problem – in cooperation and collaboration with others. The knowledge applied to assist in solving project problems does not reach learners as isolated fragments of knowledge, but rather, as appropriate capabilities for advancing the solution to a particular problem of interest, or making a useful product. Consequently, mathematical knowledge is no longer absolute, and does not simply exist on the page of a textbook, or simply remain within the head of the teacher, and is instead applied in practice (Brown et al., 1993) of participants.

Notably, Sfard (2016) has argued for the value of project-based learning, viewing exploration to lie at the heart of learning mathematics. To Sfard, learning mathematics is not confirmation of rituals, known facts for the mere purposes of certification, but it extends beyond this. In interdisciplinary STEM education, students initially experience dilemmas, impasse, hopelessness as they engage in working through a project with others in a collaborative endeavour. Classrooms in this way become 'thinking classrooms' (Liljedahl, 2021), where exploration and enquiry become the by-words of the kind of learning that is designed to proactively solve an identified problem and in so doing, expand in the applicability of mathematical knowledge and understanding.

5 Summary and discussions

This research analysed accounts of SOS teachers on interdisciplinary STEM education with special emphasis on the role of mathematics. Several themes emerge from the data regarding participant teachers' perceptions on the role of mathematics in interdisciplinary STEM education. The data proved insightful.

5.1 Findings of the first research question: what are the perceptions and experiences of South African teachers on interdisciplinary STEM education?

This study found that definite efforts to engage learners in STEM education and careers in SoS, but not necessarily in the formal South African education system. There is no explicit official STEM curriculum policy at present, nor guidelines for implementation. Efforts towards STEM integration are at a formative stage, because it is only voluntarily implemented by teachers in a small number of SoS.

Importantly, participants referred to extra curricula projects conceived of by learners in SoS, in which teachers and learners from different STEM disciplines collaborate. These are instances in which the role of mathematics needs to be explored further. Virtually, all participant teachers are convinced of the value of STEM education and the importance of mathematics in its integration.

5.2 Findings of the second research question: how do mathematics and interdisciplinary STEM discourse leverage one another at schools of specialisation (SoS) in South Africa?

Though the role of mathematics was least applied in the learning of science and technology, participant teachers in no way minimised the role of mathematics in learning other STEM subjects. This view departs from the findings of Den Braber et al., 2019) on the NFL curriculum in the Netherlands, who determined that there, participant teachers regarded mathematics as playing only a minor role the curricula.

In the study, technology was highly regarded as a 'game changer' in mathematics teaching and learning, for its ability to rouse learner motivation, provide instant feedback, and enhance classroom management. This observation shows the progress made in understanding the effects of ICT in Mathematics achievement as questioned by English in 2016. The ability of ICT to leverage learner Mathematics achievement has never before been imagined in this way. This casts doubt on the quality of Mathematics education more generally. It is a question as to whether learning is due to low quality mimicking behaviour (MB) noted by Liljedahl (2021). If that is indeed the case, then more research is needed promoting thinking classrooms (TC) (Liljedahl, 2021) supportive of explorations in mathematical modelling. Learning Mathematics with ICT was coupled with learning Physics with ICTs. One participant referred to the use of computer simulations being much better than laboratory work in teaching the topic of circuits. Learners were found to be more responsive, and the emerging scientific patterns were clearer to students when adopting the use of ICTs. Thereafter, learners would undertake laboratory work with strong basic knowledge in order to undertake practical assignments more successfully. It is a question as to whether that is not merely a form of mimicking behaviour (Liljedahl, 2021). Data in this research weakly confirms mathematical concepts and practices contributing to a better understanding of the other STEM disciplines (English, 2016), as MTLS demonstrated one of the lowest frequencies of mention in the responses gathered.

The rate of growth of a bacteria population, kinematics and dynamics, robotics, health scanning machine are examples given by the participants that prototype powerful interdisciplinary approaches, particularly if co-taught by relevant specialist teachers. Learners build mathematical models (Maass et al., 2019) that capture the patterns and prominent features of contextualised problems demonstrating mathematical aspects. In doing so, they create meaningful mathematical knowledge for themselves. The utilisation of mathematical structure, such as exponential functions for growth or decay, as well as elementary analysis become readily accepted by learners in these scenarios because they capture the important features of what they are problematising. In a situation where students are instead taught these subjects in isolation, students rarely make meaningful connections, and mathematics and science are potentially overlooked as being imbricated with one another, therein sterilising learners to the necessary act of problem-solving in real life with the knowledge they gain in the classroom. If learning problems are thoughtfully chosen from local contexts, STEM education moreover becomes inclusive of marginalised learners, such that they can take up their rightful place in STEM-related careers as both conscious and conscientious problem-solvers.

The following are suggestions for the way forward;

- Continued support for teachers' positive view of mathematics' role in interdisciplinary STEM education.
- Increased funding for STEM education and research is needed in South Africa.
- Development and introduction of a STEM, CAPS curriculum in South Africa for primary and high schools is necessary.
- Development of capacity for pre-service and in-service STEM teacher education with emphasis on Mathematics is recommended.

Authors' contribution Judah Makonye contributed to the study conception and design. Material preparation was performed by Judah Makonye, data collection were done by Pam Moodley and Judah Makonye, and analysis was performed by Judah Makonye. The first draft of the manuscript was written by Judah Makonye. All authors read and approved the final manuscript.

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Declarations

Competing interests Both authors, Judah Makonye and Pam Moodley have no relevant financial or non-financial interests to disclose.

Ethics approval All ethical protocols were observed. Permission to collect data and ethics approval to do the research were obtain from all responsible authorities as well as all participants.

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