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Investigating the correlation between metacognitive skills and conceptual understanding using self-organised learning environments pedagogy

Hodi Elias Tsamago and Anass Bayaga
Faculty of Education, Nelson Mandela University, Summerstrand, South Africa
anass.bayaga@mandela.ac.za

The relation between learners' metacognitive skills and conceptual understanding is often portrayed as an input-output relation when dealing with science, technology, engineering, and mathematics (STEM) and non-STEM disciplines. However, studies indicate that not all pedagogies yield positive correlations between learners' metacognitive skills and conceptual understanding, particularly in the science (S) strand of STEM. On the other hand, it has been revealed that self-organised learning environments (SOLEs) pedagogy incorporates the characteristics of some of the learning models that were found to induce positive correlations between learners' metacognitive skills and conceptual understanding in other non-STEM disciplines. Due to the lack of established research, particularly around the "S" in STEM, in the study reported on here we investigated the correlation between metacognitive skills and conceptual understanding under SOLEs pedagogy. We employed a quasi-experimental design which included 2 experimental and 2 control groups. Data were collected from 155 participants using the sciences (strand of STEM) performance test and metacognition self-assessment scale (MSAS) questionnaire. Data were statistically analysed using Pearson's product-moment correlation coefficient (*r*), means $(\bar{x})$, and *t*-test. The results indicate a positive correlation between learners' metacognitive skills and conceptual understanding of sciences when SOLEs pedagogy was employed.

Keywords: conceptual understanding; metacognitive skills; sciences; SOLEs pedagogy

Introduction

With the study we aimed to examine the relationship between self-organised learning environments (SOLEs) pedagogy, metacognitive skills and conceptual understanding, hinging on the aims of teaching sciences or physical sciences (a STEM strand). One of the aims of teaching these subjects should be to equip learners with reflective, self-awareness, and problem-solving skills, as well as skills for dealing with the fourth industrial revolution (4IR), in order to make them competitive in the ever-changing global economic environment (Department of Basic Education [DBE], Republic of South Africa [RSA], 2011). Reflective, self-awareness, and problem-solving skills have supposedly been linked to learners' metacognitive skills, implying that the teaching of sciences should incorporate metacognitive skills (Mangwane, 2016). In addition, 4IR skills require the integration of technology in science teaching. However, studies indicate that teachers fail to integrate metacognitive skills and technology into science teaching owing to a lack of requisite skills and traditional technological infrastructure (laptops, desktops) (Geduld, 2019; Thumbarayan, Kamaruzaman & Omar, 2023; Winter, Costello, O'Brien & Hickey, 2021).

Additionally, a discrepancy noted is that teachers do not integrate the teaching of metacognitive skills and technology in the classroom because learners are assessed based only on their conceptual understanding of sciences and not on their metacognitive and 4IR skills (Cele, Bhana & Matli, 2023). Such discrepancy implies a need for technology-based pedagogies that can simultaneously improve learners' metacognitive skills and enhance their conceptual understanding. As is pointed out in the literature, the consequence is that such pedagogies are limited in number, and some have not been experimentally tested against essential metacognitive skills-related constructs. One such pedagogy is the SOLEs pedagogy (Mitra, 2003).

SOLEs pedagogy is a technology-based teaching and learning model that requires learners to work in groups to solve problems using technological gadgets connected to the internet. Globally studies indicate that SOLEs pedagogy can potentially improve the teaching and learning of physical sciences – also in South Africa (Al Zakwani & Walker-Gleaves, 2019; Siswati & Corebima, 2017). This is supported by the fact that, internationally, it has been found to enable learners to master content that they were not formally taught in class; it has also been found to improve their language literacy skills with little intervention from their teachers (Mitra, 2003). From local literature, the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding of sciences as well as other non-language secondary school subjects, remains unknown (Al Zakwani & Walker-Gleaves, 2019). In addition, Siswati and Corebima (2017) found that not all pedagogical strategies correlate positively with metacognitive skills and conceptual understanding, as some tend to enhance metacognitive skills at the expense of the conceptual understanding of physical sciences or vice versa (Siswati & Corebima, 2017). Hence, we investigated the correlation between metacognitive skills and conceptual understanding using SOLEs pedagogy, and whether SOLEs pedagogy can enhance both.

Using various sources, forms of arguments and disciplines, authors draw extensively from both literature and theory to examine the correlation between metacognitive skills and conceptual understanding under SOLEs pedagogy. For instance, as with Chilanda (2020) who examined the teaching methods used in the physics curriculum, Azizah, Nasrudin and Mitarlis's (2019) examined the way in which metacognitive skills serve as a solution in chemistry problem-solving. Owing to the aim of the study, Yunus, Setyosari, Utaya, Kuswandi, Amirullah and Rusdi's (2021) work serves as an anchor to explore the relationship between learners' achievement motivation, metacognitive awareness, attitudes, and problem-solving abilities. Similarly, there was a need to examine how the use of metacognitive strategies for undisrupted online learning influence and prepare university students in the age of the pandemic (Anthonysamy, 2021). Guided by the topic and within the local context, Siswati and Corebima (2017) examined the correlates between metacognitive skills and concept acquisition in biology in several learning models concurrently, in line with Dolan, Leat, Smith, Mitra, Todd and Wall (2013). The latter authors also examined SOLEs in an English classroom as an example of transformative pedagogy. Other studies included the effectiveness of self-organised learning in children (Mitra & Crawley, 2014) and self-organising systems in education (Mitra, Kulkarni & Stanfield, 2016).

From a theoretical perspective, we also drew from the seminal work of Flavell (1979) on metacognition and cognitive monitoring, and Wang, Binning, Del Toro, Qin and Zepeda's (2021) analysis of the role of metacognition and self-control in predicting learner engagement in mathematics learning. Anchored on the seminal work of Mitra et al. (2016), we unpack and establish the correlates of metacognitive skills and conceptual understanding. In conclusion, we explore the aforementioned studies determining the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding of the sciences.

Problem Statement

The teaching and learning of physical sciences should enable learners to apply the knowledge they have gained in the classroom in real-life situations in a variety of contexts (Rillero, 2016). However, this has proven to be a challenge for South African learners as they demonstrate a general lack of deep conceptual understanding of the subject content (Mullis, Martin, Foy, Kelly & Fishbein 2020). Furthermore, South African teachers exhibit a lack of effective pedagogies relevant for the 21st century as they continue to use futile teaching strategies, which do not foster deep conceptual understanding of physical sciences content (Aina & Akanbi, 2013; Geduld, 2019; Kibirige, Rebecca & Mavhunga, 2014; Mbamara & Eya, 2015). Azizah et al. (2019) posit that conceptual understanding can be deepened by employing the technology-based pedagogical strategy that integrates metacognitive skills in the teaching of the subject content. The predicament is that not all technology-based pedagogies can improve learners' metacognitive skills (Al Zakwani & Walker-Gleaves, 2019). Furthermore, Gul and Shehzad (2012) found that not all pedagogies are capable of inducing a positive correlation between metacognitive skills and conceptual understanding. As a result, we argue that SOLEs pedagogy, as one of the technology-based teaching pedagogies, can assist teachers to develop learners' metacognitive skills as it incorporates the characteristics of pedagogies found to enhance metacognitive skills and improve learners' conceptual understanding.

Literature Review

The position taken in this study is based on the fact that in sciences, conceptual understanding, which is the knowledge of science concepts/content (Surif Ibrahim & Mokhtar, 2012), can be deepened by employing a pedagogical strategy that integrates metacognitive skills in the teaching of the subject content (Azizah et al., 2019; Bahri & Corebima, 2015). In essence, metacognitive skills are essential for the 21st century, which requires independent and critical thinkers to survive in the 4IR. As such, improving learners' metacognitive skills will go a long way in assisting learners to address the challenges facing the human race in the current era.

In essence, metacognitive skills refer to learners' ability to improve 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). This means that metacognitive skills include prediction, planning, monitoring and evaluation (Moore, 2004). However, measuring learners' metacognitive skills is a highly contested terrain, with conventional tools such as the metacognitive self-assessment scale (MSAS) questionnaire being used to measure these skills. We also employed the use of MSAS because it covers the four domains of metacognitive skills, namely, "Respect shown to myself"; "Respect shown to others"; "Respect shown for empathy towards others" and "Respect shown towards problem solving" (Pedone, Semerari, Riccardi, Procacci, Nicolò & Carcione, 2017:191–192) (cf. Appendix B). Moreover, we adopted the MSAS questionnaire because it was derived from two already validated instruments, namely, the metacognitive assessment scale (MAS) (Carcione, Dimaggio, Conti, Fiore, Nicolò & Semerari, 2010) and the metacognitive assessment interviews (MAI) (Pellecchia, Moroni, Carcione, Colle, Dimaggio, Nicolò, Pedone, Procacci & Semerari, 2015).

Azizah et al. (2019) indicate that metacognitive skills could assist at secondary school level where learners need to plan, monitor and evaluate their learning to achieve desirable outcomes. This is supported by Mikail, Hazleena, Harun and Normah (2017), who emphasise that motivation and metacognitive skills can boost academic performance. Thus, it would appear that metacognitive skills have a positive impact on academic success (Vrdoljak & Velki, 2012). It could also be argued that learners who lack metacognitive skills are disadvantaged in their conceptual understanding of the sciences (Anthonysamy, 2021). Hence, teachers should apply a pedagogical technique that integrates metacognitive skills in the physical sciences classroom.

However, the literature points to a poor teacher-centred approach caused by teachers' lack of an appropriate learner-centred pedagogy, as one of the factors contributing to poor learner performance in physical sciences (Alami, 2016; Chilanda, 2020; Geduld, 2019; Kapur, 2018; Olufemi, Adediran & Onyediran, 2018; Ozturk, 2020). For instance, in Zambia, it was revealed that teachers' pedagogical skills are limited and therefore, do not address poor performance by science learners (Chilanda, 2020). These findings are in accordance with Alami (2016), who posits that factors contributing to poor performance include poor teaching pedagogies. Additionally, Sari, Sunarmi and Tenzer (2018) assert that a strategy for integrating metacognitive skills that enable learners to plan, monitor, evaluate and be aware of their learning is needed. Therefore, to curb poor learner performance it becomes essential that teachers employ an effective learner-centred pedagogy in the teaching of physical sciences.

Furthermore, Geduld (2019), in the Eastern Cape (South Africa), found that despite teachers in rural secondary schools of the Eastern Cape province believing that metacognitive skills are essential for effective learning, they are doing little to improve them (metacognitive skills), especially in terms of self-regulation, as they lack appropriate pedagogies to enhance them. The lack of the integration of metacognitive skills in the teaching of science in secondary schools is mainly the result of the limited pedagogical techniques designed to do so (Ozturk, 2020). Quigley, Muijs and Stringer (2019) assert that it is easier to discuss the integration of metacognition than to implement this.

In contrast, the integration of metacognition can be easily implemented if relevant pedagogies are employed (Anthonysamy, 2021; Azizah et al., 2019). Pedagogies that can be used to enhance metacognitive skills include (but are not limited to) inquiry-based learning, cooperative learning, and an interactive learning environment (Du Toit & Kotze, 2009; Nunaki, Damopolii, Kandowangko & Nusantari, 2019). However, Munck (2007) found that inquiry-based learning does not necessarily yield positive results, as teachers who implement it exhibit a disconnect between their understandings of inquiry-based learning and their actual practice. In addition, Siswati and Corebima (2017) investigated the pedagogies that positively correlate metacognitive skills and conceptual understanding, finding that not every pedagogy can positively enhance metacognitive skills and conceptual understanding.

On the other hand, a pedagogy called self-regulated learning environments (SOLEs) spontaneously incorporates inquiry-based learning, cooperative learning and an interactive learning environment (Mitra & Crawley, 2014). For example, suppose that one of the aforementioned strategies could effectively enhance metacognitive skills. In that case, it could be argued that a SOLEs pedagogy could be even more effective as it incorporates the characteristics of pedagogies that have been found to enhance metacognitive skills. The reason for this is that a SOLEs pedagogy is designed to support self-directed learning by enabling groups of children to work together by providing them with access to the internet through the provision of technological gadgets and the requisite internet network connectivity (Mitra & Crawley, 2014).

Although this pedagogy has been around for about a decade, it has received very little attention despite having found to have the potential to transform the education sector (Al Zakwani & Walker-Gleaves, 2019; Dolan et al., 2013). This might be the reason why its impact on various variables such as metacognition, attitude, motivation, and interest in various spheres is still unknown. In addition, it is also not known whether the SOLEs pedagogy would induce a positive correlation between learners' metacognitive skills and learners' conceptual understanding. This is because few studies on SOLEs pedagogy have focused primarily on its effect on primary and secondary school learners' performance (Al Zakwani & Walker-Gleaves, 2019; Dolan et al., 2013; Mitra & Crawley, 2014).

Furthermore, the effect of a SOLEs pedagogy has been investigated with primary school learners aged 8 to 13 years, but no study conducted with secondary school learners studying physical sciences in Grade 11 was found (Mitra & Crawley, 2014; Mitra & Dangwal, 2010; Mitra & Quiroga, 2012). In addition, while the effect of SOLEs pedagogy has been investigated using a computer connected to the internet and placed in a hole in the wall (Mitra, 2006), it has never been tested with other technological portable devices that can connect to the internet such as smartphones, laptops and tablets. Again, in science education, studies on metacognition have been mainly conducted at post-secondary school level, with little attention paid to the primary and secondary school levels (Rusyati, Rustaman, Widodo & Ha, 2021). This highlights the need for additional metacognition-related research involving primary and secondary school learners in science education.

Theoretical Framework

This study is based on the two main learning theories, namely constructivism and self-regulated learning (SRL). Constructivism, as a learning theory claims that, during the learning process, learners should be able to construct their own knowledge as well as build a sense of self-awareness of their learning abilities (Dagar & Yadav, 2016; Flavell, 1979). We adopted Vygotsky's (1978) social constructivism in this study, which views interaction among learners as the basis for effective learning of the sciences. Social constructivism also encourages autonomy in the learning process (Salmi & Thuneberg, 2019; Yildiz & Yucedal, 2020). According to Yildiz and Yucedal, learners who are encouraged to learn independently, without being directed by their teacher, acquire an ability to determine their own goals and objectives. In addition, Salmi and Thuneberg (2019) believe that learners who are encouraged to learn physical sciences independently from their teachers are more likely to be intrinsically motivated to learn and develop a positive attitude towards the subject. This kind of motivation should further assist to address the mass exodus of learners from physical sciences owing to learners' negative attitudes as a result of the sustained application of futile teacher-centred pedagogies (Konyango, Ogeta, Otieno & Orodho, 2018). Several studies have reported on the impact of intrinsic motivation on deep learning behaviour, which can lead to improved scientific literacy (Leong, Tan, Lau & Yong, 2018; Tokan & Imakulata, 2019).

Tasgin and Tunc (2018) found that secondary school learners' motivation to learn science-related subjects is directly linked to the level of their participation in their own learning, which implies that for any pedagogical strategy to be successful in equipping learners with scientific literacy, it should allow them to participate in the learning process. Constructivism outlines five principles of effective physical sciences teaching and learning, namely the activation of the learners' schema (engaging learners' existing knowledge); collaboration (learner-to-learner interaction); accommodative pedagogy; contextualised learning; and timely and frequent feedback (Gentile & Pisanu, 2013). Additionally, Rohandi (2017) posits that learners' backgrounds, which are directly linked to their experiences and contexts, are essential in directing the teaching of physical sciences.

Constructivism is in agreement with SRL theories, which also suggest that effective science teaching should encourage learner autonomy and reinforce self-regulation (Schraw, Kauffman & Lehman, 2006). Self-regulation, on the other hand, is linked to two components of metacognitive skills, which are self-efficacy and learner autonomy. Both these components can assist learners to achieve any goals they set for themselves (Palos, Magurean & Petrovici, 2019). Again, self-regulation is also linked to metacognitive awareness, which is positively related to learners' intrinsic motivation and learner performance (Abdelrahman, 2020). Furthermore, this is in agreement with Wang et al. (2021) who assert that metacognition and interest in learning have a mutualistic relationship. In addition, Hadwin, Järvelä and Miller's (2011) socially shared regulated learning (SSRL) asserts that metacognitive skills can be swiftly developed in the science classroom when technology is integrated into the teaching of the subject and learners are encouraged to work in groups. Finally, SSRL theories postulate that collaboration during the learning of physical sciences improves learners' conceptual understanding more than when learners work individually (Mitra & Crawley, 2014).

In addition, technology integration can improve learners' conceptual understanding and motivation to learn, which is also linked to deep SRL (Panagiotidis, Krystalli & Arvanitis, 2023). During the implementation of SOLEs pedagogy, learners can use the internet to acquire skills they have not been formally taught, because it is the pedagogy that can potentially prepare learners for an unimaginable future (Mitra et al., 2016). SOLEs pedagogy is a transformative pedagogy that can support curricula in their current form and yield better results (Dolan et al., 2013). In this study we integrated the two theories to investigate the correlation between learners' metacognitive skills and conceptual understanding using the technology-based SOLEs pedagogy in the physical sciences classroom.

Methodology

In determining the correlation between metacognitive skills and academic performance in science, we employed a positivist approach within the context of SOLEs pedagogy. We emphasise the use of empirical observation and quantifiable data, which align with positivism (Park, Konge & Artino, 2020). The performance tests and MSAS questionnaire to assess participants' metacognitive abilities and science performance were used to collect quantitative data and were statistically analysed to determining the strength of the relation between the constructs. Using the findings, we aim to contribute to the broader understanding of the relation between metacognition and conceptual understanding in science education under the SOLEs framework.

Research Design

We used a non-equivalent quasi-experimental (control group) design to examine how SOLEs pedagogy affected learners' conceptual understanding and metacognitive skills. Four groups were included in the study – two experimental groups (EGs) and two control groups (CGs). However, one of each group was from an urban area while the other was from a rural area. A physical sciences test (cf. Appendix A) was administered to both groups as a pre- and post-test to gauge the degree of conceptual understanding prior to and following the intervention. The test had a content validity index (CVI) of 0.7 and an internal consistency reliability coefficient (Cronbach's alpha value within the context of this study) of 0.8. In addition, the level of metacognitive skills in both groups was assessed before and after the intervention using a metacognitive self-assessment scale (MSAS) questionnaire (cf. Appendix B) of which the Cronbach's alpha value was 0.84 within the study setting. Finally, the EGs studied the topic, "forces", for 4 weeks using SOLEs pedagogy, while the CGs studied the same topic through the conventional method used to teach physical sciences.

Study Sample and Sampling Method

The study population included all Grade 11 physical sciences learners in the Capricorn district of the Limpopo province of South Africa in 2019. The Capricorn district was chosen because, according to the National Senior Certificate (NSC) scores, learners in the district lacked a conceptual grasp of physical sciences (DBE, RSA, 2019). The study sample included 155 learners from four schools chosen using stratified sampling (66 learners from two rural schools and 89 learners from two urban schools. The EGs were from one school in an urban area (69 learners) and one school in a rural area (51 learners). The CGs were from a rural school (15 learners) and an urban school (20 learners).

SOLEs Pedagogy Intervention

In contrast to the initial hole-in-the-wall study, which had no time restrictions because it was not carried out in a formal learning environment, the SOLEs pedagogy implementation for this study was not open-ended with regard to time allocation. Instead, Figure 1 shows how we incorporated and implemented the SOLEs pedagogy in the formal mainstream school system.

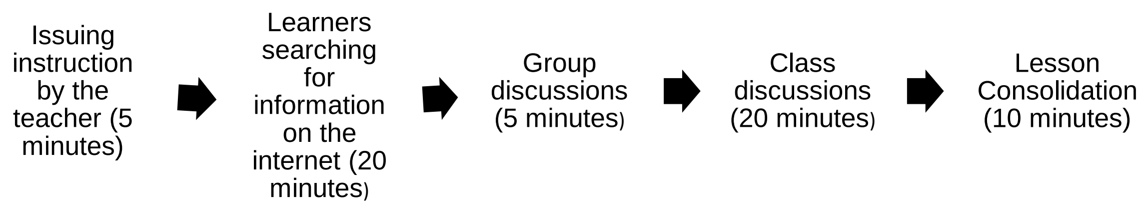

Figure 1 Adapted SOLEs pedagogy for classroom teaching

In essence, SOLEs pedagogy lessons, as used in the study, begin with a teacher giving instructions (which mainly involved asking learners difficult questions about material they have never been taught), followed by allowing them the freedom to conduct research on the topic. Afterwards, the learners present their results to the class and have group discussions about these. Finally, the teacher should draw a connection between the views expressed by the learners and the material they were expected to learn. In contrast to the initial hole-in-the-wall experiment, which used conventional technical devices (laptops and desktops), the study allowed learners to access the internet using cell phones.

Data Analysis

Data were analysed statistically using both descriptive (means, Pearson product-moment correlation coefficient (r)) and inferential (parametric t-test) statistics. The correlation moment (r) was used to answer the question: What is the correlation between learners' metacognitive skills and conceptual understanding of physical sciences under SOLEs pedagogy? The mean differences between the EGs and the CGs for the pre- and post-tests were analysed using a t-test ($p < 0.05$). In this study, means and a t-test were used to answer the question: What is the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding of physical sciences?

Ethical Considerations

The study was approved by the Nelson Mandela University Education Faculty Research, Technology and Innovation Committee of Education (ethics clearance reference number H19-EDU-ERE-04), and complied with all the ethical requirements stipulated by the National Health Act 61 of 2003, specifying the procedures to be followed when a study is conducted with minors (The Presidency, RSA, 2004). The Act requires that children at Grade 11 level assent before their parents can consent (learners and parents signed assent and consent forms respectively). In addition, permission to conduct the study at the schools was sought from the management of the institutions as well as the district official from the Limpopo DBE. In addition, the research design and methodologies were explained to the learners before the start of the research process in accordance with accepted professional research ethics. The research ethics were closely monitored to ensure that they were not violated and included honesty, integrity, objectivity, openness, carefulness, respect for intellectual property, legality, non-discrimination, competence and human subject protection (Shamoo & Resnik, 2015). To lessen the sense that they were being discriminated against throughout the study, the CG learners who were not exposed to the SOLEs pedagogy were introduced to it afterwards.

Furthermore, the right to anonymity and the right to either decline to participate in the study or withdraw entirely were communicated to the participants. All the learners in this study participated voluntarily and were aware that their responses would be used for research purposes. Furthermore, we adhered to the principle of concealment or anonymity by not providing the names of the participants. As a result, any information that would compromise the identity of the participants was not used in the report (Creswell & Creswell, 2022).

Results

With this study we investigated the correlation between learners' metacognitive skills and conceptual understanding under SOLEs pedagogy. The research questions were answered in parts, starting with the first one, which states: What is the effect of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding? This was followed by the second question: What is the correlation between learners' metacognitive skills and conceptual understanding?

The Effect of SOLEs Pedagogy on Learners' Metacognitive Skills in the Physical Science Classroom

In determining the effect of SOLEs pedagogy on learners' metacognitive skills, learners' responses were analysed. The results are displayed in Table 1.

Table 1 Mean gain scores of the combined groups in terms of learners' metacognitive skills

	Group	*N*	*M*	*SD*	*SE* Mean
Gain score	Combined experimental groups	119	6.37	8.71	0.80
	Combined control groups	35	2.60	11.21	1.90

Table 1 indicates that the metacognitive skills of learners in the EG ($\bar{x}$ = 6.37) who were taught using the SOLEs pedagogy instructions improved more than that of their counterparts in the CGs ($\bar{x} = 2.60$) who were taught using the traditional way of teaching the sciences. The *t*-test was conducted to check whether the difference in mean gain scores was statistically significant.

Table 2 The *t*-test of mean gain scores was statistically significant

		Levene's test for equality of variances		*T*-test for equality of means						
									95% CI of the difference	
		f	Sig.	*t*	*df*	Sig. (2-tailed)	Mean difference	*SE* difference	Lower	Upper
Gain score	Equal variances assumed	4.36	0.38	2.10	152.00	0.037	3.77	1.79	0.23	7.31
	Equal variances not assumed			1.83	46.70	0.073	3.77	2.06	-0.37	7.91

As displayed in Table 2, the results of Levene's test indicate that equal variances can be assumed as the significant value (p = 0.38). Assuming equal variances means a statistically significant difference between the experimental and control groups regarding learners' metacognitive skills, as indicated in Table 2 (p = 0.037). Therefore, it may be concluded that SOLEs pedagogy significantly improved learners' metacognitive skills.

The Effect of SOLEs Pedagogy on Learners' Conceptual Understanding in the Physical Sciences Classroom

The pre- and post-test scores were analysed for the experimental and CGs to determine the effect of the SOLEs pedagogy on learners' conceptual understanding of physical sciences. Table 3 indicates the mean performance of the two groups in the pre-test.

Table 3 Mean performance of the combined groups in the physical sciences pre-test

	Group	*N*	*M*	*SD*	*SE* mean
Pre-test	Combined experimental groups	120	10.83	5.84	0.53
	Combined control groups	35	8.43	3.09	0.52

Table 3 indicates that the participants (EGs and CGs) were performing at the same level in terms of the conceptual understanding of physical sciences before the start of the intervention. The results align with the *t*-test results (Table 4), which indicate no statistically significant difference in learners' conceptual understanding between the groups.

Table 4 *T*-test results for the combined groups' performance in the pre-test

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

The *p*-value for the *t*-test is 0.21, which is greater than the significance level of 0.05. As a result, the learners in the EGs were not significantly different from their counterparts in the CGs before the intervention in terms of their conceptual understanding of physical sciences. The means for the EGs and the CGs for the post-test are displayed in Table 5.

Table 5 Mean performance of the combined groups in the post-test

	Group	*N*	*M*	*SD*	*SE* mean
Post-test	Combined experimental groups	120	21.17	4.62	0.42
	Combined control groups	35	11.66	4.12	0.70

The mean performance of the EGs in the post-test ($\bar{x} = 21.17$) was higher than the mean score of the CGs ($\bar{x} = 11.66$). The difference in mean scores is statistically significant, as indicated in Table 6.

Table 6 *T*-test results for the combined groups' performance in the post-test

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

The *p*-value for the t-test is less than the significance level of 0.05, which means that the mean for EGs was more significant than the mean for the CGs in a statistically significant way. The results imply that SOLEs pedagogy improved learners' conceptual understanding of physical sciences.

Correlation between Metacognitive Skills and Conceptual Understanding of Physical Sciences

In this section we answer the question: What is the correlation between learners' metacognitive skills and conceptual understanding of physical sciences? In doing so, Pearson's product-moment correlation coefficient (PPMCC) was used, and Table 7 indicates the correlation moment for the EGs before the intervention.

Table 7 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and cognition in the experimental groups prior to the intervention

		Performance pre-test	MSAS pre-test
Performance pre-test	Pearson correlation	1.000	-0.086
	Sig. (1-tailed)		0.175
	N	120	120
MSAS pre-test	Pearson correlation	-0.086	1.000
	Sig. (1-tailed)	0.175	
	N	120	120

The results in the Table 7 indicate that before the intervention, a very weak negative correlation existed between metacognitive skills and conceptual understanding of physical sciences for EGs, as the correlation moment (r = -0. 086) was approximately -0.1. It is worth stating that the negative correlation was statistically insignificant as the significant value (p = 0.175) was greater than 0.05. Despite the statistical insignificance of the negative correlation between metacognitive skills and conceptual understanding of physical sciences, the results imply that before the intervention, learners with high metacognitive skills demonstrated low conceptual understanding of physical sciences. However, after the intervention, there was a moderate positive correlation (r = 0.09) between metacognitive skills and conceptual understanding of physical sciences in EGs, which was also statistically insignificant because the significant value (p = 0.163) was greater than 0.05, as indicated in Table 8.

Table 8 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and cognition in the combined experimental groups' post intervention

		Performance post-test	MSAS post-test
Performance post-test	Pearson correlation	1.000	0.090
	Sig. (1-tailed)		0.163
	N	120	120
MSAS post-test	Pearson correlation	0.090	1.000
	Sig. (1-tailed)	0.163	
	N	120	120

The same trend of negative correlation prior to the intervention and positive correlation after the intervention applies when the results for the urban EG were analysed (cf. Tables 9 and 10).

Table 9 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and cognition in the urban experimental group prior to the intervention

		Performance pre-test	MSAS pre-test
Performance pre-test	Pearson correlation	1.000	-0.044
	Sig. (1-tailed)		0.359
	N	69	69
MSAS pre-test	Pearson correlation	-0.044	1.000
	Sig. (1-tailed)	0.359	
	N	69	69

Table 10 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and cognition in the urban experimental groups' after the intervention

		Performance post-test	MSAS post-test
Performance post-test	Pearson correlation	1.000	0.133
	Sig. (1-tailed)		0.137
	N	69	69
MSAS post-test	Pearson correlation	0.133	1.000
	Sig. (1-tailed)	0.137	
	N	69	69

Table 9 indicates that the correlation between metacognitive skills and conceptual understanding of physical sciences before the intervention had a weak negative correlation. However, as Table 10 indicates, after the intervention, there was a moderate positive correlation between the two variables because the correlation moment (r = 0.133) was approximately 0.1. For both the pre- and post-intervention, the significant values were greater than 0.05, indicating statistical insignificance in both correlations. The correlation was also analysed separately for rural and urban groups. With the rural EGs, things were slightly different, as the correlation moment improved from r = 0.105 to 0.270, and for the post-test the improvement was statistically significant, as indicated in Tables 11 and 12.

Table 11 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and conceptual understanding in the rural experimental group prior to the intervention

		Performance pre-test	MSAS pre-test
Performance pre-test	Pearson correlation	1.000	0.105
	Sig. (1-tailed)		0.232
	N	51	51
MSAS pre-test	Pearson correlation	0.105	1.000
	Sig. (1-tailed)	0.232	
	N	51	51

Table 12 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and conceptual understanding in the rural experimental group after the intervention

		Performance post-test	MSAS post-test
Performance post-test	Pearson correlation	1.000	0.270
	Sig. (1-tailed)		0.028
	N	51	51
MSAS post-test	Pearson correlation	0.270	1.000
	Sig. (1-tailed)	0.028	
	N	51	51

The results of the correlation moment indicate that the rural learners benefited significantly from instruction that integrated metacognitive skills in the teaching of physical sciences compared to their counterparts who were not exposed to such teaching. However, for the CGs, which did not experience the SOLEs pedagogy, there was a positive correlation prior to the intervention ($r = 0.156$), which changed to a negative correlation after the intervention ($r = -0.062$) as indicated in Tables 13 and 14.

Table 13 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and cognition in the rural control group prior to the intervention

		Performance pre-test	MSAS pre-test
Performance pre-test	Pearson correlation	1.000	0.156
	Sig. (1-tailed)		0.186
	N	35	35
MSAS pre-test	Pearson correlation	0.156	1.000
	Sig. (1-tailed)	0.186	
	N	35	35

Table 14 Pearson's product-moment correlation coefficient for the relationship between metacognitive skills and cognition in the rural control group after the intervention

		Performance post-test	MSAS post-test
Performance post-test	Pearson correlation	1.000	-0.062
	Sig. (1-tailed)		0.362
	N	35	35
MSAS post-test	Pearson correlation	-0.062	1.000
	Sig. (1-tailed)	0.362	
	N	35	35

The results of this study indicate that when learners' metacognitive skills were not enhanced by the use of a SOLEs pedagogy, the development of their conceptual understanding of physical sciences was not supported. However, when a SOLEs pedagogy was employed, metacognitive skills developed together with a conceptual understanding of physical sciences to a medium degree. In addition, we found that the SOLEs pedagogy significantly assisted rural learners' conceptual understanding of physical sciences, and thus, the development of their metacognitive skills compared to their counterparts who were not exposed to the SOLEs pedagogy.

Discussion

In this study we investigated the correlation (if any) between metacognitive skills and the conceptual understanding of physical sciences that can be induced by implementing the SOLEs pedagogy. The main issues that we intended to investigate were the effects of SOLEs pedagogy on learners' metacognitive skills and conceptual understanding of physical sciences, and whether the SOLEs pedagogy would induce a positive correlation between the two constructs. In this section we discuss the findings of this study according to each research question, starting from the first.

The Effects of SOLEs Pedagogy on Learners' Metacognitive Skills and Conceptual Understanding

In this study we found that the SOLEs pedagogy can meaningfully enhance learners' metacognitive skills and conceptual understanding of physical sciences. We suggest that technology integration and metacognitive skills can improve learners' conceptual understanding of physical sciences, and in turn, learner performance in an examination and tests. In essence, this study forms a building block towards integrating technology and metacognitive skills in science education. In addition, SOLEs pedagogy encourages learners to work in manageable groups, which assists them to adapt to collaborative learning (Salmi & Thuneberg, 2019; Tasgin & Tunc, 2018; Yildiz & Yucedal, 2020). Furthermore, it maximises interaction among the learners, which, according to the social constructivist learning theory, forms a basis for effective learning of physical sciences (Dagar & Yadav, 2016; Du Toit & Kotze, 2009; Nunaki et al., 2019), as well as for the swift development of metacognitive skills according to Hadwin et al.'s (2011) SSRL.

Learners taught through the SOLEs pedagogy are afforded a chance to learn independently, which induces deep learning and better conceptual understanding (Yildiz & Yucedal, 2020). Affording learners the opportunity to learn independently allows them to set their own learning goals without being instructed by their teacher, and work autonomously towards achieving them. In addition, this study aligns with the assertion by Tasgin and Tunc (2018) that, allowing secondary school physical sciences learners to play a leading role in their learning motivates them to learn. SOLEs pedagogy, in this study, allowed learners to play a leading role in their learning, improving their motivation to learn and reaching the learning outcomes. SOLEs pedagogy also minimises learners' reliance on their teachers, as learners are expected to solve problems with little assistance from their teachers, using the internet as their primary source of information. The findings confirm that learner autonomy is imperative for effective and deep physical sciences learning (Al Zakwani & Walker-Gleaves, 2019; Salmi & Thuneberg, 2019; Schraw et al., 2006; Wood, 2019). Amir, Mohamed and Mnjokava (2016), Heslup (2018), Salmi and Thuneberg (2019), Wang et al. (2021) and Wood (2019) found that learner autonomy has the potential to improve metacognitive skills and learning outcomes because it improves learners' attitudes towards physical sciences learning which was found to be among the factors contributing to poor performance in the subject. That is because learner autonomy in the science classroom has a direct positive impact on learners' intrinsic motivation and interest in science (Salmi & Thuneberg, 2019).

Furthermore, secondary school learners' motivation to learn physical sciences is positively related to their level of participation in their learning (Tasgin & Tunc, 2018). Additionally, motivation is positively linked to deep learning (Leong et al., 2018; Tokan & Imakulata, 2019). We argue that SOLEs pedagogy maximises learners' participation in their learning process, which, in turn, maximises their motivation to learn and achieve the learning outcomes.

In addition, an autonomous learning environment, as applied in the SOLEs pedagogy, encourages independent learning, accelerating learners' ability to determine their own goals and objectives without being instructed by their teachers (Yildiz & Yucedal, 2020). Learner autonomy is further enhanced by the fact that SOLEs pedagogy integrates technology which spontaneously fosters autonomous problem-solving, as each learner or group of learners need to operate the technological gadgets without significant interference from their teachers (Mitra & Crawley, 2014). Furthermore, the study clarifies the positive interplay between metacognitive skills and problem-based pedagogies, as Yunus et al. (2021) deduced. One of the functional ingredients of the SOLEs pedagogy is that it incorporates problem-solving into the science classroom. This is in agreement with other studies in which it was found that metacognitive skills can be developed in the classroom if relevant pedagogies are employed (Anthonysamy, 2021; Azizah et al., 2019; Mikail et al., 2017). Hence, we argue that SOLEs pedagogy is one of the pedagogies that can be implemented to enhance metacognitive skills and conceptual understanding of physical sciences simultaneously.

The Type of Correlation that SOLEs Pedagogy can Induce between Metacognitive Skills and Conceptual Understanding

In terms of the type of correlation, we found that the teaching where SOLEs pedagogy was not employed resulted in a negative moderate correlation between metacognitive skills and conceptual understanding of physical sciences. However, teaching in which SOLEs pedagogy was employed, resulted in a positive correlation. This study thus adds the SOLEs pedagogy to the inventory of pedagogical strategies that can induce a positive correlation between metacognitive skills and conceptual understanding. Abdelrahman (2020) and Anthonysamy (2021) found that learners who lack metacognitive skills are the ones disadvantaged when it comes to a conceptual understanding of physical sciences. As such, this study adds to these findings by indicating that learners with higher-level metacognitive skills can be advantaged only when there is a deliberate attempt to enhance such skills in the physical sciences classes. This study also broadens our understanding of the SOLEs pedagogy, which is bemoaned by Al Zakwani and Walker-Gleaves (2019) as being under-researched. In conclusion, we found that, although Palos et al. (2019) are of a view that metacognitive skills can assist learners in achieving any goals they set for themselves, they (metacognitive skills) need to be enhanced in physical sciences classes through pedagogical strategies like SOLEs, which integrates technology, problem-solving and collaborative learning, or else metacognitive skills will have a negative impact on the learning outcomes.

The study induced a positive correlation between metacognitive skills and conceptual understanding, as it embeds the functional features of the pedagogies that Siswati and Corebima (2017) found to induce a positive correlation. Technology integration, collaborative learning, problem-based learning, maximisation of learner autonomy and SRL are identified. The SOLEs pedagogy accommodates learners' prior knowledge, encourages learner-to-learner interaction, enables the learning process to take place at the learner's pace, and enables learners to link their classroom experience to the out-of-classroom environment through the use of the internet. It also enables teachers to provide learners with timely, frequent feedback. According to Gentile and Pisanu (2013), in order to develop both metacognitive skills and conceptual understanding, all these aspects are necessary.

Conclusion

In this study we investigated the correlation between learners' metacognitive skills and conceptual understanding in the sciences (STEM) using the SOLEs pedagogy. We found that the SOLEs pedagogy can induce a positive correlation between metacognitive skills and conceptual understanding in the sciences. These findings add the SOLEs pedagogy to the list of instructional strategies that can simultaneously improve learners' metacognitive skills and conceptual understanding of the sciences.

Recommendations

We recommend that science teachers incorporate the use of SOLEs pedagogy during their teaching as it allows learners to develop the 4IR skills that are needed in the 21st century, while also developing their metacognitive skills and conceptual understanding. In addition, we recommend further research involving other strands of STEM in order to determine whether SOLEs will induce a positive correlation between metacognitive skills and conceptual understanding in those subjects.

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Authors' Contributions

HET conducted the interviews, collected the data and interviews, and conducted all statistical analyses. AB was the supervisor and ensured correctness of the technical details.

Notes

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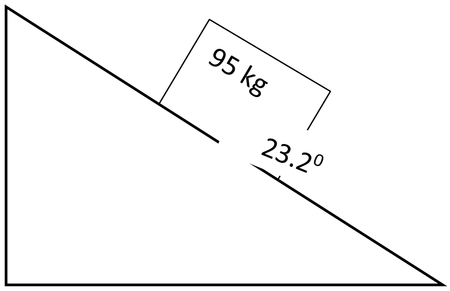
Appendix A: Physical Sciences Test
GRADE 11 **PHYSICAL SCIENCES**
Name of a learner……………………………………………………………………………………………

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)

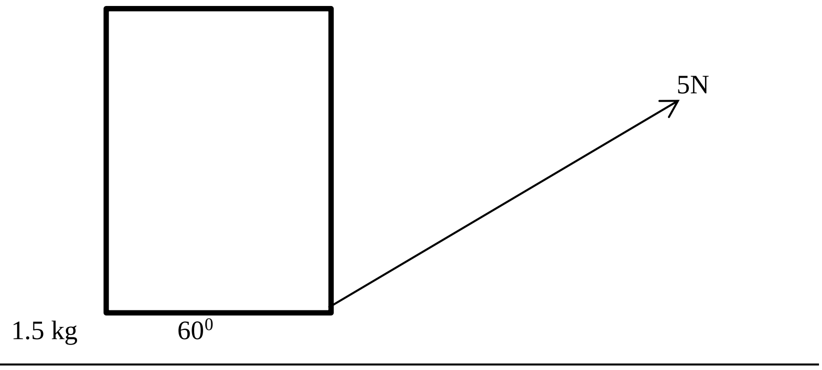
1.2 Sketch a free body diagram showing the force(s) acting on the crate at its current position. (3)

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 GREATER 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: Metacognition Self-assessment Scale (MSAS) Questionnaire

A	RESPECT TO MYSELF, USUALLY…	Never	Rarely	Sometimes	Frequently	Almost always
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 realised and that I have a limited power to influence things.	1	2	3	4	5
6	I can clearly perceive and 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 centre of the others' thoughts, feelings and emotions and that others' behaviours 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 and events in a different way from me and interpret them differently.	1	2	3	4	5
3	I am aware that age and life experience can touch others' thoughts, emotions and behaviour.	1	2	3	4	5
D	RESPECT TO SOLVING PROBLEMS, USUALLY…					
1	I can deal with the problem voluntarily imposing or inhibiting a behaviour 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 the problems trying to challenge or enrich my views and 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 the problems, recognizing and accepting my limitations in managing myself and influencing events.	1	2	3	4	5