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Review article

The effect of self-organized learning environments (SOLEs) pedagogy on the different aspects of learners' metacognitive skills in the Physical Sciences classroom

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ABSTRACT

The development of metacognitive skills should be holistic, which implies that it should focus on different (metacognitive skills) aspects. However, the literature indicates that metacognitive skills are often investigated in general terms with little focus on their aspects. In response to the established findings this far, the current study aimed to examine the effect of Self-organized learning environments (SOLEs) pedagogy on the different aspects of learners' metacognitive skills in Physical Sciences classrooms. The study employed the quasi-experimental design in which four (two urban and two rural) groups (155 participants) were involved. Data were gleaned using a metacognition-self assessment scale (MSAS) questionnaire and analysed using descriptive (means and effect size) and inferential (*t*-test) statistics. The results indicate that SOLEs pedagogy improved all aspects of metacognitive skills, but empathy towards others improved more than other aspects such as Respect shown to me, Respect shown to others, and Respect shown towards problem-solving. The current study concludes that SOLEs pedagogy can holistically develop metacognitive skills as it improves all aspects of metacognitive skills. In addition, SOLEs pedagogy makes learners empathetic toward each other during the learning process, which results in a conducive learning environment.

1. Introduction

South African learners continue to perform poorly in Physical Sciences, as depicted by the National Senior Certificate (NSC) and Trends in International Mathematics and Science Study (TIMSS) [1–6]. DBE reports that most learners fail to obtain a mark of 50 % and above in Physical Sciences, which is in line with [6], who report that South African learner are the lowest performing in the international Physical Sciences assessment. The challenge of poor performance in Physical Sciences is not solely a South African problem but the global one. This far, what is drawn from studies by Flavell [1–6] is that poor performance is due to the application of futile teacher-centered pedagogies, which do not harness learners' conceptual understanding, as noted by other studies [7–9]. For instance some authors [7,8] observed that teachers used teacher-centered pedagogies to teach Physical Sciences because they lack innovative learner-centered pedagogies. Furthermore [9] blamed learners' underperformance and their lack of motivation and interest in learning Physical Sciences on the application of poor teacher-centered pedagogy. On the other hand, other studies indicate that conceptual understanding can be enhanced when metacognitive skills are developed through innovative learner-centered pedagogy [10–14]. For

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example [10] found that learners who are trained to apply metacognitive skills (self-planning; self-monitoring and self-evaluation) in the learning of Physical Sciences have a higher prevalence of achieving their learning goals than their counterparts who are not trained to apply metacognitive skills. The term "metacognitive skills" emanates from the term "Metacognition," which is the term that was first coined by Flavell [15] to describe the understanding and regulation of one's own cognitive processes, the fields of cognitive psychology and education have been inundated with a multitude of definitions and distinguishing components. Despite its widespread use, the concept of metacognition lacks a unified framework, having been defined in various ways and further broken down into numerous subcomponents. For example [16] subdivided metacognition into two main aspects: metacognitive knowledge, which involves awareness, and metacognitive monitoring and self-regulation, often referred to as metacognitive skills. Metacognitive knowledge pertains to having declarative awareness of how personal attributes, task intricacies, and available strategies interact within a learning context. On the other hand, metacognitive skills encompass the procedural knowledge necessary for effectively managing and directing one's learning activities. These skills encompass task orientation, planning, monitoring, checking, recapitulation, and reflection, and can be acquired and eventually executed implicitly. Alternatively, researchers may employ different terms to represent the same metacognitive skills.

Over the years, the concept of metacognition, introduced by [15], has generated a multitude of definitions. However, the definition that resonates with this study is Flavell's [15] characterization of metacognition as "thinking about thinking." This signifies that learners possess the ability to reflect on their own cognitive processes when addressing problems. Furthermore, a range of other metacognitive terms has arisen under this umbrella, including metacognitive beliefs, metacognitive awareness, metacognitive experiences, metacognitive knowledge, and metacognitive skills, among others [17]. This study primarily focuses on metacognitive skills due to their demonstrated capacity to empower learners to plan, monitor, and evaluate their learning progress [18]. Essentially, metacognitive skills enable learners to enhance their self-awareness of their cognitive strengths and weaknesses. This, in turn, empowers them to set goals, monitor their progress, and assess whether these goals have been achieved [19]. Research [20] suggests that metacognitive skills inherently incorporate a feedback mechanism, allowing learners to pre-plan their actions to facilitate smooth task progression. Without this pre-planning, actions may prove futile. During the planning phase, learners must establish connections between newly acquired knowledge and existing knowledge. Developing these links necessitates the acquisition of metacognitive skills to effectively self-monitor their learning progress. This, in turn, enables learners to identify and rectify initial errors. During discussions, learners engage in self-assessment to gauge their comprehension and learning achievements. If initial approaches prove unsuccessful, learners employ alternative strategies, constituting a fundamental aspect of self-evaluation.

Studies [11,12] deduced a mutualistic relationship between metacognitive skills and conceptual understanding. There is overwhelming evidence on the positive relationship between metacognitive skills and conceptual understanding [10–12,14]. The relationship is that, if metacognitive skills are enhanced, conceptual understanding is improved [12].

Regrettably, metacognitive skills are not enhanced in the Physical Sciences classroom due to the lack of a suitable pedagogy [7]. For example [21] recommends that no child should be left behind in terms of technology integration in the learning of Physical Sciences, thus STEM, including learners with special educational needs (LSENS). Additionally [22] found that technology-based pedagogies such as Self-organized learning environments (SOLEs) have the potential to improve the learning outcomes as they optimize learner autonomy and motivation to learn. SOLEs pedagogy is an inquiry-based techno-political model that provides learners with an opportunity to self-organize and learn over the Internet with minimal intervention from the teacher [23]. Physical Sciences is an inquiry-based subject that is learned effectively when learner autonomy and discussions involving learner argumentation are prioritized [24]. Arguably, (SOLEs) pedagogy can improve learners' perception of Physical Sciences learning and their performance as it is technology based.

Therefore, the researchers of the current study argue that SOLEs pedagogy, as a technology-based learner-centered pedagogy, has the potential to incorporate metacognitive skills in the teaching of Physical Sciences.

While different effects of SOLEs pedagogy on the different aspects of learners' metacognitive skills in the Physical Sciences classroom are on the rise, keenly, metacognitive skills in the Physical Sciences classroom combined with SOLEs pedagogy are gradually receiving prominent attention for various reasons. For instance, metacognitive skills can only develop if explicitly taught in a Physical Sciences classroom. The predicament is that, although teachers are aware that metacognitive skills are essential in the teaching of Physical Sciences for conceptual understanding, they are failing to do it because they lack the requisite skills to do so. Furthermore [13] pointed out that the lack of integration of metacognitive skills in the teaching of Physical Sciences may be due to limited pedagogical strategies available to integrate metacognitive skills in the teaching of Physical Sciences. The lack of metacognitive skills integration denies learners an opportunity to develop empathy towards others, the Respect shown to myself and others, which is essential for a conducive learning environment; and Respect shown for problem-solving, which plays an essential role in the cognition process [25, 26]. The effect of SOLEs pedagogy on these aspects of metacognitive skills, which are essential for learning Physical Sciences, is poorly known, hence, the current study.

On the other hand, the socially shared regulated learning (SSRL) theory indicates that metacognitive skills can improve when there is technology integration in the classroom, where learners are encouraged to work collaboratively and autonomously to solve their problems [27]. It implies that the pedagogy that can enable technology integration while allowing learners to work in their groups independently with little assistance from their teacher will go a long way in improving their metacognitive skills and conceptual understanding of Physical Sciences. While evidence points to the fact that SOLEs pedagogy as a technology-based pedagogy can assist in developing metacognitive skills as it provides learners with an opportunity to work in groups when solving problems independently from their teacher, little to no research thus far establishes that conjecture. Thus, unfortunately, even though SOLEs pedagogy has been there for over a decade, there has never been a study that investigated its effect on metacognitive skills.

In conclusion, metacognitive skills are essential for conceptual understanding of Physical Sciences [10–14]. However, literature indicates that Physical Sciences teachers do not explicitly incorporate them in the Physical Sciences classroom due to a lack of a suitable pedagogy. Therefore, a pedagogy implemented to integrate metacognitive skills in the teaching of Physical Sciences must develop them holistically. The implication is that the pedagogy must be able to develop all aspects (empathy towards others, Respect shown to me, Respect shown to others, and Respect shown for problem-solving) of metacognitive skills, as they are all critical in the learning process. Untested evidence points out that SOLEs pedagogy can holistically develop metacognitive skills while developing all aspects of learners' metacognitive skills; hence the current study examined the effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in the Physical Sciences classroom.

2. Literature review

The literature review will discuss metacognitive skills and SOLEs as pedagogical strategies to teach Physical Sciences.

2.1. Metacognitive skills in the Physical Sciences classroom

The metacognitive skills are paramount for learners' academic achievement and problem-solving abilities [18]. Metacognitive skills can be defined as the skills that enable one to control one's thoughts and actions to effectively perform a specific learning task [28]. While we know that they (metacognitive skills) encompass understanding the information, resources, skills, and techniques needed to accomplish the task effectively, they also involve the mental and emotional interactions related to cognitive performance [29]. Generally, four aspects of metacognitive skills are essential in the effective learning of Physical Sciences. The four aspects are self-awareness and reflection (Respect for myself), social interaction (Respect shown to others); cooperation with peers (Respect shown for empathy toward others); and problem-solving (Respect shown towards problem-solving). Self-awareness and reflection refer to the learners' ability to think about what strategies worked well during learning and make necessary adjustments to new strategies based on their experiences [30]. The implication is that a learner who is aware of his/her learning abilities and challenges can always choose a study method that will suit his/her abilities and compensate for his/her challenges [19].

Furthermore, self-awareness and reflection enable the learner to self-correct the mistakes committed during the learning process, which prepares him/her for future learning [31]. On the other hand, social interaction is implied to be a social interaction that gives learners chances to become aware of their metacognitive methods and decisions during problem-solving, as well as those of their fellow learners [32]. In addition, cooperation with others aspect of metacognitive skills involves the learners' ability to question the problems and their solution processes, analyze their mistakes, and planning skills [33].

Regardless of the four mentioned aspects [33], found that learners with high metacognitive skills tend to solve problems correctly using appropriate strategies, mathematical notations, and logical reasons. This is in line with [34], who deduced a positive correlation between metacognitive skills and achievement in the Physical Sciences. This relationship is facilitated by research [16] theory of metacognitive skills, as it explains what metacognitive skills are and how they can be used to encourage deep learning of concepts to improve problem-solving skills. Finally, metacognitive skills foster deep learning of subject concepts and transform learners into critical thinkers [35–37]. Interestingly research [18], concluded that metacognitive skills could also lead learners to solve problems more easily through group discussions and, in the process, think about their thinking. In addition, metacognitive skills have been found to encourage interaction and collaboration among learners during the learning process [38]. This is why metacognitive skills need to be incorporated into the classroom to ensure a deep conceptual understanding of Physical Sciences.

In contrast [39] found that Physical Sciences teachers still neglect the development of learners' metacognitive skills, which often demotivates them (learners) and lowers their interest in the subject. Similarly [7] in the Eastern Cape province of South Africa, found that metacognitive skills are not taught in the Physical Sciences classroom due to limited pedagogical strategies. In addition, Physical Sciences teachers with little knowledge of metacognitive skills resist implementing metacognitive skills enhancing pedagogies [40]. This raises a need to train teachers on the knowledge of metacognitive skills and implement metacognitive skills in enhancing pedagogies. Regrettably, there are limited experimentally trialed metacognitive skills enhancing pedagogies available for Physical Sciences teachers to use in their classrooms, hence, the current study.

2.2. Measuring metacognitive skills

There are varieties of methods that can be used to measure metacognitive skills. One method that is effective in measuring metacognitive skills is thinking aloud, where learners verbalize their thoughts which are then recorded [41]. According to research [42], this method can be applied to effectively unearth learners' metacognitive behaviors during a learning activity or task. Moreover, the technique is deemed to be a powerful predictor of performance. However, the technique has a significant drawback as it is complex to execute and time-consuming [43]. The current study opted not to use this technique due to the sample size (155) and the limited time that the study took.

Another technique that seems to be effective in measuring metacognitive skills is self-report questionnaires [43]. There are various self-report questionnaires which include the Motivated Strategies for Learning Questionnaire (MSLcQ) [44], the Learning and Study Strategies Inventory (LASSI) [45], the Metacognitive Awareness Inventory (MAI) [46] and the Metacognitive Self-Assessment Scale (MSAS) [47]. The benefit of using these questionnaires is that they can be administered on a large scale [48], thus allowing teachers who teach larger classes to administer the questionnaire without significant difficulties. The current study adopted the MSAS questionnaire to assess the learners' metacognitive skills. The reason the current study adopted the MSAS questionnaire is that MSAS is a tool derived from two already validated instruments, namely, the Metacognitive Assessment Scale (MSA) [49] and the Metacognitive

Assessment Interviews (MAI) [50].

Moreover, the MSAS has a good factorial validity and internal consistency in large non-clinical cross-validated samples, and again it is consistent with an established model of metacognition (MMFM) [51,52]. Since the sample size (N) of the current study was 155, there was a need to use a tool that would save time and could be administered to a larger population. According to Ref. [47], administration of the MSAS takes approximately 10–15 min, and as a self-report instrument, it can be used to provide a fast screening assessment of functional metacognitive abilities. This made it relevant for use in the current study. Moreover, the MSAS can also be easily used to assess change and metacognitive improvement during and at the end of treatment. Finally, the current study wanted to examine the effect of SOLEs pedagogy on all aspects of metacognitive skills in the Physical Sciences classroom, and the MSAS questionnaire contains all these aspects, so the administration of the MSAS questionnaire was deemed relevant.

2.3. SOLEs pedagogy in the classroom

Seguta Mitra initially invented the SOLEs pedagogy with his "Hole-in-wall" experiments in India, where learners were learning how to use a computer connected to the internet without adult intervention [23]. When Mitra initially experimented with SOLEs pedagogy outside the classroom, surprisingly, learners who used computers placed on the wall and did not speak English could surf through the internet, giving English instructions without prior exposure [53]. Furthermore, it demonstrated the same effect when implemented in a classroom. When applied in a classroom, SOLEs pedagogy involves a session between 30 and 90 min where a teacher asks a challenging question that learners have to answer in line with the curriculum objectives. Learners organize themselves in small groups of approximately four members per group and use a computer connected to the internet to find the solution to the given problem [54]. However, learners can join other groups to seek more information and return it to their original groups. The teacher's involvement during the SOLEs pedagogy session remains minimal until learners are required to give feedback on their findings. In the process, learners demonstrated an improved understanding of concepts without the teacher's guidance [55]. The findings imply that equipping learners with a technological device connected to the internet and allowing them to learn develops their metacognitive skills, which enhance their conceptual understanding without involving a teacher.

Although SOLEs pedagogy was found to be effective in developing learners' metacognitive skills and enhancing conceptual understanding, it has only been trialed experimentally once with primary school learners and has never been trialed with secondary school learners or in Physical Sciences classrooms [53,56]. Even at the primary school level, where SOLEs pedagogy was trialed, the focus was never on aspects of metacognitive skills [56]. Thus, what sets the current study apart is that it investigated the effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in the Physical Sciences classroom at the secondary school level. The original SOLEs pedagogy implementation used a computer on the wall, and in contrast, the current study used smartphones as moveable ICT equipment as opposed to computers on the wall. The reason for using smartphones was that the department of basic education (DBE), through their annual infrastructure and ICT surveys, indicated that 58.16% of South African schools lacked proper ICT infrastructure [6]. Moreover, the survey results indicated that 73.5% of schools with proper ICT infrastructure do not use ICT for teaching and learning as teachers lack the required expertise.

Furthermore, the studies that investigated metacognitive skills did not pay much attention to the effect of SOLEs pedagogy on the different aspects of metacognitive skills [28,39]. For example [39] focused on students' perception of seven aspects of metacognitive development activities, and they found that metacognitive reflection is one aspect that contributes significantly to the development of metacognitive skills. However, they did not indicate the pedagogy employed to develop metacognitive skills. Additionally [28] used a metacognitive inventory to investigate the metacognitive awareness of secondary school learners, and they, too, did not employ SOLEs pedagogy in checking the metacognitive awareness of the learners. The current study consequently argues that SOLEs pedagogy can improve all aspects of metacognitive skills as a technology-based pedagogical strategy. However, there is limited empirical evidence of that effect; hence the current study examines the effect of SOLEs pedagogy on the aspects of metacognitive skills in the Physical Sciences classroom.

3. Research questions

The current study aimed to investigate the effect of SOLEs pedagogy on different aspects of learners' metacognitive skills in Physical Sciences classrooms. In order to achieve the objective, the following questions were formulated:

- What is the effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in Physical Sciences?
- Which aspect of metacognitive skills will be most affect the implementation of the SOLEs pedagogy?

4. Theoretical framework

Several reasons have motivated the use of multi-theories in the current research. Thus, theories underpinning the current study are constructivism, Flavell's model of metacognitive skills, and self-regulated learning (SRL) theories. According to constructivist theory, learners' conceptual understanding can be developed when they are allowed to construct their knowledge [57]. This means that constructivism regards learning processes as a learner-centered endeavor, which requires the following actions to be implemented in the classroom:

- The teaching of Physical Sciences prioritizes learner autonomy

- The integration of metacognitive skills
- The expansion of the learning environment by integrating internet access into the teaching of Physical Sciences

The researcher of the current study argues that the pedagogy that can be used for integrating metacognitive skills needs to develop all the aspects of metacognitive skills for the learning process to take place as prescribed by constructivism.

On the other hand, Flavell's theory of metacognitive skills and self-regulated learning theory is significant for attempting to integrate metacognitive skills into Physical Sciences education. The significance of these theories is that they outline the basis for the development of metacognitive skills [16]. According to Flavell's theory, metacognitive skills can develop when learners are allowed to interact in groups during the learning process and take charge of their learning process. Similarly, self-regulated learning emphasizes setting cognitive goals, implementing cognitive strategies, time management, and self-reflection [27]. SRL theory calls for teachers to encourage learners plan, choose the strategy to implement, and evaluate their actions, which was found not to be done in secondary schools [58]. In addition, the SSRL model calls for technology to be integrated into Physical Sciences education which has also not been adequately done [27]. In a nutshell, a pedagogy aimed at developing learners' metacognitive skills should prioritize learners' autonomy, adapt learners to collaborative learning, and integrate technology in the Physical Sciences classroom. Regrettably, such pedagogies are limited. As a result, the current study argues that SOLEs pedagogy can allow learners to set cognitive goals, implement cognitive strategy, manage their activities and time, and conduct thorough self-reflection. Consequently, implementing SOLEs pedagogy can enhance different aspects of learners' metacognitive skills and, as a result, their conceptual understanding; however, there is limited research evidence to support that notion.

5. Research methodology

The current study aimed to examine the effect of SOLEs pedagogy on the different aspects of metacognitive skills in the Physical Sciences classroom. Examining the effect of SOLEs pedagogy relied mainly on using statistics, which fall under quantitative research methodology.

5.1. Research design

The current study used a non-equivalent quasi-experimental (control group) design to investigate the effect of SOLEs pedagogy on the different aspects of metacognitive skills in the Physical Sciences classroom. Four (two rural and two urban) groups participated in the study. Two (one urban and one rural) experimental groups (EGs) and two control groups (CGs) formed part of the study. In addition, a metacognitive self-assessment scale (MSAS) 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 intervention. In addition, EGs were taught the topic of forces for four weeks, using SOLEs pedagogy, while the CGs were taught the same topic of forces through the traditional (chalk-and-talk) way of teaching Physical Sciences.

5.2. Study sample and sampling method

All Grade 11 learners (with average age of 16 years) who were taking Physical Sciences in the Capricorn district of the Limpopo province of South Africa in 2019 comprised the study's population. The Capricorn district was chosen because, according to the National Senior Certificate (NSC) scores, learners lacked a conceptual understanding of Physical Sciences (DBE, 2018). The following Table 1 indicates the sample size that includes 155 learners from four schools, chosen using stratified sampling (66 students from two rural schools and 89 students from two urban schools) (two from rural strata and two from urban strata). Two schools were treated as the experimental groups (51 learners from a rural school and 69 from an urban school) and the other two as control groups (15 learners from a rural school and 20 learners from an urban school).

5.3. Soles pedagogy implementation

The current study implemented the SOLEs pedagogy in a formal classroom environment where time allocation was a factor, unlike in the case of Mitra's Hole-in-wall experiment, where the use of SOLEs pedagogy was open-ended and conducted informally with no time limitation. The implementation of SOLEs pedagogy in a Physical Sciences classroom was done, as the following diagram (Fig. 1) indicates.

Table 1
Sample size of gender based rural and urban strata.

	Sample size	Male	Female	Number	Total
Rural Strata	School B (Experiment)	20	31	51	66
	School C (Control)	6	9	15	
Urban Strata	School A (Experiment)	28	41	69	89
	School D (Control)	11	9	20	
Number		65	90	155	

Fig. 1. Implementation of SOLEs pedagogy in Physical Sciences classroom.

The implementation of SOLEs pedagogy in a formal classroom environment starts with the teacher issuing instructions (basically, asking learners challenging questions, such as (why do drivers have to keep safe following distance all the time when driving, and why does the distance have to be doubled on a rainy day?) that could be beyond their comprehension and would require investigation) and allowing them to engage in finding the solution to the problem given [54]. As learners search for the information, they are also allowed to interact with members of other groups to share information, and after that, they consolidate their solutions within their groups before they share the information with the rest of the group during the class discussions. As a result, the teacher consolidates learners' views and findings and relates them to the relevant content to be learned in a classroom. Finally, the current study allowed learners to use cell phones as one of the technological gadgets that can be used to connect to the internet, unlike the original hole-on-wall experiment by Mitra, who used traditional technological gadgets (desktops).

5.4. Instrumentation

The MSAS questionnaire instrument (see Annexure A) was administered to measure the metacognitive skill levels of learners in the two groups before and after the intervention. This was in an attempt to answer the research questions. The instrument contains four broad aspects regarding what people think about their ability to identify and describe their thoughts, emotions, and the social relationships in which they are involved. The items were answered on a five-point interval scale where [1] stands for *never* and [5] for *almost always* (see Annexure A). The four main aspects involved were:

- A: Respect is shown to me (7 items coded as A1, A2, A3, A4, A5, A6, A7)
- B: Respect is shown to others (3 items coded as B1, B2, B3);
- C: Respect is shown for empathy towards others (3 items coded as C1, C2, C3);
- D: Respect shown towards problem-solving (5 items coded as D1, D2, D3, D4, D5).

The total number of items in the instrument was 18, and the instrument was adopted from Ref. [47]. It was first validated and used in Italy (Naples), with a reliability factor (Cronbach's alpha value) of 0.72 and 0.87, indicating that the instrument was reliable within the Italian context. To validate this instrument within the South African context in the Capricorn district, four Physical Sciences teachers were given the questionnaire to rate and piloted with 35 learners who did not become part of the main study. The content validity index (CVI = 1) was 100%, and the internal consistency reliability index (Cronbach's alpha value) was 0.84. This implies that the tool was both valid and reliable under the context it was used.

5.5. Data analysis

The current study used descriptive (means and effect size) and inferential (*t*-test) statistics. Means were used to comparing the average metacognitive skills of the learners before and after the intervention; on the other hand, a *t*-test was used to evaluate if any mean difference was of statistical significance, while effect size was used to examine which aspect of metacognitive skills was greatly affected by the implementation of SOLEs pedagogy.

6. Results

The current study examined the effect of SOLEs pedagogy on the different aspects of metacognitive skills and whether there are aspects of metacognitive skills that are greatly affected by the implementation of SOLEs pedagogy. In achieving this objective, the MSAS questionnaire was given to the experimental and the control groups as pre-and post-tests. However, as the control group had no intervention, the interest lies with the experimental group (both urban and rural) and, more specifically, the differences between the means. This section discusses the results of the current study based on the research questions.

6.1. The effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in Physical Sciences

The results of the items in each aspect were summed, and a mean score was obtained. The aspect of Respect shown to me is the first aspect discussed.

Respect is shown to me [Section A of the MSAS questionnaire].

The results obtained by comparing the pre-test to the post-test MSAS results for the experimental group using a paired sample *t*-test were:

$[Respect\ shown\ to\ myself - \underline{X}_{Post} = 3.88; \underline{X}_{Pre} = 3.46; t(119) = 7.73; p = 0.000]$

When all seven items of the first aspect in the MSAS questionnaire are considered together, there is a statistically significant difference between the pre-test and post-test results for the experimental group ($p < 0.05$). This indicates that the learners in the experimental group perceived items in this aspect more frequently in the post-test than before the intervention. However, this does not indicate which of the seven items differed significantly from one another. The mean differences between pre-and post-tests for the seven comparisons are given in Table 2:

Table 2 shows that the experimental group perceived items A1, A2, A3, A6, and A7 significantly more frequently after the intervention than before. As the degrees of freedom are the same for all five significant differences, the *t*-scores will reflect the effect sizes (r-values) according to the formula:

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Table 3 shows the effect sizes for each of the seven items in Section A of the MSAS questionnaire and their rankings.

Item A1 had the largest effect size for differences between means ($r = 0.372$). This item measured learners' perceptions of their mental abilities, such as remembering, imagining, dreaming, desiring, foreseeing, and thinking. Thus, the effect of the intervention was significant on this item of the MSAS questionnaire, with a medium effect. Items A2, A6, A3, and A7 had the second, third, fourth, and fifth largest effect sizes, respectively. These four items included the metacognitive aspect of emotional regulation. It can be deduced that the intervention positively affected learners' abilities to perceive and regulate their emotions. Items A4 and A5 had small effect sizes found to be non-significant (see Table 3).

Respect is shown to others (Section B of the MSAS questionnaire).

The responses to the "respect shown to others" aspect of the MSAS questionnaire were also analysed. The results of the experimental group pre-and post-test for the facet of Respect shown to others were:

$[Respect\ shown\ to\ others - \underline{X}_{Post} = 3.87; \underline{X}_{Pre} = 3.61.t(119) = 3.28; p = 0.000]$

The paired sample *t*-test result for Section B of the MSAS questionnaire indicates that when all three items are tested together, there is a statistically significant difference between the post-test mean and the pre-test mean on the aspect of *Respect shown to others*. However, there was evidence that the intervention influenced respondents' frequency of showing Respect to others, as the post-test mean was significantly more significant than the pre-test average. Regardless, the results above do not show which of the three items contained in the empathy facet are responsible for this difference. Therefore, the significance of differences between the means per item is given in Table 4.

Table 4 shows that it was only on item B2 [*I can identify and understand the emotions of people I know*] where a statistically significant difference was present ($p < 0.05, r = 0.271$). Items B1 [*I can understand and distinguish the different mental activities (of other people) as when they are, for example, remembering, imagining, having fantasies, dreaming, desiring, deciding, foreseeing, and thinking*] and B3 [*I can describe the thread that binds the thoughts and emotions of people I know, even when they differ from one moment to the next*] were non-significant. Thus, the intervention positively impacted learners' abilities to show Respect to others only in identifying and understanding their emotions. Moreover, it did not significantly influence the participants' abilities to understand and describe different mental activities in others.

Empathy towards others (Section C of the MSAS questionnaire).

The responses to the "empathy towards others" aspect of the MSAS questionnaire were analysed. The results of the experimental group pre- and post-test on the aspect of *Respect for empathy to others* were:

$[Empathy\ towards\ others - \underline{X}_{Post} = 3.95; \underline{X}_{Pre} = 3.47; t(119) = 4.76; p = 0.000]$

When the three items were tested together, a statistically significant difference was found between the post-test and pre-test mean scores concerning empathy towards others ($p < 0.05$). However, this test does not indicate which of the three items differs from one

Table 2
Paired samples test concerning myself.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95 % Confidence interval of the difference				
				Lower	Upper			
A1 Post-A1 Pre	0.57	1.42	0.130	0.31	0.82	4.376	119	.000*
A2 Post-A2 Pre	0.57	1.59	0.145	0.28	0.85	3.913	119	.000*
A3 Post- A3 Pre	0.43	1.59	0.145	0.14	0.71	2.926	119	.004*
A4 Post- A4 Pre	0.25	1.52	0.139	−0.02	0.52	1.803	119	.074
A5 Post-A5 Pre	0.23	1.84	0.168	−0.10	0.57	1.392	119	.167
A6 Post- A6 Pre	0.60	1.68	0.154	0.30	0.90	3.907	119	.000*
A7 Post- A7 Pre	0.35	1.59	0.145	0.06	0.64	2.410	119	.018*

Note. * Significant at $\alpha = 0.05$.

Table 3
Effects sizes of items in Section A of the MSAS.

Item Code	Description	Effect size (r)	Rank
A1	I can distinguish and differentiate my mental abilities (e.g., remembering, imagining, having fantasies, dreaming, desiring, foreseeing, and thinking).	0.372	1
A2	I can define, distinguish and name my own emotions.	0.338	2
A3	I am aware of the thoughts or emotions that lead my actions.	0.259	4
A4	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.	0.163	6
A5	I know that what I wish or expect may not be realised and that I have limited power to influence things.	0.127	7
A6	I can perceive and describe my thoughts, emotions, and relationships in which I am involved.	0.337	3
A7	I can describe the thread that binds my thoughts and my emotions even when they differ from one moment to the next.	0.216	5

Note. Effect size: 0.10 − 0.29 (small); 0.30− 0.49 (medium); 0.50+ (large effect).

Table 4
Paired samples test for Respect to others.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95 % Confidence interval of the difference				
				Lower	Upper			
B1 Post- B1 Pre	0.13	1.45	0.132	−0.13	0.40	1.008	119	0.316
B2 Post - B2 Pre	0.43	1.54	0.141	0.15	0.71	3.076	119	0.003*
B3 Post – B3 Pre	0.23	1.47	0.134	−0.033	0.50	1.738	119	0.085

Note. * Significant at $\alpha = 0.05$.

another. Table 5 provides more details.

Table 5 shows that the experimental group perceived items C1, C2, and C3 significantly more frequently after the intervention than before ($p < 0.05$). Item C2 [*I am aware that others may perceive facts and events differently from me and interpret them differently*] had the largest mean difference with an effect size of r = 0.370. This was followed by item C3 [*I am aware that age and life experience can touch others' thoughts, emotions, and behaviour*] with r = 0.235, and item C1 [*I am aware that I am not necessarily at the center of others' thoughts, feelings and emotions and that others' behaviours arise from reasons and goals that can be independent of my perspective and my involvement in the relationship*] with r = 0.227. It can therefore be concluded that the SOLEs pedagogy improved learners' empathy towards others concerning metacognitive skills.

Respect to solving problems (Section D of the MSAS questionnaire).

The responses to the "respect to solving problems" aspect of the metacognitive skills were also analysed for experimental groups. The result of testing the five items in the facet of Respect to solving problems was:

$$[Respect\ to\ solving\ problems - \underline{X}_{Post} = 3.63; \underline{X}_{Pre} = 3.36; t(119) = 3.64; p = 0.000]$$

When testing all five items together, the experimental group was found to have a statistically significantly higher mean score than the pre-test group ($p = 0.000$). The items that caused this statistically significant difference are shown in Table 6:

Table 6 indicates that only the differences between items D2 and D3 displayed statistically significant differences between the experimental post- and pre-test scores in the MSAS. Item D2 [*I can deal with the problems voluntarily by trying to follow my mental order*] had an effect size of $r = 0.213$, and item D3 [*I can deal with the problems by trying to challenge or enrich my views and my beliefs on problems themselves*] had an effect size of $r = 0.194$. Thus, items D2 and D3 are the ones that resulted in a positive overall outcome in Section D of the MSAS questionnaire. Items D1, D4, and D5 were non-significant and were not further analysed. In a nutshell, SOLEs pedagogy

Table 5
Paired samples test for empathy towards others (Experimental group).

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95 % Confidence interval of the difference				
				Lower	Upper			
C1 Post - C1 Pre	0.40	1.72	0.157	0.09	0.71	2.545	119	0.012*
C2 Post - C2 Pre	0.61	1.54	0.140	0.33	0.89	4.340	119	0.000*
C3 Post – C3 Pre	0.44	1.83	0.167	0.11	0.77	2.647	119	0.009*

Note. * Significant at $\alpha = 0.05$.

Table 6
Paired samples test for resolving problems.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95 % confidence interval of the difference				
				Lower	Upper			
D1 Post – D1 Pre	0.29	1.75	0.160	−0.02	0.61	1.825	119	0.071
D2 Post – D2 Pre	0.32	1.46	0.133	0.053	0.58	2.375	119	0.019*
D3 Post – D3 Pre	0.29	1.48	0.135	0.02	0.56	2.158	119	0.033*
D4 Post – D4 Pre	0.23	1.77	0.161	−0.09	0.55	1.447	119	0.151
D5 Post – D5 Pre	0.24	1.41	0.129	−0.02	0.50	1.872	119	0.064

Note. * Significant at $\alpha = 0.05$.

has a statistically significant effect on all aspects of metacognitive skills, namely, Respect shown to me, Respect shown to others, Respect shown for empathy towards others, and Respect shown towards problem-solving.

6.2. Metacognitive skills are affected mainly by the implementation of the SOLEs pedagogy

The second question stated: Which aspect of metacognitive skills is mainly affected by the implementation of SOLEs pedagogy? Since it was established through the *t*-test that SOLEs pedagogy affects all aspects of metacognitive skills, the effect size was used to establish which aspects of the metacognitive skills were significantly affected by the implementation of SOLEs pedagogy. Table 7 summarizes the key findings emerging from the paired samples tests on the experimental group regarding the analysis of the MSAS data:

The results from Table 7 indicate that two components (A1 and A2) of the "respect shown to me" aspect of metacognitive skills were mostly affected by the implementation of SOLEs pedagogy with the effect sizes ($r = 0.372$ and $r = 0.338$, respectively) greater than 0.3. This edges one component of the "empathy to others" aspect of metacognitive skills with an effect size of 0.370. Overall, the aspect that has shown more significant improvement after the implementation of the SOLEs pedagogy is "Empathy shown to others" with an overall mean improvement of 0,48 at a p-value of 0.00, which edges "respect shown to me at a mean improvement of 0.42 at a p-value of 0.00. This implies that SOLEs pedagogy improved "empathy to other" aspect of metacognitive skills more than the other aspects.

For comparison with the traditional talk-and-chalk, an analysis of pre-and post-test responses on the MSAS for the control group was conducted, and the results show non-significant differences in three of the four sections of the MSAS questionnaire.

Respect for myself (Section A of the MSAS questionnaire).

The control groups also analysed the responses to the "respect for myself" aspect of the metacognitive skills. The seven items involved with the aspect of showing *Respect for myself* were tested using a paired sample *t*-test, and the following results were obtained:

$$[Respect\ for\ myself - \underline{X}_{Post} = 2.89; \underline{X}_{Pre} = 2.76; t(34) = 0.924; p = 0.362]$$

No statistically significant differences between the control post- and pre-test MSAS data regarding showing *Respect for myself* ($p = 0.362$) could be found. However, no further investigation is necessary if no significant differences exist at this combined level. Respondents from post- and pre-test groups did not differ statistically significantly from one another, and both groups thought that the items were *rarely applicable* to them.

Respect for others (Section B of the MSAS questionnaire).

The control groups also analysed the responses to the "respect for others" aspect of the metacognitive skills. The results for the three items in Section B tested together using paired sample *t*-test were:

Table 7
Major findings from the experimental group MSAS data.

Item Code	Description	Effect Size	Rank
A1	I can distinguish and differentiate my mental abilities (e.g., remembering, imagining, having fantasies, dreaming, desiring, foreseeing, and thinking).	0.372	1
C2	I am aware that others may perceive facts and events differently from me and interpret them differently.	0.370	2
A2	I can define, distinguish and name my own emotions.	0.338	3
A6	I can perceive and describe my thoughts, emotions, and relationships in which I am involved.	0.337	4
B2	I can identify and understand the emotions of people I know.	0.271	5
A3	I am aware of the thoughts or emotions that lead my actions.	0.259	6
C3	I know that age and life experience can touch others' thoughts, emotions, and behaviour.	0.235	7
C1	I am aware that I am not necessarily at the center of others' thoughts, feelings and emotions and that others' behaviours arise from reasons and goals that can be independent of my perspective and involvement in the relationship.	0.227	8
A7	I can describe the thread that binds my thoughts and my emotions even when they differ from one moment to the next.	0.216	9
D2	I can deal with problems voluntarily, trying to follow my mental order.	0.213	10
D3	I can deal with problems by trying to challenge or enrich my views and beliefs on the problems.	0.194	11

$$\left[Respect\ for\ others - \underline{X}_{Post} = 2.75; \underline{X}_{Pre} = 2.70; t(34) = 0.359; p = 0.728\right]$$

No significant statistical difference could be found at the multivariate level ($p = 0.728$), so no further testing was needed. However, the control group believed that *Respect for others* was *rarely applicable* to them.

Empathy towards others (Section C of the MSAS questionnaire).

The responses to the "empathy towards others" aspect of the metacognitive skills were also analysed for control groups. The results for the three items in the facet of *Respect for empathy towards others* were:

$$\left[Empathy\ towards\ others - \underline{X}_{Post} = 2.92; \underline{X}_{Pre} = 2.54; t(34) = 2.330; p = 0.026\right]$$

The three items tested together showed a statistically significant difference, with the post-test scores having a statistically significant, higher mean than the pre-test scores. The various pairs are now investigated to determine which items had significant differences. The data for this test are shown in Table 8:

Respect to solving problems (Section D of the MSAS questionnaire).

The control groups also analysed the responses to the "respect to solving problems" aspect of the metacognitive skills. The five items in Section D of the MSAS questionnaire, when tested together, had the following statistical results:

$$\left[Respect\ to\ solving\ problems - \underline{X}_{Post} = 2.86; \underline{X}_{Pre} = 2.78; t(34) = 0.516; p = 0.609\right]$$

No statistically significant effect could be found when the five items were tested together ($p = 0.609$). Hence, no further testing at the univariate level was needed.

Taken together, the results of the control group responses on the MSAS questionnaire indicate that traditional teaching methods had no substantial effect on the learners' metacognitive skills.

7. Summary of results as per each research question

The current study examined the effect of SOLEs pedagogy on the different aspects of metacognitive skills. The guided questions for the current study were "What is the effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in Physical Sciences?" and "Which aspect of metacognitive skills will be most affected by the implementation of the SOLEs pedagogy?" In terms of the first research question, the current study found that SOLEs pedagogy improves all four significant aspects of metacognitive skills but significantly improves only three, excluding the "respect shown to problem-solving" aspect, which was found to improve but not significantly. The results indicate that the "respect shown to myself" aspect improved from the mean value of 3.46–3.88 with a p-value ($p = 0.00$) less than the significant value of 0.05. Similarly, for "respect shown to others," the mean improved from 3.61 to 3.87 with a p-value ($p = 0.00$) less than the significant value. "Empathy shown to others'' aspect also improved from 3.47 to 3.95 at the p-value of 0.00. "Respect shown to problem-solving experienced the improvement (statistically insignificant), from 2.78 to 2.86 at the p-value of 0.61. The results of the second research question revealed that SOLEs pedagogy improved the "empathy shown to others" aspect of metacognitive skills more than the other three main aspects at an overall mean improvement of 0.48.

8. Discussion

The current study was triggered by poor learner performance in Physical Sciences, which is believed to result from teachers' application of poor teacher-centered pedagogies, which do not help develop learners' conceptual understanding [1–6] Previous studies suggested integrating metacognitive skills and technology in the teaching of Physical Sciences as ways of remediating the lack of conceptual understanding of Physical Sciences [10,27]. According to Ref. [10], learners with a high level of metacognitive skills have a higher prevalence of achieving their learning goals. On the other hand, research [27], canvasses technology integration as one of the interventions that can be employed to facilitate self-regulated Physical Sciences learning and improve learning outcomes. Despite that, Physical Sciences teachers continue to apply futile teacher-centered pedagogies, which do not integrate metacognitive skills and technology [7–9]. Some studies [7,8] singled out limited pedagogical strategies as one of the plausible explanations for the continued use of ineffective teacher-centered pedagogies. Untested evidence places SOLEs pedagogy among pedagogies that can be applied to integrate metacognitive skills and technology to develop learners' conceptual understanding of Physical Sciences. Hence, the current

Table 8
Paired samples test for empathy towards others (Control group).

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95 % confidence interval of the difference				
				Lower	Upper			
C1 Post – C1 Pre	0.20	2.13	0.36	−0.53	0.93	0.557	34	0.581
C2 Post – C2 Pre	0.40	1.88	0.32	−0.25	1.05	1.258	34	0.217
C3 Post – C3 Pre	0.54	1.87	0.32	−0.10	1.18	1.719	34	0.095

The data in Table 8 show that none of the post-test and pre-test differences in mean scores significantly differed. Hence, one may conclude that when the three items under Section C [*respect for empathy towards others*] act together, there is a moderate effect, while there is no significant effect when the items are considered separately. Thus, the unexpected results obtained earlier could have originated from this section of the MSAS questionnaire.

study investigated the effect of SOLEs pedagogy on different aspects of learners' metacognitive skills in Physical Sciences classrooms. The aim was accomplished by addressing the following research questions: What is the effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in Physical Sciences? Which aspect of metacognitive skills will most affect the implementation of the SOLEs pedagogy? The current study's findings are discussed according to the answers to the research questions starting with the first research question.

8.1. The effect of SOLEs pedagogy on the different aspects of learners' metacognitive skills in Physical Sciences

Since SOLEs pedagogy was previously poorly researched, its effect on metacognitive skills in Physical Sciences classrooms at the secondary school level was poorly known. Furthermore, there was a need to establish whether SOLEs pedagogy would affect the different aspects of metacognitive skills. The current study found that SOLEs pedagogy improved all aspects of metacognitive skills. The findings confirm [27] SSRL theory which regards technology integration in the teaching of Physical Sciences as a basis for developing learners' metacognitive skills. SOLEs pedagogy improved all aspects of metacognitive skills because it complies with the requirements set out by the metacognitive skills development theories [27,58]. SOLEs pedagogy conforms to technology integration and collaborative learning and accustoms learners to autonomous learning, as hypothesized by Ref. [27]. In addition, SOLEs pedagogy incorporates problem-solving, maximizes learners' learning autonomy, and enables learners to relate their classroom experiences with their day-to-day experiences, which are prescribed by all the theories underpinning the current study as the basis for the development of the metacognitive skills [27,29,57–60,61]. SOLEs pedagogy provides learners with an opportunity to use the internet to create their knowledge which is crucial in developing their self-reflection, self-awareness, and conceptual understanding, according to Ref. [57]. The study also confirms [16] theory which stipulates that the development of learners' metacognitive skills requires a pedagogy that would allow learners to work independently from their teacher, which is the case with SOLEs pedagogy.

8.2. The aspect of metacognitive skills will be most affected by the implementation of the SOLEs pedagogy

The current study also examined the aspect of metacognitive skills greatly affected by SOLEs pedagogy as studies that investigated metacognitive skills took a blanket approach without detailing different aspects of metacognitive skills. In addition, the effect of SOLEs pedagogy on the different aspects of metacognitive skills is a poorly explored terrain; hence it is imperative also to evaluate which of the four aspects will be significantly affected. In this regard, it was found that empathy for others was the aspect of metacognitive skills affected mainly by the implementation of SOLEs pedagogy. The current study's findings align with the literature that links the development of empathy for others with group activities. For example, research [25,26] found that learners who are adapted to collaborative learning tend to be sympathetic to one another. SOLEs pedagogy in the current study adapted learners to collaborative learning, which means that learners were free to participate in group activities, which led to the development of metacognitive skills. These findings align with [26] who deduced a positive correlation between collaborative learning and empathy for others. Binaguiohan and Bolofer further found that learners with a higher level of empathy for others have a lower prevalence of bullying their peers, which implies that SOLEs pedagogy can reduce bullying in the classroom as it improves empathy for others. In addition, the current study is in line with [62], who found that empathy with others can be improved through problem-based learning; SOLE's pedagogy incorporates problem-based learning; hence it succeeded in improving learners' empathy with others.

8.3. Implications of this study

8.3.1. Advancing metacognitive skills in Physical Sciences education

Learners' poor performance in Physical Sciences examinations is often blamed on the persistent application of poor teacher-centered pedagogies, which do not help develop learners' conceptual understanding. For example, integration of metacognitive skills in the teaching of Physical Sciences was viewed as one way of improving learners' metacognitive skills, but the predicament is that there were limited pedagogical strategies to integrate metacognitive skills in Physical Sciences classrooms. The study is a step in the right direction to find ways to integrate metacognitive skills and improve learner performance. The study found that SOLEs, a technology-based pedagogy, can be employed in Physical Sciences classrooms to integrate metacognitive skills and technology in the teaching of Physical Sciences.

8.4. Extend existing notions of student-centered pedagogy

The current study employed technology (the internet) as a tool for secondary school Physical Sciences learners to create their knowledge (with minimal intervention from their teacher). This study was conducted with language learners at the primary school and information outside the school environment, where time was not a factor. In both cases, the effect of SOLEs pedagogy on metacognitive skills was not investigated. In addition, the two studies used traditional technological infrastructure (such as laptops and desktops), which are not available in most South African schools. The current study found that a cellphone can be used to facilitate learner-centered Physical Sciences learning while enhancing their metacognitive skills.

The study found that cellphones and smartphones (with internet accessibility), when used through the application of SOLEs pedagogy, can close a gap between resourced and under-resourced schools in terms of technology integration. These gadgets can facilitate self-directed learning and the development of metacognitive skills. Therefore, the current study implies that Physical Science teachers need to use SOLEs pedagogy through cellphones or smartphones to facilitate self-regulated learning, which is essential for developing learners' conceptual understanding. In addition, schools with policies that restrict the use of cellphones or smartphones by learners should consider revising their policies to allow the use of cell phones for the teaching and learning of Physical Sciences. Finally, Physical Sciences textbook authors should include assignments that would entice learners to use the internet in the classroom.

9. Limitation of the study

Since quasi-experimental (control group) design was used in this study, the researchers could not modify the variables or randomise the subjects [63]. Additionally, the study was conducted for a period of four weeks with only a small number of 155 Grade 11 learners studying Physical Sciences in Capricorn District of Limpopo Province of South Africa; hence, the results cannot be generalizable to all learners who study Physical Sciences in other districts of Limpopo Province and the entire country. Moreover, an instrument used to measure metacognitive skills was not based on material content; as a result, learning outcomes were not obtained. However, the findings are significant as they identify SOLEs pedagogy as the technology-based pedagogy that can improve all aspects of metacognitive skills in Physical Sciences. These results can be a step into the right direction in terms of identifying the technology-based pedagogies that can be employed to improve aspects of metacognitive skills in Physical Sciences and other subjects.

10. Conclusion

The current study concludes that SOLEs pedagogy is a technology-based pedagogy that can be holistically employed in Physical Sciences classrooms as it was found to improve all aspects of metacognitive skills. Furthermore, SOLEs pedagogy improves the "empathy shown to others" aspect of metacognitive skills more than the other three aspects; respect shown to problem-solving, respect shown to myself, and respect shown to others. Therefore, the researchers of the current study argue that SOLEs pedagogy develops learners' ability to adapt to collaborative learning, which makes group interaction productive and enhances the learning process according to constructivism, which regards social interaction as the basis for effective Physical Sciences learning.

11. Potential contributions

It was previously known that SOLEs pedagogy could assist learners in learning ahead of their time [53,61,64]. However, it was poorly known that SOLEs pedagogy could improve all aspects of metacognitive skills, and the current study contributes to understanding the effect of SOLEs pedagogy on different scholastic constructs. The current study further revealed that SOLEs pedagogy could improve learners' empathy with others, which was previously under-reported.

12. Recommendations

The findings confirm that SOLEs pedagogy improves all aspects of metacognitive skills. Thus, it is recommended that SOLEs pedagogy be used in conjunction with other teaching approaches like laboratory work aimed at ensuring that Physical Sciences learners develop metacognitive skills that will reinforce their conceptual understanding of Physical Sciences concepts. Additionally, the current study recommends the implementation of SOLEs pedagogy in the teaching of Physical Sciences as it improves all aspects of metacognitive skills. The implementation of SOLEs pedagogy in the classroom has the potential to reduce bullying as it improves learners' empathy for others. Moreover, this study recommends that Physical Sciences teachers undergo in-service training on how to employ SOLEs pedagogy in a classroom setup for maximum benefit. Considering the limited time and small sample size of the current study, a further study with a longitudinal design involving a bigger sample size and an instrument based on material content to measure metacognitive skills, could contribute more knowledge on the implementation of SOLEs pedagogy to improve learners' metacognitive skills.

Ethical statement

The Nelson Mandela University Education Faculty Research, Technology, and Innovation Committee granted ethical approval at a meeting on February 18, 2019. The ethics clearance reference number is H19-EDU-ERE-04. The researchers were permitted to conduct research in four Capricorn district secondary schools on February 27, 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, privacy, anonymity, confidentiality, honesty, integrity, objectivity, openness, carefulness, respect for intellectual property, legality, non-discrimination, competence, and human subject protection [65]. All learners from the participating schools signed an assent form, and their parents signed a consent form to grant the researcher 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.

Data availability statement

The data associated with this study have not been deposited into a publicly available repository,
However, they will be made available on request.

CRediT authorship contribution statement

Hodi Tsamago: Conceptualization, Formal analysis, Investigation. **Anass Bayaga:** Project administration, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices.

	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 other's thoughts, feelings and emotions and that other's 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 other's 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

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