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Self-organized learning environments (SOLEs) pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM: The South African study

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ABSTRACT

The current study examined self-organized learning environments (SOLEs) pedagogy as a conduit to learners' metacognitive skills and conceptual understanding in physical sciences and science, technology, engineering, and mathematics (STEM) as a whole in Capricorn District of Limpopo Province of South Africa. The aim was based on ongoing debates related to integrating technology and metacognitive skills in STEM education to improve educational outcomes. Anchored upon the aim and through experimental (one urban and one rural) groups and control (one urban and one rural) groups, the study employed a non-equivalent quasi-experimental (control group) design to glean and analyze data from 155 selected participants through a stratified sampling method. Data were collected using physical sciences pre- and post-tests and metacognition self-assessment scale questionnaire. Data analysis employed descriptive (mean [M], standard deviation, and effect size) and inferential (parametric t-test) analysis. The findings indicate that the mean gain score (M=6.37) of the experimental groups (that were taught through SOLEs pedagogy) was higher than that of their counterparts (M=2.60) in the control groups with a p-value (p=0.037) that is less than 0.005.

Similarly, in terms of conceptual understanding, the findings indicate that the experimental groups improved significantly more than the control groups at a significant p-value of 0.00. Finally, the study concludes that SOLEs pedagogy improves learners' metacognitive skills that, in turn, enhance conceptual understanding of physical sciences content. Furthermore, the current study recommends further longitudinal studies with larger sample sizes to explore SOLEs pedagogy in STEM.

Keywords: conceptual understanding, metacognitive skills, technology integration, self-regulated learning, social interaction

INTRODUCTION

Physical sciences is among the school subjects that the South African Government advocates as central for the country's economic growth through its national development plan (NDP) vision 2030 and education departments (basic and higher education departments). The South African Government envisages increasing the number of learners who would pass physical sciences by 50% and above from 350,000 in 2024 to 450,000 in 2030 in order to have more learners qualifying to study science, technology, engineering, and mathematics (STEM) related courses (National Planning Commission, 2011). However, the teaching and learning of each component of STEM, particularly science (often called physical science) (S) themes in South Africa, remains problematic and worrying, as indicated by the national senior certificate (NSC) examination results

(Department of Basic Education [DBE], 2015, 2016, 2017, 2018, 2019, 2020, 2021). The results indicate that only 22.7% of 174,310 (which declined from 192,710 in 2016) managed to obtain the envisaged mark of 50% and above. The poor performance and the decline in learner enrolment are an indication that both the enrolment goal of a minimum of 350,000 learners enrolling for science (physical sciences) in 2024 and the performance goal of all of them passing at 50% and above will not be realized in 2024 as the numbers are generally declining.

Internationally, the trends in international mathematics and science study (TIMSS) conducted in 2019 found that South African learners were outperformed by their counterparts from the other 38 participating nations as they demonstrated a general lack of deep conceptual understanding of the science (physical sciences) contents assessed (Mullis et al., 2020). In essence, learners failed to respond to questions that required them to describe and explain (Human Sciences Research Council, 2020), which showed that they lacked conceptual understanding. Conceptual understanding forms the bases for acquiring STEM-related skills as it forms the foundation of Bloom's taxonomy skills pyramid (Forehand, 2005). The researchers of this study argue that if learners lack conceptual understanding, they may find it difficult to acquire other STEM-related skills such as problem-solving and critical thinking.

In this regard, the TIMSS's (2019) results have profound implications for the teaching of "S" in STEM in South Africa (Mullis et al., 2020). The poor performance in the international evaluations by South African learners indicates that there are flaws in "S" in STEM education in South Africa in that conceptual understanding is not being catered for. Instead, teachers in South Africa continue to employ futile teacher-centered pedagogical strategies, which do not promote learners' conceptual understanding (Geduld, 2019; Kibirige et al., 2014). For instance, Geduld (2019) found that physical sciences teachers in the Eastern Cape Province of South Africa continue to use futile teacher-centered pedagogy despite knowing that it does not assist in developing learners' conceptual understanding. Kibirige et al. (2014) observed the same pattern and found that "S" in STEM teachers in Limpopo Province of South Africa also relied more on teacher-centered pedagogy, which did not improve learners' conceptual understanding. South African learners' conceptual understanding is not wholly catered for in "S" in STEM.

To cater to learners' conceptual understanding development, teachers need to employ innovative learner-centered pedagogies. For example, at the post-secondary school level, technology in a science classroom has proven to yield positive results in fostering deep conceptual understanding and engaging students in critical thinking (Al Zakwani & Walker-Gleaves, 2019). Bleeker (2019) suggests that using technology can be essential in enabling learners to achieve high-quality education and engage them in lifelong learning.

Furthermore, studies have shown that metacognitive skills have positively improved information retention and learner performance in STEM education (Afoan & Corebima, 2018; Rumahlatu & Sangur, 2019). For example, Afoan and Corebima (2018) reported a correlation between metacognitive skills and learning results toward students' information retention in biology learning. Additionally, Rumahlatu and Sangur (2019) indicated that project-based learning strategy can improve metacognitive skills, concept gaining, and information retention of the students at senior high school. However, there are limited pedagogical strategies that can simultaneously integrate technology and metacognitive skills in teaching "S" in STEM in South Africa at the secondary school level to improve conceptual understanding. Hence, the current study investigated whether the employment of SOLEs pedagogy would positively affect learners' metacognitive skills and conceptual understanding of "S" in STEM education in Capricorn District of Limpopo Province of South Africa.

Research Questions

The current study aimed to investigate the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding. In order to achieve this objective, two questions were formulated:

1. How does applying SOLEs pedagogy affect learners' conceptual understanding of the "S" in STEM?
2. How does applying SOLEs pedagogy affect learners' metacognitive skills in the "S" in STEM?

LITERATURE REVIEW

This section in the current study will outline the literature and the gaps in conceptual understanding, metacognitive skills, and self-organized learning environments (SOLEs) pedagogy.

Conceptual Understanding

There is overwhelming evidence of a lack of conceptual understanding of physical sciences concepts in South Africa, which can be attributed to the employment of poor teacher-centered pedagogical strategies (DBE, 2017, 2018, 2019, 2020; HSRC, 2020; Mullis et al., 2020; Surif et al., 2012). For example, DBE (2017, 2018, 2019, 2020) reported that learners who wrote the physical sciences NSC examinations suffered from a lack of conceptual understanding of the subject. In addition, HSRC (2020) reports that South African learners are the least performing in physical sciences compared to their counterparts from other countries as they lack requisite conceptual understanding. This is in line with the 2019 TIMSS report, which indicated that South African learners generally lacked conceptual understanding (Mullis et al., 2020). Surif et al. (2012) outline two different types of understanding, namely, conceptual understanding and procedural understanding. Conceptual understanding in physical sciences can be defined as the knowledge of physical sciences concepts/content, while procedural understanding can be defined as the ability to apply the knowledge of concepts in the problem-solving process (Surif et al., 2012). Conceptual understanding in physical sciences precedes any other form of understanding, including procedural understanding (Nahdi & Jatisunda, 2019). DBE (2017, 2018, 2019, 2020) reported that learners lacked knowledge of physical sciences concepts, which indicates that they lacked conceptual understanding of physical sciences. In essence, if learners lack knowledge of physical sciences concepts, they will not be able to apply them in problem-solving; hence, it is essential to focus on developing learners' conceptual understanding as the foundation of scientific literacy.

In order to develop learners' conceptual understanding in physical sciences classrooms, some factors need to be considered (Phage, 2018). These factors are pedagogical strategies, approaches, cooperative learning, learner-to-learner interaction during the lessons, frequent assessment, technology integration, and timeous feedback. Mitra and Crawley (2014), Phage (2018), and Torrijo et al. (2021) found that learners' conceptual understanding is enhanced when they learn collaboratively and cooperatively rather than when they learn as individuals. Torrijo et al.'s (2021) finding is in line with Hadwin et al.'s (2011) socially shared regulated learning (SSRL) theory and Vygotsky's (1968) social constructivism, which view social interaction as a precondition to effective physical sciences learning. In addition, Jazuli et al. (2017) assert that problem-based learning improves conceptual understanding, mainly if it puts a learner at the center of learning.

The inference is that the teaching of physical sciences should involve giving learners more problems to solve independently with little assistance from the teacher. The assertion is also supported by Al-Mutawah et al. (2019), who found that problem-solving ability and conceptual understanding are interdependent. This further implies that there should be a deliberate effort to simultaneously develop conceptual understanding and problem-solving of "S" in STEM.

Other studies have also found that learners' conceptual understanding in the physical sciences classroom can be improved by employing a pedagogical strategy that integrates technology (Aina, 2013; Ghavifekr & Rosdy, 2015). For example, Ghavifekr and Rosdy (2015) found that integrating technology into physical sciences classrooms improves conceptual understanding because it involves learners in active learning. As a result, it is argued that a pedagogy incorporating collaborative learning, problem-solving, and technology integration will improve learners' conceptual understanding and, consequently, their performance in physical sciences examinations. Similarly, the South African Government recommends technology integration in the teaching of physical sciences and other related subjects. However, teachers fail to integrate technology in teaching "S" in STEM due to a lack of requisite technological skills and limited pedagogical strategies to implement it.

Metacognitive Skills

Studies have found that metacognitive skills improve learners' conceptual understanding (Anthonysamy, 2021; Azizah & Mitarlis, 2019; Bahri & Corebima, 2015; Ozturk, 2020; Panchu et al., 2016). Note that metacognitive skills refer to learners' ability to improve their self-awareness of their thinking and learning abilities and disabilities, which will, in turn, enable them to set goals, monitor their progress, and evaluate whether the set goals have been achieved (Rahimi & Katal, 2012). Anchored upon the definition of metacognitive skills, for example, Azizah and Mitarlis (2019), Bahri and Corebima (2015), and Panchu et al. (2016) found that conceptual understanding and metacognitive skills are positively related. Anthonysamy (2021) also found that learners who lack metacognitive skills are disadvantaged when it comes to conceptual understanding of "S" in STEM. The lack of integration of metacognitive skills in science teaching in secondary school thus results mainly from the limited pedagogical techniques designed for doing this (Ozturk, 2020). As a result, there is a need for pedagogy to assist in teaching metacognitive skills to learners who study physical sciences.

Nevertheless, the anecdotal report suggests that conceptual understanding can be developed by maximizing social interaction among the learners, involving learners in problem-solving activities, integrating technology in the "S" in STEM classrooms, and integrating metacognitive skills in the teaching process. On such basis, it is thus argued that SOLEs pedagogy has the potential to involve learners in all aspects mentioned above.

Self-Organized Learning Environments Pedagogy

Note that the SOLEs pedagogy was first developed and used through Mitra's "hole-on-the-wall" experiments, which found that equipping learners with a technological device connected to the internet and allowing them to learn enhanced their conceptual understanding without involving a teacher (Mitra, 2003). This means that SOLEs pedagogy can improve how school subjects like "S" in STEM are taught and learned. However, secondary school science education studies, in Southern Africa, have paid little attention to pedagogy that can improve the teaching and learning of "S" in STEM; instead they focus on the factors that lead to poor performance. (Al Zakwani & Walker-Gleaves, 2019; Heslup, 2018). For example, after studying the literature based on the SOLEs pedagogy, Heslup (2018) found that of the few studies that have been conducted using SOLEs pedagogy, almost all of them were based on English second language learning. However, the literature consulted by Heslup (2018) underscores the importance of SOLEs pedagogy in minimizing learners' dependence on their teacher and improving their ability to learn beyond the regular classroom. Heslup's (2018) finding is in line with Al Zakwani and Walker-Gleaves (2019), who found that SOLEs pedagogy improved post-secondary school students' learning autonomy and boosted their motivation to learn English. It was further asserted that SOLEs pedagogy is a poorly researched pedagogy (Al Zakwani & Walker-Gleaves, 2019). It can be argued that SOLEs pedagogy provides learner autonomy, and the implementation of SOLEs pedagogy motivates learners to engage in deep learning. For example, Wood (2019) asserts that learners' desire for autonomy is among the factors influencing how they view their teacher and, in turn, their motivation. In addition, Salmi and Thuneberg (2019) report that learner autonomy in the science classroom directly impacts learners' intrinsic motivation and interest in science.

Moreover, several studies that were carried out on SOLEs pedagogy in languages across the learning spectra concur when it comes to the benefits of SOLEs in the learning environment (Mitra & Crawley, 2014; Mitra & Dangwal, 2010). For example, Mitra and Dangwal (2010) found that SOLEs pedagogy can improve the language skills of primary school learners aged between eight to thirteen years. In addition, Mitra and Crawley (2014) found that SOLEs pedagogy can help learners to learn ahead of time and with little or no help from the teacher. Mitra and Crawley (2014) further found that SOLEs pedagogy improves learners' interest in learning, equipping them with skills to become lifelong learners. They further add that working in groups during SOLEs interventions improves learners' conceptual understanding compared to working individually. Hence, this study argues that SOLEs pedagogy can foster the development of metacognitive skills because it stimulates learner interaction, as learners are encouraged to work in groups, and the learning process becomes autonomous. Learners who are encouraged to learn independently acquire the ability to determine their own goals and objectives themselves (Yildiz & Yucedal, 2020).

Anis and Anwar (2020, p. 203) postulate that SOLEs pedagogy can be an appropriate pedagogy for secondary school as it can arguably heighten their "self-confidence, independence, freedom in learning, and responsiveness to the surrounding environment." It would appear that SOLEs pedagogy integrates the emotional dimension of "S" in STEM, which was reported to be among the factors contributing to high failure rates and low enrolment in physical sciences (Chilanda, 2020; Hinton et al., 2012; Konyango et al., 2018; Zenda, 2016). In addition, Mitra et al. (2016) found that SOLEs pedagogy can enable learners to use the internet to acquire skills they were not formally taught in their classrooms. Furthermore, Mitra et al. (2016) argue that SOLEs is a pedagogy that prepares our children for an unimaginable future because SOLEs pedagogy equips learners with 21st century ICT skills simultaneously with subject area content. Thus, SOLEs pedagogy is a transformative pedagogy that can support curricula in their current form and yield better results (Dolan et al., 2013). SOLEs pedagogy further improved the reading ability of primary school learners in the United States of America with minimal or no assistance from the teacher (Vega et al., 2020), in line with Khandan and Shannon (2021), who found that internet-based learning improves learner engagement better than face-to-face and blended face-to-face-online.

One fundamental assumption from Mitra and Dangwal (2017) is that SOLEs pedagogy could be effective across all demographic divides. However, Mitra and Dangwal's (2017) assumption needs to be guided by empirical evidence from classroom practices. Additionally, most studies investigating SOLEs pedagogy do not focus on its effect on metacognitive skills to determine its potential to enhance them (metacognitive skills); and used traditional technological infrastructures like desktops and laptops during the investigation. Thus, there is a need for SOLEs pedagogy to be experimentally trialed in "S" in STEM classrooms before it could be implemented. In addition, there is ICT infrastructure backlog in South African schools (Gillwald et al., 2018). Consequently, the current study used Mobile technology (cellphones), which are easily accessible and do not require sophisticated technological skills, to investigate the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding.

SOLE Pedagogy, Metacognitive Skills, & Conceptual Understanding in "S" in STEM in South Africa

There is overwhelming evidence of ineffective "S" in STEM education in South Africa (DBE, 2019, 2020, 2021; Mullis et al., 2020; Reddy et al., 2014). For instance, the department of education in South African, through their annual diagnostic, reports, repeatedly (over the years) highlighted that learners' poor performance in "S" in STEM is directly linked to their lack of conceptual understanding of the subject (DBE, 2019, 2020, 2021). The trend of exhibiting limited conceptual understanding is also reported by international evaluation bodies like TIMSS where in 2019 South Africa was outperformed by their 38 counterparts (Mullis et al., 2020). In addition, Reddy et al. (2014) found that STEM education in secondary schools of South Africa does not adequately prepare learners for STEM related courses at the university level in terms of conceptual understanding. This clearly demonstrates that learners at secondary school are not taught in a way that encourages deep conceptual understanding.

Studies carried out in South Africa generally recommended either the integration of technology in the teaching of "S" in STEM or the incorporation of metacognitive skills (Azizah & Mitarlis, 2019; Bahri & Corebima, 2015; Havenga, 2015; Kibirige & Tsamago, 2019; Siyaya et al., 2022). For example, Kibirige and Tsamago (2019) found that technology integration can deepen learners' conceptual understanding of "S" in STEM. A study in the Ester Cape Province of South Africa found that learners have poor conceptual understanding of "S" in STEM as a result of limited number of real-life examples in learners' in the teaching of the subject (John et al., 2015). Technology integration provide learners to search for the real-life scenarios linked to the topic they are learning and to simulate some scientific phenomena (Kibirige & Tsamago, 2019). In addition, Azizah and Mitarlis (2019) and Bahri and Corebima (2015) found that conceptual understanding and metacognitive skills are positively related. In addition, A study with South African Computer Science University students found that students' knowledge becomes compartmentalized when metacognitive skills are not nurtured in the classroom (Havenga, 2015). Furthermore, Siyaya et al. (2022) deduced interdependence between metacognitive skills and technology integration. Similarly, Tachie (2019a, 2019b) found that metacognitive skills are useful in enhancing learners' "M", in STEM, process skills and recommended that studies should focus more on finding pedagogies to integrate the teaching of metacognitive skills in STEM education. Untested evidence point out to SOLEs pedagogy as one of the incorporative pedagogical strategies that can be implemented in STEM education to enhance educational outcomes while equipping learners with 4IR skills,

Summary of Literature Review

Table 1 summarizes the literature review of the current study.

Table 1. Summary of the literature review

Theme	Research gap	Source	Research link
Conceptual understanding	Learners fail to understand physical sciences concepts, & teachers lack requisite skills to teach for conceptual understanding.	DBE (2017, 2018, 2019, 2020), Geduld (2019), HSRC (2020), Kibirige and Mavhunga (2014), & Mullis et al. (2020)	It contributes to finding an effective physical sciences pedagogy that enables teaching of conceptual understanding.
Integration of metacognition	Lack of pedagogy to integrate metacognitive skills in teaching of physical sciences. There is little empirical evidence on integrating metacognitive skills at secondary school level, as most studies focus on post-secondary school level.	Geduld (2019)	It contributes to pedagogy that integrates metacognitive skills in teaching physical sciences. It contributes to knowledge of integrating metacognitive skills at secondary school level.
SOLEs	SOLEs, being technology-based learning, can assist in integrating metacognitive skills & technology. Few studies have trialed SOLEs pedagogy at secondary school level.	Al Zakwani and Walker-Gleaves (2019), Heslup (2018), & Mitra and Dangwal (2017)	It experimentally examine effects of SOLEs pedagogy on metacognitive skills & technology integration in physical sciences classrooms at secondary schools.

This section discussed the prevailing situation in "S" in STEM education. It further gave the background in terms of the difficulties learners have in understanding "S" in STEM, as well as the flaws present in the teaching of the subject from the teachers' perspective. Moreover, the factors contributing to poor learner performance in "S" in STEM were pointed out, and a lack of suitable pedagogies to teach "S" in STEM was highlighted.

In this regard, there is a need for a pedagogy that will improve learners' conceptual understanding of "S" in STEM by fostering cooperative and collaborative learning, which will, in turn, encourage independent learning to foster learner autonomy. In addition, a pedagogy that integrates metacognitive skills will improve learners' conceptual understanding across the subject and learning levels. As a result, the researchers of the current study argue that SOLEs pedagogy being the technology-based pedagogy, can be employed to address the challenges teachers face in teaching "S" in STEM, as it complies with all the characteristics of such pedagogy. However, SOLEs pedagogy is poorly researched, hence the current study.

THEORETICAL FRAMEWORK

The current study examined SOLEs pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM. This is against the backdrop that teachers continue to employ futile pedagogical strategies failing to enhance learners' conceptual understanding. As discussed in the literature review section, integrating metacognitive skills and technology are among the strategies that can be used to teach "S" in STEM innovatively. The current study presents SOLEs pedagogy as one of the pedagogies that can integrate technology and metacognitive skills in teaching "S" in STEM content. Although evidence points out that SOLEs pedagogy has the potential to integrate technology and metacognitive skills in the teaching of "S" in STEM, there is no empirical evidence to support that notion. As a result, the current study integrated three theories to explore SOLEs pedagogy in "S" in STEM education.

The three learning theories underpinning the current study are the ones that place the learner at the center of the learning process and postulate that the learning process should be autonomous and collaborative in order to yield desirable outcomes. The theories include constructivism, Flavell's (1979) metacognitive theory, and self-regulated learning (SRL) theory, as **Figure 1** indicates.

The constructivist theory fits well with the current study as it encourages learners to employ metacognitive skills (self-awareness and self-evaluation) (Dagar & Yadav, 2016; Flavell, 1979). Dagar and Yadav (2016) emphasize that teaching "S" in STEM should allow learners to think independently. Independent and autonomous learning derives authority from constructivism, as they all describe effective teaching and learning as a learner-centered process instead of teacher-centered, which is in contrast to the tendencies teachers display as outlined by Al-Mutawah et al. (2019). Furthermore, Al-Mutawah et al. (2019) refer to conceptual understanding as a process in which learners can vigorously construct new knowledge from prior knowledge and experiences. As such, constructivism as a learner-centered pedagogy encourages learners to build on their prior knowledge; hence it is considered relevant for this study.

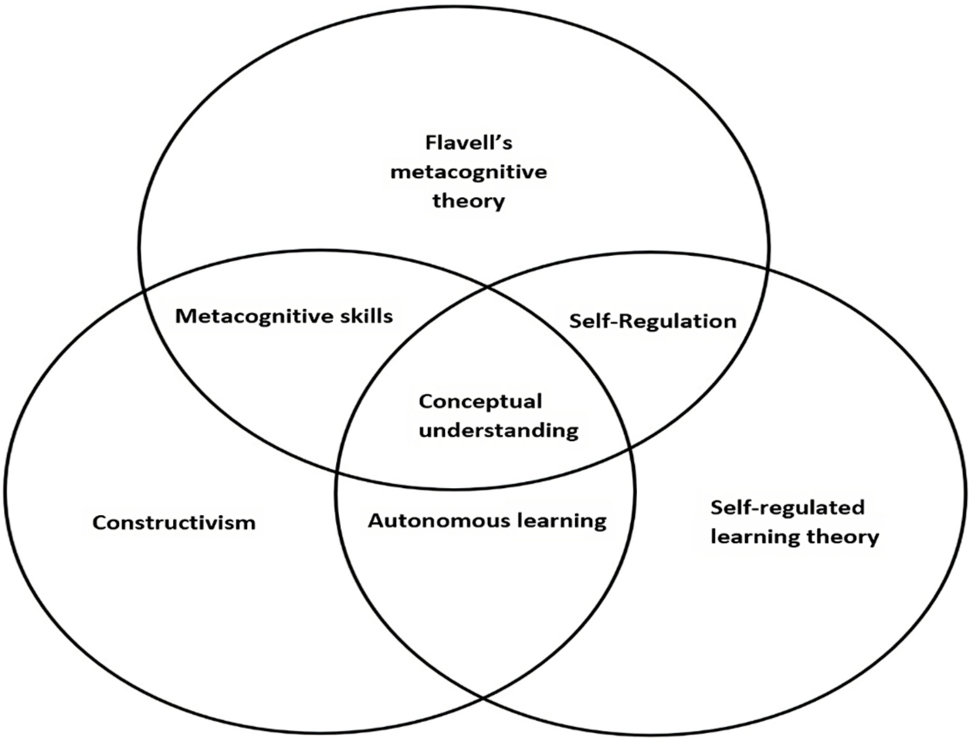

Figure 1. Three theories underpinning the study (Source: Authors' own illustration)

The other theory essential to the current study is Flavell's (1979) metacognitive theory. Flavell (1979) posits that metacognitive skills are the product of the interactions and actions between knowledge, experiences, cognitive goals or tasks, and cognitive strategies or actions. Additionally, Flavell (1979) postulate that metacognitive skills can develop when learners are allowed to learn autonomously and conduct self-reflection. The third theory underpinning the current study is SRL theory. According to Schraw et al. (2006, p. 1063), SRL theory refers to the "ability to understand and control the learning environments". SRL postulates that an effective physical sciences pedagogy should give learners a platform to take control of their learning, which will, in turn, require them to self-regulate. SRL theory outlines steps that can be followed to develop metacognitive skills; hence, it is considered vital for the current study. For example, Hadwin et al.'s (2011) socially shared regulated learning (SSRL) theory outlines technology integration and learner adaptation to collaborative learning as the basis for the development of metacognitive skills and conceptual understanding of "S" in STEM. This study, guided by the three theories, investigated the effects of SOLEs pedagogy, as a technology-enhanced pedagogy, on learners' metacognitive skills and conceptual understanding of "S" in STEM education in Capricorn District of South Africa.

RESEARCH METHODOLOGY

The current study employed a quantitative research methodology as it investigated the causal relationship between SOLEs pedagogy and metacognitive skills, and conceptual understanding. Quantitative research methods were chosen because the current study investigated social constructs (metacognitive skills and conceptual understanding) that can be represented statistically (Rahman, 2017). Again, quantitative research methods were used because the researchers aimed to arrive at an objective conclusion that excludes biases, which is only possible when quantitative methods are employed (Queirós et al., 2017).

Research Design

A non-equivalent quasi-experimental (control group) design was used to investigate SOLEs pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM. A quasi-experimental research design in this study tested the causal relationship between variables (Dutra & Reis, 2016; Rahi, 2017).

In addition, a quasi-experimental research design was used because the groups pre-existed before the intervention, and randomization of participants was impossible (Gravetter & Forzano, 2018). White and Sabarwal (2014) posit that a quasi-experimental design requires that both the experimental and control groups should have pre-treatment characteristics for a fair comparison, a principle that was upheld in this study. This is why pre-tests in both the experimental and control groups were administered. Two experimental groups (EGs) (one from an urban area and one from a rural area) and two control groups (CGs) (one from an urban area and one from a rural area) formed part of the study. Physical sciences test (**Appendix A**) (with content validity index (CVI) of 0.7 and the internal consistency reliability coefficient (Cronbach's alpha value under the study context) of 0.8) was given to both groups as a pre-and post-test to determine the level of conceptual understanding before and after the interventions.

Similarly, a metacognitive self-assessment scale (MSAS) (**Appendix B**) questionnaire (with Cronbach's alpha value of 0.84 under the study context) as a pre-and post-test was administered to both groups to determine the level of metacognitive skills before and after the interventions. MSAS is a self-reporting metacognitive skills measuring questionnaire consisting of four main domains, which are "respect shown to myself", "respect shown to others", "respect shown for empathy towards others", and "respect shown towards problem-solving" (Pedone et al., 2017, p. 191) (**Appendix B**). EGs were taught the topic of forces for four weeks, using SOLEs pedagogy, while the CGs were taught the same topic using the traditional way of teaching physical sciences.

Study Sample and Sampling Method

The study sampled 155 learners from four schools (two schools from urban area and the other two from rural area) in a population of all grade 11 learners enrolled for physical sciences in the Capricorn District in Limpopo Province, South Africa. Learners in this district demonstrated a lack of conceptual understanding of "S" in STEM in the previous NSC examination results (DBE, 2017, 2018, 2019, 2020). The schools were sampled through a multistep stratified sampling method in which two schools were selected from the urban stratum, and the other two were selected from the rural stratum. In addition, the assignment of schools to experimental groups (one rural and one urban) and control groups (one rural and one urban) was random.

Ethical Consideration

The researchers were permitted to conduct research in four Capricorn District schools on 27 February 2019 by the Department of Basic Education. The ethical principles that were closely monitored to ensure that they were not violated during the study period include honesty, integrity, objectivity, openness, carefulness, respect for intellectual property, legality, non-discrimination, competence, and human subject protection (Shamoo & Resnik, 2009). All learners from the participating schools signed an assent form, and their parents signed a consent form to grant the researchers permission to conduct the study. The right to anonymity and the right to either decline to participate in the study or withdraw entirely were communicated to the participants. It is worth-noting that ethical compliance did not affect the validity of the study findings, as the study methods did not require the researchers and the participants to go beyond minimum ethical standards.

SOLEs Pedagogy Intervention

For the current study, the implementation of SOLEs pedagogy was not open-ended in terms of time allocation, as in the case of the original hole-on-the-wall, which did not have time constraints as it was not conducted within a formal learning environment. Instead, the current study adopted the SOLEs pedagogy to the formal mainstream education system and implemented it, as **Figure 2** indicates.

In short, SOLEs pedagogy lessons, as implemented in the current study, start with a teacher issuing instructions (which comprise mainly asking learners challenging questions on the content they have never been taught), followed by allowing them to search for information. Afterward, learners discuss the findings in their respective groups and share them with the whole class. Additionally, the teacher should conclude by consolidating learners' views and relating them to the content they are supposed to learn. A distinctive feature of SOLEs pedagogy is its use of internet to search for information about the topic that was never taught to the learners before. Finally, the current study used a cellphone as a technological gadget for learners to access

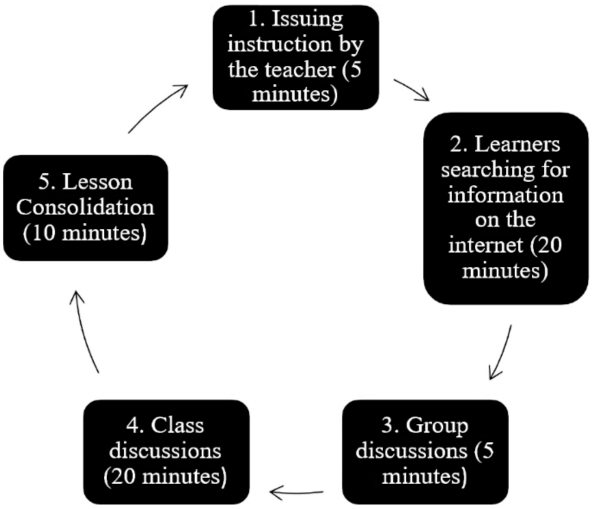

Figure 2. Adapted SOLEs pedagogy for classroom teaching (Source: Authors' own illustration)

the internet as opposed to the original hole-on-wall experiment, which used traditional technological gadgets (desktops).

RESULTS

The current study examined the implementation of (SOLEs) pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM. Learners' lack of conceptual understanding triggered the study as a result of teachers applying teacher-centered pedagogies in teaching "S" in STEM in the South African schools. STEM teachers continue to use traditional methods of teaching "S" in STEM despite the call for them to change their teaching approach by integrating technology and metacognitive skills in the teaching of STEM subjects. Teachers' actions as described above persists due to a lack of experimentally trialed pedagogical strategies to integrate technology and metacognitive skills in STEM education. Evidence points out the fact that SOLEs pedagogy has the potential to assist teachers in integrating technology and metacognitive skills and improve learners' conceptual understanding of STEM subjects. However, SOLEs pedagogy has not been experimentally trialed to establish the veracity of the untested evidence. As a result, this section presents the results of this study, starting with the effect of SOLEs pedagogy on learners' metacognitive skills in "S" in STEM and ending with the effect of SOLEs pedagogy on learners' conceptual understanding of "S" in STEM.

The Effect of SOLEs Pedagogy on Learners' Metacognitive Skills in the "S" in STEM

To evaluate the effect of SOLEs pedagogy on learners' metacognitive skills, the metacognition self-assessment scale (MSAS) questionnaire was used to collect data. MSAS questionnaire was given to all the participants before any teaching was provided (to assess the level of learners' metacognitive skills before the intervention) and after the intervention (to assess if the intervention affected the learners' metacognitive skills level). The learners' responses were analyzed through a t-test to establish whether the metacognitive skills level of the learners in the experimental groups was the same as that of their counterparts in the control groups before the commencement of the interventions for fair comparison. A t-test was used because the data collected were from independent samples and represented a normally distributed population with equal variance and the level of measurement was ordinal or continuous scales, and the sampled groups were independent from one another (Kim, 2015). **Table 2** shows the results of the analysis of the MSAS pre-test of the combined (combined experimental and combined control) groups.

The results of Levene's test indicate that equal variances can be assumed for this data as the significant value (p=0.30) is greater than 0.05. This implies that the t-test values that assume equal variances were considered. Therefore, the results indicated a statistically significant difference between the combined experimental and control groups regarding learners' metacognitive skills, as the significant value for the t-test (p=0.000) is less than 0.05. For these data, it will be statistically flawed to compare the means of the pre-test

Table 2. The t-test results of MSAS pre-test of combined (combined experimental & combined control) groups

		Levene's test for EVs		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% CI of difference	
									Lower	Upper
Gain score	EVs assumed	1.08	0.30	-11.76	153	0.00	-13.2	1.12	-15.47	-11.01
	EVs not assumed			-10.99	50.57	0.00	-13.24	1.20	-15.66	-10.82

Note. CI: Confidence interval & EVs: Equal variances

Table 3. Mean gain scores of the combined groups in terms of learners' metacognitive skills

Group		n	Mean	Standard deviation	Standard error mean
Gain score	Combined experimental groups	119	6.37	8.71	0.80
	Combined control groups	35	2.60	11.21	1.90

Table 4. The t-test of mean gain scores was statistically significant

		Levene's test for EVs		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% CI of difference	
									Lower	Upper
Gain score	EVs assumed	4.36	0.38	2.10	152.00	0.037	3.77	1.79	0.23	7.31
	EVs not assumed			1.83	46.70	0.073	3.77	2.06	-0.37	7.91

Note. CI: Confidence interval & EVs: Equal variances

Table 5. Mean gain scores for the urban groups in terms of learners' metacognitive skills

Group		n	Mean	Standard deviation	Standard error mean
Gain score	Urban experimental groups	69	6.94	9.36	1.13
	Urban control groups	20	-3.55	7.22	1.61

with those of the post-test because any difference may not be associated with the intervention as the groups were different even before the intervention. Hence, the current study compared the mean gain scores between the combined experimental and control groups.

Table 3 indicates the mean gain scores of the combined groups regarding learners' metacognitive skills. The results from **Table 3** show that the combined experimental groups who were taught through SOLEs pedagogy gained more (mean [M]=6.37) than their counterparts in the combined control groups (M=2.60) who were taught through the traditional way of teaching "S" in STEM.

The t-test was conducted to check whether the mean gain scores' difference was statistically significant, as in **Table 4**. **Table 4** regarding Levenes' test results indicate that equal variances can be assumed as the p-value (p=0.38) is greater than the significant value of 0.05. Assuming equal variances means a statistically significant difference between the combined experimental and control groups regarding learners' metacognitive skills, as indicated in **Table 4** (p=0.037). Therefore, it can be concluded that SOLEs pedagogy significantly affects learners' metacognitive skills.

The mean gain scores were also compared in terms of geographical demographics, starting with the urban groups. For example, **Table 5** compares mean gain scores for the urban groups regarding metacognitive skills. **Table 5** indicates that the metacognitive skills of the urban experimental group improved as their mean gain score was positive (M=6.98), while that of their counterparts in the control group declined (M=-3.55).

Table 6 indicates that the difference in their mean gain scores does not happen by chance. **Table 6** indicates that the difference in mean gain scores of learners' metacognitive skills does not happen by chance as it is statistically significant (p=0.000). This implies that the metacognitive skills of learners in the urban experimental group (who were taught through SOLEs pedagogy) improved better than those in the urban control group who did not experience SOLEs pedagogy. As a result, this indicates that SOLEs pedagogy positively affects learners' metacognitive skills.

Table 6. The t-test results for the urban groups in terms of learners' metacognitive skills

		Levene's test for EVs		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% CI of difference Lower	95% CI of difference Upper
Gain score	EVs assumed	1.83	0.179	4.62	87.00	0.000	10.49	2.27	5.98	15.00
	EVs not assumed			5.33	39.39	0.000	10.49	1.97	6.51	14.47

Note. CI: Confidence interval & EVs: Equal variances

Table 7. Mean gain scores for the rural groups in terms of learners' metacognitive skills

	Group	n	Mean	Standard deviation	Standard error mean
Gain score	Rural experimental groups	51	6.18	8.77	1.23
	Rural control groups	15	10.80	10.41	2.69

Table 8. The t-test for gain scores for the rural groups in terms of learners' metacognitive skills

		Levene's test for EVs		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% CI of difference Lower	95% CI of difference Upper
Gain score	EVs assumed	1.28	0.262	-1.72	64.00	0.090	-4.62	2.69	-9.99	0.75
	EVs not assumed			-1.56	20.20	0.133	-4.62	2.96	-10.79	1.54

Note. CI: Confidence interval & EVs: Equal variances

Table 9. Mean performance of the combined groups in the physical sciences pre-test

	Group	n	Mean	Standard deviation	Standard error mean
Pre-test	Combined experimental groups	120	10.83	5.84	0.53
	Combined control groups	35	8.43	3.09	0.52

Table 10. The t-test results for the combined groups' performance in the pre-test

		t-test for equality of means						
		t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% CI of difference Lower	95% CI of difference Upper
Pre-test	EVs assumed	2.34	153.00	0.21	2.40	1.03	0.37	4.44
	EVs not assumed	3.22	108.27	0.002	2.40	0.75	0.93	3.88

Note. CI: Confidence interval & EVs: Equal variances

The positive effect can also be observed in the rural experiment group, as **Table 7** indicates. The mean gain score for the rural experimental group (M=6.18) is comparable with the urban experimental group (M=6.94).

Surprisingly, **Table 6** indicates that the rural control group gained more than their counterparts in the experimental group. However, **Table 8** shows that the difference in the mean gain scores is not statistically significant.

The theory expected the mean gain score for the experimental group to be bigger than the one of the control group (Hadwin et al., 2011). However, the discrepancy warrants further study. Nevertheless, the results of the current study indicate that SOLEs pedagogy positively affects learners' metacognitive skills.

The Effect of SOLEs Pedagogy on Learners' Conceptual Understanding of "S" in STEM

The other research question of the current study stated: How does the application of SOLEs pedagogy affect learners' conceptual understanding of the "S" in STEM? To answer the question, the group performances of the learners in the physical sciences pre-and post-tests were analyzed for the combined experimental and control groups. **Table 9** shows the mean performance of the two groups in the pre-test.

The mean score for the combined experimental group was 10.83, which is bigger than the average score of 8.43 obtained by the combined control group. The combined experimental group pre-test scores were more spread out than the combined control group scores, as the standard deviation (SD) of the combined experimental group (SD=5.84) was greater than that of the combined control group (SD=3.09). To check the groups' comparability before the intervention, a *t*-test was performed on the pre-test results. The results of the *t*-test are shown in **Table 10**.

Table 11. Mean performance of the combined groups in the post-test

	Group	n	Mean	Standard deviation	Standard error mean
Post-test	Combined experimental groups	120	21.17	4.62	0.42
	Combined control groups	35	11.66	4.12	0.70

Table 12. The t-test results for the combined groups' performance in the post-test

		t-test for equality of means						
		t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% CI of difference	
							Lower	Upper
Post-test	EVs assumed	10.97	153.00	0.000	9.51	0.87	7.80	11.22
	EVs not assumed	11.69	61.21	0.000	9.51	0.81	7.88	11.14

Note. CI: Confidence interval & EVs: Equal variances

The p-value measured at a confidence interval difference of 95% is 0.21, which is greater than the significance level of 0.05. As a result, the learners in the combined experimental groups were not significantly different from their counterparts in the combined control groups before they participated in the study in terms of their conceptual understanding of "S" in STEM. Therefore, any differences in conceptual understanding in physical sciences after the interventions could be attributed to the effect of the interventions provided during the study. Therefore, the means for the combined experimental and control groups in the post-test are displayed in **Table 11**.

The mean score of the combined experimental groups is higher than the mean score of the combined control groups. Both groups showed some improvement compared to their pre-test mean scores. The data in the combined experimental groups are more spread out than those in the combined control groups, as the SD of the combined experimental groups is bigger than the SD of the combined control groups. A t-test was performed on the post-test results to determine if there was any statistically significant difference in the mean scores. **Table 12** shows the t-test results obtained.

The p-value for the t-test is less than the significance level of 0.05, which means that the mean for combined experimental groups was greater than the mean for the combined control groups in a statistically significant way. The difference in means can be attributed to the effect of the intervention provided in the experimental groups where the use of SOLEs pedagogy was employed in teaching the physical sciences concept of forces. This is evidenced by the intervention significantly and positively affecting learners' conceptual understanding and metacognitive skills in learning about forces. The effect size can be calculated, as follows:

$$Effect\ Size\ d_{Cohen} = \frac{\bar{x}_2 - \bar{x}_1}{SD_{pooled}} = \frac{21.17 - 11.66}{4.51} = 2.11,$$

where $\bar{x}_2$ is the mean of the combined experimental groups; $\bar{x}_1$ is the mean of the combined control groups; and $SD_{pooled} = \sqrt{\frac{(N_2-1)(SD_2)^2+(N_1-1)(SD_1)^2}{N_2+N_1-2}}$ with Bessel's correction for bias in the estimate of sample variance.

The effect size is 2.11, which is much bigger than the standard minimum acceptable value of 0.8 for a large effect size based on Cohen's benchmarks (Lakens, 2013). The large effect size implies that SOLEs pedagogy significantly affects learners' conceptual understanding of physical sciences concepts.

Summary of the Findings

Pre-test results from the MSAS and physical sciences test were used to establish learners' existing metacognitive skills and levels of conceptual understanding of physical sciences concepts before the intervention. Results for the MSAS (urban: M=63.45, rural: M=60.55, p=0.000) and physical sciences test results (p=0.21) showed that learners across all four groups had low levels of metacognitive skills and conceptual understanding of "S" in STEM concepts prior to the intervention. Thus, past learning experiences have had little influence on their abilities to self-regulate and monitor their thinking processes and behavior in the "S" in STEM. Low achievement scores on the physical sciences pre-test provided evidence of the grade 11 learners' poor conceptual understanding and lack of problem-solving and critical thinking skills across all four groups. Post-test results from the MSAS (urban: M=70.59, rural: M=66.73, p=0.000) and the physical sciences test (p=0.000) were used to address the two research questions in the current study. Post-intervention data from the MSAS revealed that SOLEs pedagogy significantly affected the learners' metacognitive skills. Furthermore, post-intervention data on the physical sciences test showed a statistically significant increase in average performance for learners taught through the SOLEs pedagogy. It may be concluded that SOLEs pedagogy can be the pathway for developing learners' metacognitive skills and conceptual understanding in in "S" in STEM education in Capricorn District of Limpopo of South Africa.

DISCUSSION

Before discussing the results of this study in line with the study objectives, it is worth mentioning that the results of the MSAS pre-test for both the experimental and the control groups revealed that learners possessed low levels of metacognitive skills. Moreover, the finding validates the assertion that there is a gap in integrating metacognitive skills, as outlined in the introduction and literature review sections. The same applies to learners' conceptual understanding, which the finding of this study indicates that it was not adequately addressed as learners performed poorly in the pre-test. Finally, this section discusses the findings of the study per research question.

The Effect of SOLEs Pedagogy on Learners' Metacognitive Skills

These results imply that learners' metacognitive skills have not been trained prior to the interventions implemented in the current study, as the mean score of the experimental group was 63.45, and that of the control group was 60.55. These values imply that the learners' metacognitive skills were low. This finding resonates well with previous studies, which found that learners at the secondary school level lack metacognitive skills because they have not been explicitly taught to them (Ben-David & Orion, 2012; Du Toit & Kotze, 2009; Geduld, 2019). Ben-David and Orion (2012), Du Toit and Kotze (2009), and Geduld (2019) singled out limited pedagogies to integrate the teaching of metacognitive skills in the teaching of subject content as one of the challenges to the teaching of metacognitive skills. In addition, Geduld (2019) found that physical sciences teachers are willing to integrate metacognitive skills in their daily classroom practices, but the predicament is that they lack the pedagogical expertise to do so.

Previous studies have reported that SOLEs pedagogy can improve learners' language skills at the primary and post-secondary school levels, but SOLEs pedagogy was never experimentally trialed with learners studying STEM at the secondary school level (Mitra & Dangwal, 2017). Furthermore, the effect of SOLEs pedagogy on learners' metacognitive skills was poorly known. As such, the current study's findings revealed that SOLEs pedagogy could improve learners' metacognitive skills in physical sciences classrooms because the mean gain score of the combined experimental groups (M=6.37) was greater than those of the participants in the control groups (M=2.60). The t-test revealed that the difference in the mean gain scores is statistically significant, as the p-value=0.037 was less than 0.05. Therefore, it was concluded that using SOLEs pedagogy had a statistically significant effect on the learners' metacognitive skills in the physical sciences classroom. This finding validates SRL theory, which hypothesizes that a pedagogy that maximizes learning autonomy encourages collaborative learning, and integrating technology will go a long way in developing learners' metacognitive skills (Hadwin et al., 2011). The researchers of the current study argue that SOLEs pedagogy improved learners' metacognitive skills because it maximized learning autonomy, involved learners in collaborative learning, and integrated technology through the use of the internet, as Hadwin et al.'s (2011) SRL theory.

Furthermore, the findings revealed that learners' metacognitive skills could be trained simultaneously with teaching the content in physical sciences classrooms through SOLEs pedagogy as the results indicate that when SOLEs were applied, the learners' conceptual understanding improved with their metacognitive skills. The current study's findings resonate well with Kane et al.'s (2014) assertion that every learner can learn and acquire metacognitive skills if relevant pedagogies are employed. Unlike Kane et al. (2014), who failed to provide a clearly defined pedagogy to integrate metacognitive skills, the current study introduces SOLEs pedagogy as one of the strategies that can be employed in "S" in STEM to integrate metacognitive skills in the teaching of subject content. Thus, SOLEs pedagogy yields positive results in developing metacognitive skills as it incorporates technology and collaborative learning. The current study's findings provide empirical evidence that supports the assertion by Cadamuro et al. (2019) that technology integration can be used to enhance learners' metacognitive skills. Cadamuro et al. (2019)'s assertion emerged from their literature study, which pointed out that technology can enhance metacognitive skills. However, Cadamuro et al. (2019) bemoan the lack of a pedagogy that enables learners to use technology to develop their metacognitive skills. The findings revealed that SOLEs pedagogy could be appropriate for developing learners' metacognitive skills through technology. In addition, the technology used in the current study was easily accessible as cellphones (tools to access the internet) were used. As a result, using cell phones as technological devices extends the study by Cadamuro et al. (2019), which used laptops and desktops as technological devices, thus excluding using cell phones to develop metacognitive skills. The findings are significant as they provide a context within which technology can be used to develop learners' metacognitive skills in physical sciences classrooms, which was lacking in the case of the study by Cadamuro et al. (2019). Furthermore, the findings indicate that cell phones can be used in physical sciences classrooms to develop learners' metacognitive skills.

Before this study, there was limited information on the pedagogies that could be used to teach metacognitive skills in physical sciences classrooms at the secondary school level. The lack of suitable pedagogy left most physical sciences teachers (including those interested in teaching metacognitive skills but who lacked the requisite skills) with no option but to ignore the teaching of metacognitive skills, which led to ineffective physical sciences teaching (Geduld, 2019). The untested evidence pointed to SOLEs pedagogy as an appropriate pedagogy for improving learners' metacognitive skills while learning "S" in STEM concepts. The dilemma was that the effect of SOLEs pedagogy on learners' metacognitive skills was poorly known. As a result, the effect of SOLEs pedagogy on metacognitive skills and whether it could be used to teach them (metacognitive skills) at the secondary school level was investigated. The findings play a significant role in addressing the challenge of the lack of a suitable pedagogy for teaching metacognitive skills in "S" in STEM education, which should be mandatory, according to Anthonysamy (2021). A recommendation to make metacognitive teaching skills mandatory arose from the finding that learners who lack metacognitive skills are disadvantaged in acquiring a conceptual understanding of "S" in STEM, leading to poor performance in examinations. The implementation of SOLEs pedagogy can play an essential role in irradiating the lack of integration of metacognitive skills in secondary school STEM education that Ozturk (2020) linked to a lack of pedagogical strategies.

Therefore, in terms of the research question that states: How does the application of SOLEs pedagogy affect learners' metacognitive skills in the "S" in STEM? The current study concludes that SOLEs pedagogy enhances learners' metacognitive skills in the "S" in STEM classrooms.

The Effects of SOLEs Pedagogy on Learners' Conceptual Understanding

Low pass rates in physical sciences have consistently been reported in South Africa (DBE, 2020). The low pass rate is attributed to learners' lack of conceptual understanding. On the other hand, the lack of conceptual understanding was also linked to learners' poor metacognitive skills, which can be attributed to an ineffective teacher-centered pedagogy (John, 2019). As a result, most learners cannot regulate and monitor their choice of strategies in solving physical sciences problems. Furthermore, learners cannot identify and correct their mistakes, instead relying on the teacher to learn physical sciences concepts (John, 2019). The current pedagogical practices by STEM teachers, further aggravated by limited innovative STEM education pedagogy, are among some of the leading causes of learners' behavior described above (Geduld, 2019; Kibirige et al., 2014). Consequently, the current study investigated the effect of SOLEs pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM.

The results show that SOLEs pedagogy improves learners' conceptual understanding of physical sciences content, as the mean of the combined experimental group improved from 10.83 to 21.17. This dwarfs the improvement in the control group, where the mean improved from 8.43 to 11.66, thus showing that the combined experimental group improved by 10.35, which is almost a 100% improvement compared to the combined control group's 38%. The p-value (p=0.000) for the t-test is less than the significance level of 0.05 for the post-test, which means that the SOLEs pedagogy had a statistically significant effect on learners' conceptual understanding. Therefore, this pedagogy can play an essential role in developing learners' conceptual understanding on top of metacognitive skills, as discussed earlier. Thus, the study provides empirical evidence to the constructivist notion that a learner-centered pedagogy that provides learners with an opportunity to interact, think independently, and learn autonomously with little assistance from the teacher can go a long way in improving learners' conceptual understanding (Al-Mutawah et al., 2019; Dagar & Yadav, 2016). In view of the fact above, the implementation of SOLEs pedagogy, which is a learners-centered pedagogy, provides learners with an opportunity to create their knowledge using the internet, with minimal intervention from the teacher.

Furthermore, the results indicate that SOLEs pedagogy can improve metacognitive skills and conceptual understanding. As a result, it can be conjectured that the results of the study validate the constructivist view that the pedagogy that improves metacognitive skills can also enhance conceptual understanding (Dagar & Yadav, 2016). Moreover, SOLEs pedagogy yielded desirable results in terms of the development of conceptual understanding because it bears all the characteristics of ideal pedagogical strategies that foster understanding as prescribed by Phage (2018). Therefore, it can be argued that SOLEs pedagogy instigates cooperative learning, encourages learner-to-learner interaction, and integrates technology in the form of the internet, improving conceptual understanding.

The findings are significant because they extend our knowledge of the effect of SOLEs pedagogy. After all, the study explores the implementation of SOLEs pedagogy as a pathway to developing metacognitive skills and conceptual understanding of "S" in STEM, which was never done before. For example, Mitra's (2003) original "hole-on-the-wall" experiments took place outside the formal classroom environment. These experiments investigated learners' ability to learn language-related concepts without the teacher's assistance, and the SOLEs pedagogy used succeeded in that regard (Mitra, 2003). In addition, a formal classroom study employed SOLEs pedagogy at the primary school level in an English first additional language classroom to investigate the effect of the pedagogy on learners' reading abilities (Vega et al., 2020). Vega et al. found that SOLEs pedagogy improves learners' reading abilities. Before the current study, little information was available about the effect of SOLEs pedagogy on learners' conceptual understanding of the "S" in STEM (Al Zakwani & Walker-Gleaves, 2019). Therefore, in terms of the research question that states: How does the application of SOLEs pedagogy affect learners' conceptual understanding of the "S" in STEM? It can be concluded that SOLEs pedagogy enhances learners' conceptual understanding.

CONCLUSION

The study employed a quasi-experimental design to examine SOLEs pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM. Therefore, SOLEs pedagogy is indeed the conduit to developing learners' metacognitive skills and conceptual understanding.

Delimitations of the Study

This study was conducted with grade 11 learners enrolled for "S" in STEM in Capricorn District of Limpopo Province of South Africa. The results of this study cannot be generalized to learners studying "S" in STEM in other grades, other subjects, other districts of Limpopo Province and other countries. However, the results of the current study are a step in the right direction in an endeavor to find technology-based pedagogy that can simultaneously improve learners' metacognitive skills and conceptual understanding of "S" in STEM.

Study Contributions

The current study makes immense contributions to knowledge, theory, and practice. Regarding knowledge contribution, the study found that SOLEs pedagogy improves learners' metacognitive skills and conceptual understanding, which was previously poorly known. Regarding theoretical contribution, the study found that learners' metacognitive skills and conceptual understanding can simultaneously be developed in a physical sciences classroom through integrating technology and collaborative learning. Lastly, regarding contribution to practice, the current study has proven that SOLEs pedagogy can be employed in the physical sciences classroom at the secondary school level. The study adds to the previous studies, which used SOLEs pedagogy outside the formal classroom situation, where time was not a factor, and at the primary school level, it was used to investigate its effect on language-related constructs. The current study makes an enormous contribution as it also suggests a model (see methodology section under SOLEs pedagogy intervention) that can be used to implement SOLEs pedagogy at the secondary school level.

Recommendations

The current study was triggered by learners' lack of conceptual understanding of physical sciences, displayed during the writing of examinations and tests. The literature links the integration of metacognitive skills to learners' conceptual understanding. The predicament is that limited pedagogies can be used to integrate metacognitive skills in the teaching of physical sciences. As a result, the current study investigated the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding of physical sciences. The findings subsequently indicate that SOLEs pedagogy positively affects learners' metacognitive skills and conceptual understanding.

In addition, the current study's findings have implications for educational practice for all relevant stakeholders in the education sector. Furthermore, the current study's findings significantly contributed to knowledge, theory, pedagogy, and methodology in teaching physical sciences. Although the number of participants who took part in the study was limited and may affect the degree of generalizability, the study forms a strong foundation for other future research that would attempt to find a pedagogy that would improve learners' metacognitive skills in physical sciences classrooms by the integration of technology. Finally, the current study provided recommendations for future studies to investigate why the rural control group improved more than the rural experimental group regarding learners' metacognitive skills. Finally, the current study recommends using SOLEs pedagogy in the classroom and in-service training on implementing SOLEs pedagogy.

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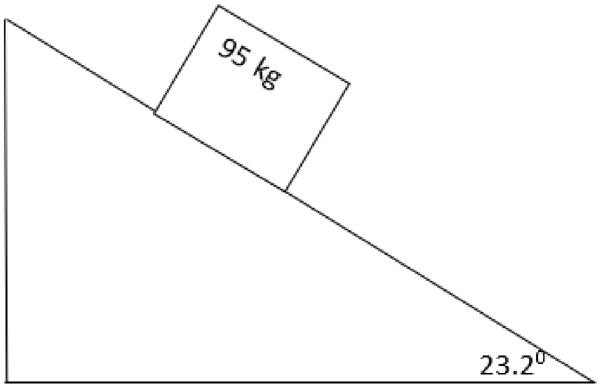
APPENDIX A: PHYSICAL SCIENCES TEST

GRADE 11 **PHYSICAL SCIENCES**

Name of a learner: ……………………………………………………………………………………………

1. A crate of mass 95 kg lies on a frictional surface inclined at 23.2^0. At this angle the crate is just about to move down the incline. Refer to the diagram below.



1.1 Define the term frictional force (2).

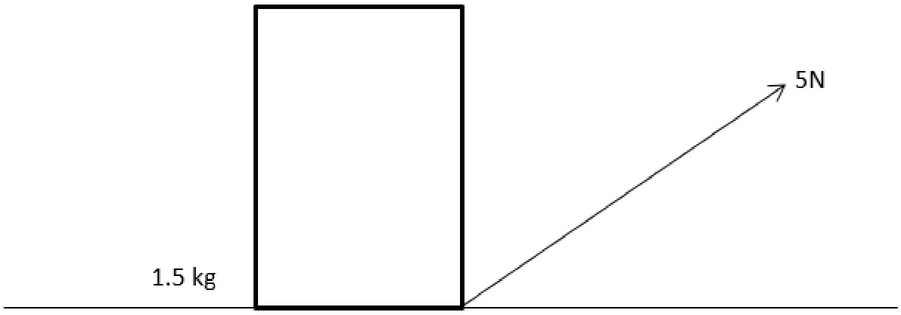
1.2 Sketch a free body diagram showing the force(s) acting on the crate at its current position (3).

1.3 Calculate:

1.3.1. The magnitude of the static frictional force (3).

1.3.2. The coefficient of static friction between the surface and the block (5).

1.4 The surface is now tilted at an angle of 20.0^0. State whether the static friction force will be LESS THAN; EQUAL TO; OR GREAT THAN Question 1.3.1 above AND explain your answer (3).



2. A box of 1,5 kg is pulled at constant velocity across a table by a rope. The rope is at an angle 60^0 and the force applied is 5N as shown in the diagram above. What is the coefficient of kinetic friction between the table and the box? (5).

3. People are able to walk on land, but they are unable to walk on water. Explain using the knowledge of forces (3).

4. During a rainy day motorists are advised to drive cautiously and keep a larger following distance on the road as the roads are slippery. Explain why drivers need to keep a larger following distance during a rainy day than a normal dry day (3).

5. The ball is rolled on a smooth frictionless surface, explain with the use of the correct law of physics what will happen to the ball as it rolls on the surface (3).

APPENDIX B

Table B1. Metacognition self-assessment scale (MSAS) questionnaire

A	Respect to myself, usually …	N	R	S	F	AA
1	I can distinguish and differentiate my own mental abilities (e.g., remembering, imagining, having fantasies, dreaming, desiring, foreseeing and thinking).	1	2	3	4	5
2	I can define, distinguish and name own emotions.	1	2	3	4	5
3	I am aware of what are the thoughts or emotions that lead my actions.	1	2	3	4	5
4	I am aware that what I think about myself is an idea and not necessarily true. I realize that my opinions may not be accurate and may change.	1	2	3	4	5
5	I am aware that what I wish or what I expect may not be realized and that I have a limited power to influence things.	1	2	3	4	5
6	I can clearly perceive & describe my thoughts, emotions and relationships in which I am involved.	1	2	3	4	5
7	I can describe the thread that binds my thoughts and my emotions even when they differ from one moment to the next.	1	2	3	4	5
B	Respect to others, usually …					
1	I can understand and distinguish the different mental activities as when they are, for example, remembering, imagining, having fantasies, dreaming, desiring, deciding, foreseeing and thinking.	1	2	3	4	5
2	I can identify and understand the emotions of people I know.	1	2	3	4	5
3	I can describe the thread that binds thoughts and emotions of people I know, even when they differ from one moment to the next.	1	2	3	4	5
C	Respect to "put yourself in somebody 's shoes", usually …					
1	I'm aware that I am not necessarily at the center of the others' thoughts, feelings and emotions and that others' behaviors arise from reasons and goals that can be independent from my own perspective and from my own involvement in the relationship.	1	2	3	4	5
2	I am aware that others may perceive facts & events in a different way from me & interpret them differently.	1	2	3	4	5
3	I am aware that age and life experience can touch others' thoughts, emotions and behavior.	1	2	3	4	5
D	Respect to solving problems, usually …					
1	I can deal with the problem voluntarily imposing or inhibiting a behavior on myself.	1	2	3	4	5
2	I can deal with the problems voluntarily trying to follow my own mental order.	1	2	3	4	5
3	I can deal with problems trying to challenge or enrich my views & my beliefs on problems themselves.	1	2	3	4	5
4	When problems are related to the relationship with the other people, I try to solve them on the basis of what I believe to be their mental functioning.	1	2	3	4	5
5	I can deal with problems, recognizing & accepting my limitations in managing myself & influencing events.	1	2	3	4	5

Note. N: never; R: rarely; S: Sometimes; F: Frequently; & AA: Almost always