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Enhancing learners' self-regulated learning in physical sciences classrooms through formative assessment intervention strategies

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Abstract
Fostering self-regulated learning (SRL) in the context of physical sciences is crucial for promoting twenty-first-century learning skills and establishing a solid foundation for academic achievement among science students. In South African schools, the physical sciences curriculum holds significant importance, serving as a cornerstone for students' educational development. This research aimed to investigate the effectiveness of formative assessment interventions in cultivating SRL among grade 10 physical sciences students. Utilizing survey methodology, quantitative data were gathered through questionnaires administered to 175 grade 10 physical sciences students selected purposively. The study utilized the self-regulatory skills scale, appropriately adapted to the specific context, with a model of self-regulated learning serving as the conceptual framework. Data analysis involved both descriptive and inferential statistics. The study revealed that implementing formative assessment practices in physical sciences classrooms effectively promotes students' SRL behaviors. The findings underscored the positive impact of formative assessment practices as interventions in enhancing students' SRL and improving academic performance. It is recommended that formative assessment strategies be integrated into teaching methodologies at the secondary level, offering valuable benefits to learners.

Keywords: self-regulated learning, formative assessment, physical sciences

INTRODUCTION

There is widespread acknowledgment of the significance of self-regulated learning (SRL) within science classrooms. On the global stage of education, nations like Singapore in Southeast Asia and Scotland in Northwestern Europe have integrated the concept of the 'self-regulated learner' into their curriculum's desired learning outcomes (Ministry of Education, Singapore, 2014). Substantial empirical evidence underscores the importance of SRL in facilitating learners' academic achievements (Zimmerman & Kitsantas, 2014). Scholars such as Zumbrunn et al. (2011) define SRL as a process aiding learners in managing their thoughts, behaviors, and emotions to navigate their learning experiences successfully. Similarly, Luftenegger et al. (2011) stress the significance of SRL, citing it as fundamental to the school's core functionality, with its primary aim being to foster learners' autonomy and lifelong learning habits.

In the realm of science education, teachers hold a pivotal role in promoting learners' SRL. Zimmerman and Kitsantas (2014) highlight the importance of integrating self-regulatory processes or beliefs, such as goal setting, strategy use, and self-evaluation, into classroom practices, particularly during formative assessments. It is imperative for teachers to possess knowledge of SRL, as learners' proficiency in self-regulation hinges on how effectively teachers engage them in SRL-promoting experiences. In science classrooms, learners encounter new knowledge and scientific skills that they must integrate with their existing understanding. In cases where teachers lack expertise in merging SRL with formative assessment, learners are compelled to regulate their learning processes independently (Taranto & Buchanan, 2020). Research indicates that this situation persists, as not all learners effectively self-regulate. Many struggle to assess their learning strengths and weaknesses and how these

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Contribution to the literature

- The article makes a significant contribution to the literature by addressing the critical intersection of self-regulated learning (SRL) and formative assessment in science education.
- It highlights how formative assessment strategies can foster students' ability to take control of their own learning processes, particularly in the context of Physical Sciences.
- The study contributes to the ongoing discourse on improving educational outcomes through innovative assessment approaches, positioning formative assessment as a tool not just for evaluation, but to develop learners' capacity for independent learning and problem-solving.

align with task requirements (Taranto & Buchanan, 2020).

Studies underscore the critical role of physical science teachers in facilitating SRL (Meece, 2023). However, despite the strong empirical support for self-regulatory processes, not all teachers effectively equip learners to learn independently (Spruce & Bol, 2015). Despite the documented importance of SRL in teacher practice, research by Dignath and Sprenger (2020) reveals that teachers lack clarity on the extent and nature of support required to enhance their learners' SRL capacities.

While numerous studies have explored the integration of SRL in other countries, there is a dearth of research in a South African context, specifically in the UMkhanyakude district of KwaZulu-Natal province. Despite the pivotal role of teachers in promoting SRL, investigations into teachers' practices related to SRL in science education have been limited. Hence, this pragmatic study was deemed essential and timely to explore the significance of implementing formative assessment to empower learners to self-regulate their learning processes.

LITERATURE REVIEW

The Relationship Between SRL and Formative Assessment

The concept of formative assessment has undergone significant evolution over the years, beginning with Sadler (1998) and progressing to the insights of Black and Wiliam (2018), who define it as an instructional approach aimed at furnishing feedback on learners' performance to enhance and expedite learning. These scholars broaden the understanding of formative assessment to encompass all activities undertaken by teachers and/or learners that furnish information for formative feedback, thereby modifying the teaching and learning activities in which learners are involved. Black and Wiliam (2018) emphasize that formative assessment does not solely entail formal tests (summative assessment) but rather encompasses various instructional methods aimed at providing a continuous stream of evidence of learners' progress and learning to learners, teachers, and parents.

Research underscores the essential link between SRL and formative assessment. Building upon the definition by Leggett et al. (2019), Nicol and MacFarlane-Dick (2006) propose that formative assessment, incorporating the seven key principles of effective feedback and internal motivation practices, can support SRL. Additionally, Black and Wiliam (2018) highlight specific instructional resources such as conditions, operations, standards, and evaluations that learners can utilize to complete tasks, thereby fostering SRL. Consequently, formative assessment practices and activities should be designed to incorporate such instructional resources to facilitate SRL.

Teacher Self-Regulation and the Promotion of Learners' SRL

Just as physical science teachers expect learners to self-regulate their learning, similar expectations extend to teachers themselves (Dignath & Sprenger, 2020). Given the evolution of SRL and its characteristics within formative assessment, self-regulated teachers are better positioned to comprehend learners' learning strategies and must acknowledge and address learners' needs, obstacles, and challenges in becoming self-regulated (Delfino et al., 2010). Furthermore, self-regulated science teachers in classrooms may possess a deeper understanding of specific learning approaches and formative assessment strategies associated with SRL development, thereby better preparing for potential congruences in teacher-learner SRL development. Scholars such as Van der Steen et al. (2023) argue that teachers are more inclined to promote formative assessment strategies they perceive as effective based on their past experiences, indicating that self-regulated teachers demonstrate proficiency in teaching and learning goals, thereby embodying the essence of SRL. They implement these goals in classroom practices by fostering a conducive classroom environment and facilitating learners' SRL development.

Teachers' Understanding of SRL and Insights into Formative Assessment

If formative assessment strategies modelled by teachers in teaching and learning are crucial for enhancing and promoting learners' SRL, physical sciences teachers must acquire requisite knowledge of

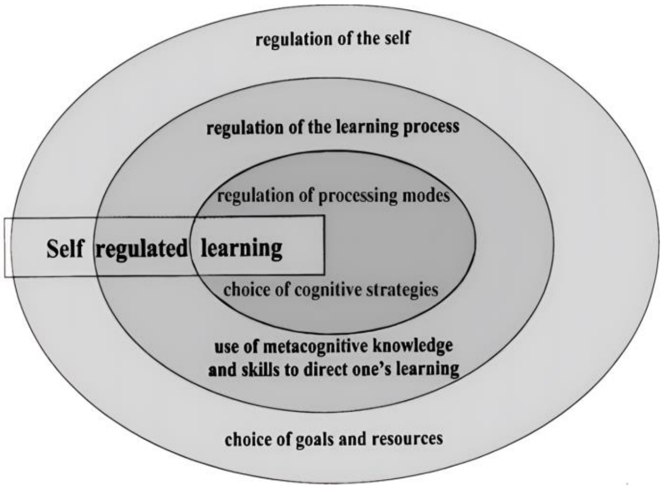

Figure 1. The three-layered model of self-regulated learning (Boekaerts, 1999)

SRL. Delfino et al. (2010) suggest that teachers' understanding of SRL is predominantly tacit and remains unconscious until they are prompted to elucidate their understanding of SRL while implementing formative assessment strategies. Teachers can enhance their understanding of SRL through professional development workshops focused on formative assessment. Through these workshops, teachers can augment their knowledge and comprehension of SRL, thereby identifying more opportunities to foster SRL across diverse settings (Granberg et al., 2021). Increased knowledge of SRL among teachers enables them to make it more visible to learners. Apart from formative assessment practices, understanding and knowledge of SRL can be enhanced through collaborative reflections, including articulation of tacit knowledge and dialogue with peers to facilitate knowledge construction. Considering the significance of SRL in classrooms, the lack of knowledge, understanding, skills, and self-efficacy to effectively promote and guide learners' SRL poses a significant barrier to actualizing SRL in classrooms (Karlen et al., 2020). Professional development has been identified as a solution to equip teachers with the necessary knowledge to promote SRL among learners. Fortunately, Bartimote-Aufflick et al. (2010) assert that contemporary professional development models have adapted their approach to develop proactive professionals, recognizing teacher self-regulation as an essential teacher competency tool.

CONCEPTUAL FRAMEWORK

Boekaerts (1999) introduced a SRL model in 1999, comprising three interconnected layers, which offers a conceptual framework for comprehending and fostering learners' SRL within science classroom contexts, as depicted in **Figure 1**. This model delineates three layers: firstly, the exploration of learning approaches or processing styles (cognitive-innermost layer); secondly, how learners navigate and oversee their learning journey (metacognitive-middle layer); and thirdly, how learners endeavor to regulate their motivation (motivation-outermost layer).

When fostering learners' SRL in the physical sciences classroom through formative assessment, this model offers a comprehensive perspective for examining the interaction among cognitive processes, metacognitive strategies, and motivational aspects. Formative assessment, a continual process of collecting evidence of learners' progress to guide instructional decisions, closely aligns with the principles of SRL. At the cognitive level (innermost layer), formative assessment practices such as timely feedback, clarification of learning objectives, and provision of scaffolded support aid learners in developing a deeper grasp of scientific concepts and procedures. Through self-monitoring and self-evaluation, learners actively regulate their cognitive processes, identifying strengths and areas needing further attention. The metacognitive layer (middle layer) underscores the significance of metacognitive awareness and regulation in facilitating effective learning.

Formative assessment encourages learners to reflect on their learning strategies, monitor their comprehension, and adjust their approaches accordingly. For instance, learners may utilize formative feedback to gauge their understanding of scientific concepts and adapt their study methods accordingly. Additionally, the motivation layer (outermost layer) emphasizes the influence of motivation, interest, and beliefs on learners' engagement and persistence in learning endeavors. Formative assessment activities that cultivate supportive and positive learning environments can enhance learners' intrinsic motivation and self-efficacy beliefs in science. By fostering autonomy, competence, and relatedness, teachers can instill a sense of ownership over learning and nurture learners' intrinsic motivation to excel.

In essence, Boekaerts' (1999) three-layered model of SRL offers a valuable framework for understanding how formative assessment can promote SRL in science classrooms. By addressing cognitive, metacognitive, and motivational factors, physical sciences teachers can develop effective formative assessment practices that empower learners to take charge of their learning and attain meaningful academic outcomes in physical sciences education.

METHODOLOGY

Research Design

This research study utilized a descriptive research design and collected data through a survey method, incorporating both pre- and post-questionnaires. The study followed a correlational approach.

Table 1. Number of learners by school and by group

	Intervention		Control		Total	
School	n	%	n	%	n	%
A	26	22.0			26	14.9
B	40	33.9			40	22.9
C	52	44.1			52	29.8
D			18	31.6	18	10.3
E			39	68.4	39	22.9
Total	118	100	57	100	175	100

Targeted Population and Sampling Procedure

This study involved grade 10 physical science learners from five secondary schools within the UMkhanyakude District. The total participant count stood at 175 learners, categorized into two groups. The experimental group comprised 118 learners, while the control group consisted of 57 learners. **Table 1** delineates the distribution of participants in the intervention and control groups across the five secondary schools under investigation. For each school, **Table 1** presents the number of learners assigned to the intervention group and the percentage this represents of the total intervention group participants. Likewise, it illustrates the number of learners allocated to the control group and the corresponding percentage. For instance, in school A, 26 learners, constituting 22.0% of the total intervention group, took part, while another 26 learners, accounting for 14.9% of the total control group, were assigned to the control group. This breakdown recurs for each school involved in the study, offering a comprehensive portrayal of participant distribution across both intervention and control groups. Totals in **Table 1** at the bottom summarize the number of learners in each group across all schools, along with the corresponding percentages.

Formative Assessment Intervention Practices

As this study seeks to investigate the effects of implementing an intervention on enhancing learners' SRL within the experimental group, it is essential to delve into the specifics of the formative assessment interventions integrated into this group and the corresponding conditions in the control group. The formative assessment interventions or treatment protocols drew upon the framework established by Ozan and Kincal (2018), with adaptations made by the researchers to suit the study's context. The instructions pertaining to the intervention were crafted based on the four primary strategies of formative assessment outlined by Ozan and Kincal (2018), as depicted in **Table 2**.

Research Tool

Brace (2008) highlighted the researcher's proficiency in translating study objectives into a set of informational needs, which in turn shape the research questions aimed at gathering pertinent information and subsequently transforming these questions into a questionnaire. In this study, data collection occurred through questionnaires administered as pre- and post-tests to evaluate learners' self-regulation skills, utilizing the self-regulated skills scale (SRSS) devised by Seyhan (2015). The questionnaires underwent validation by subject matter experts in science teaching. Initially comprising 29 items, the questions comprised predominantly positive and negative statements, organized into eight constructs:

Table 2. Actual practices took place during the integrating of formative assessment intervention practices in both groups

Formative assessment intervention practices	Actions in experimental group	Actions in control group
Lessons content: Electricity and magnetism (3-weeks content)		
1. Explaining and clarifying learning objectives and success criteria	• Explanation of day' learning objectives at the beginning of the lesson was clearly stated. • Learners were constantly reminded of the learning objectives throughout the lesson	• No explanation was given, instead teachers ask for prior knowledge
2. Engineering effective and quality dialogue and inquiry	• Cooperative groups were considered and formed in a heterogenous manner. • Questions incorporated did stimulate high-order thinking and fostered dialogue	• Group were formed but not heterogenous it was upon learners to choose other members. • Questions incorporated did not consider all cognitive levels of physical science
3. Providing feedback that moves learners forward	• Teachers provided feedback to learners using comments instead of scores. • Learners were given ample opportunities to engage with feedback. • Instructional engagements were adjusted based on learners' feedback to teachers	• Feedback in terms of scores dominated the lesson. • Opportunities for learners to engage with the feedback were slim, as teachers were rushing to cover up the lesson concept
4. Using self and peer assessment	• Self and peer assessments were consistently integrated throughout the lesson. • Learners were instructed on the procedures for conducting self-assessments and peer assessments, and these assessments were discussed in each instance	• Self and peer assessments were integrated unintentional

effort regulation, attention focusing, utilization of additional resources, motivation regulation, summary strategy, self-instruction, planning, and highlighting strategy (refer to **Appendix A**). To ensure face and content validity, the questionnaires were presented to experts for feedback. Following expert opinions, some items underwent rephrasing or editing, with no items removed. Subsequently, after tool development and validation, pilot testing was conducted in a school within the Free State Province to assess reliability. The pilot testing affirmed the reliability of the learners' questionnaires.

Data Analysis

The data was analyzed using SPSS version 26 (statistical package for social sciences), while graphs were produced using Microsoft Excel 2021. The statistical approach employed was the 2-way ANOVA with repeated measures, chosen to ensure a high level of confidence in the results.

Exploratory Factor Analysis

Researchers chose to examine the relationship among the variables of the SRSS using exploratory factor analysis (EFA). EFA is a statistical method employed to uncover the underlying structure within a set of variables, aiming to identify latent factors that explain the shared variance among observed variables (Surucu et al., 2022). This technique aids researchers in understanding the fundamental dimensions or constructs influencing the observed data patterns (Surucu et al., 2022).

To explore potential alternative groupings of items beyond the original theoretical framework proposed by Seyhan (2015), an EFA was conducted. The EFA model utilized principal components extraction and oblimin rotation. Diagnostic statistics indicated the suitability of proceeding with factor analysis, with a Kaiser-Meyer-Olkin measure of sampling adequacy of 0.770 and a statistically significant chi-square value of 1,110.221 for Bartlett's test of sphericity with 406 degrees of freedom. Initially, ten factors for self-regulation were revealed. However, based on item grouping interpretation, factor loadings, and internal consistency results, a decision was made to conduct a second EFA, excluding specific items (SRS14, SRS25, SRS18, SRS7, SRS26, and SRS1).

In EFA, items are often removed to improve the clarity and validity of the identified factors. Items like "While studying for a topic, I take a break when I don't understand something" or "I motivate myself to study in order to be loved by my teacher" were excluded as they did not load strongly on any particular factor, or if they introduce excessive noise or overlap with other items. For instance, an item might not align well with the theoretical construct being measured, or it might not provide clear, distinctive information about the underlying dimensions of the construct. Additionally, statements that reflect very specific or less relevant aspects of study behavior might not contribute meaningfully to the overall factor structure and can dilute the interpretability of the factors. Removing such items helps to refine the factor structure, ensuring that the remaining items more accurately represent the underlying constructs and improve the reliability and validity of the factor solution.

The subsequent EFA yielded a Kaiser-Meyer-Olkin measure of sampling adequacy of 0.793, with Bartlett's test of sphericity resulting in a statistically significant chi-square value of 835.787 for 253 degrees of freedom. This refined analysis identified six factors with eigenvalues exceeding 1, explaining 51.647% of the variation. The first factor accounted for 21.796%, followed by the second (7.030%), third (6.775%), fourth (5.862%), fifth (5.257%), and sixth (4.927%). The pattern matrix, illustrating item grouping by factor with factor loadings, is presented in **Appendix B**.

Factor 1, consisting of items SRS15, SRS13, SRS12, and SRS16, was categorized as motivation regulation. Factor 2, comprising items SRS19, SRS17, SRS9, SRS24, SRS10, and SRS23, was labelled various strategies. Factor 3, composed of items SRS27, SRS29, and SRS28, was designated as a highlighting strategy. Factor 4, encompassing items SRS2, SRS3, and SRS11, was identified as Effort regulation. Factor 5, consisting of items SRS5, SRS6, SRS4, and SRS8, was denoted Attention focus. Factor 6, composed of items SRS20, SRS22, and SRS21, was categorized as planning. The EFA items were grouped accordingly, and colored; coloring groups in EFA is crucial for enhancing visualization and interpretation of the factor structure. By assigning different colors to each factor or group of items, researchers and readers can clearly distinguish between factors, identify patterns, and ensure accurate item-group associations. This visual differentiation simplifies understanding complex data, reduces the risk of misinterpretation, and effectively communicates findings to others. Lastly, coloring helps organize and present factor analysis results in a more intuitive and accessible manner.

Cronbach's alpha internal consistency measures for the empirical factors one through six were 0.716, 0.629, 0.638, 0.345 (0.541 with item SRS11 removed), 0.569, and 0.624, respectively. It is noteworthy that while certain reliability coefficients appear low, some factors comprise only three or four items, and the items within these factors may be conceptually related.

FINDINGS

The mixed between-within ANOVA has revealed a significant interaction effect concerning effort regulation, as depicted in **Table 3** and **Table 4**.

Table 3. Pre-intervention comparison of learners' self-regulation skills in term the **effort regulation** between the experimental and the control group

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	2.701	0.799	0.000	0.089	Medium
Control	57	2.895	0.767			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 4. Post-intervention comparison of learners' self-regulation skills in term of **effort regulation** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	2.124	0.397	0.000	0.089	Medium
Control	57	2.731	0.589			

Note. *Pearson correlation is quite significant with p-value of 0.000

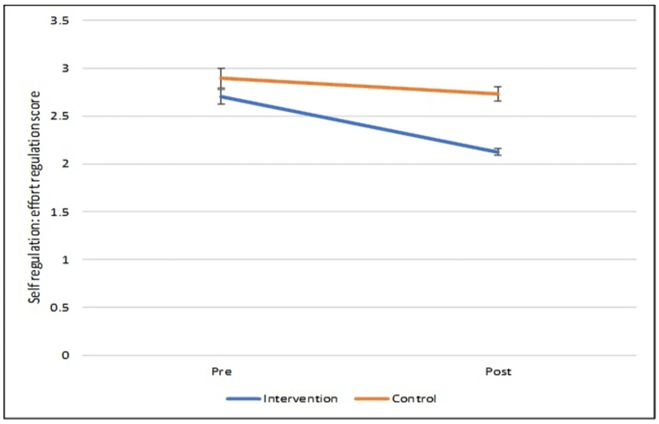

Figure 2. Pre- and post-self-regulation: effort regulation rating for intervention and control groups (Source: Authors' own elaboration)

In the pre-intervention phase, the experimental group exhibited an average score of 2.701, with a standard deviation of 0.799. Conversely, during the post-intervention phase, the average score decreased to 2.124, accompanied by a standard deviation of 0.397. In contrast, the control group, not subjected to the intervention, displayed average scores of 2.895 and 2.731 in the pre- and post-intervention phases, respectively. The standard deviations for the control group in the pre- and post-intervention phases were 0.767 and 0.589, respectively. The observed difference in the change pattern of effort regulation scores between the intervention and control groups is deemed to have a medium effect size, as indicated in **Table 3** and **Table 4**.

Figure 2 depicts the mean scores for effort regulation along with the standard error of the mean for both the intervention and control groups before and after the intervention. The graph indicates that effort regulation scores were comparable for both groups during the pre-measurement phase. However, after the intervention period, the experimental group shows a decline in effort regulation scores, whereas the control group maintains scores like those observed during the pre-measurement phase. This implies that exposure to formative assessment results in a decrease in effort regulation.

The mixed between-within ANOVA has detected a significant interaction effect for attention focus, as delineated in **Table 5** and **Table 6**.

In the pre-intervention phase, the average score for the experimental group was 3.843, with a standard deviation of 0.760, while in the post-intervention phase, it increased to 4.549, accompanied by a standard deviation of 0.384. On the other hand, the control group, devoid of any intervention, exhibited a pre-intervention average score of 3.636, with a standard deviation of 0.718, and a post-intervention average score of 3.873, with a standard deviation of 0.537. The observed disparity in the change pattern of attention focus scores between the intervention and control groups is considered to have a substantial effect, as elucidated in **Table 5** and **Table 6**.

Figure 3 depicts the mean scores for attention focus alongside the standard error of the mean for both the intervention and control groups before and after the intervention. The graph indicates that scores for attention focus were comparable for both groups during the pre-measurement phase. However, following the intervention period, the intervention group shows an uptick in attention focus scores, whereas the control group maintains scores like those observed during the pre-measurement phase. This implies that exposure to formative assessment enhances attention focus.

The mixed between-within ANOVA, aimed at assessing the influence of exposure to formative assessment across two time points (pre- and post-

Table 5. Pre-intervention comparison of learners' self-regulation skills in term of **attention focus** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	3.843	0.760	0.000	0.176	Large
Control	57	3.636	0.718			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 6. Post-intervention comparison of learners' self-regulation skills in term of **attention focus** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	4.549	0.384	0.000	0.176	Large
Control	57	3.873	0.537			

Note. *Pearson correlation is quite significant with p-value of 0.000

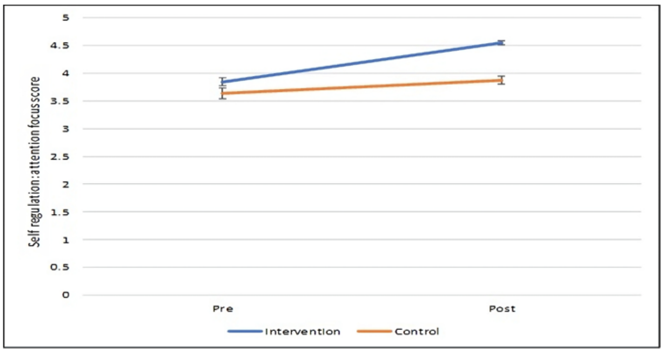

Figure 3. Pre- and post-self-regulation: attention focus rating for intervention and control groups (Source: Authors' own elaboration)

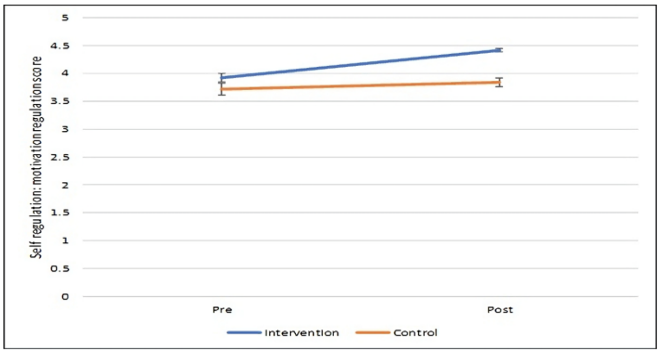

Figure 4. Pre- and post-self-regulation: motivation regulation rating for intervention and control groups (Source: Authors' own elaboration)

intervention), unveiled a noteworthy interaction effect for motivation regulation, as delineated in **Table 7** and **Table 8**.

In the pre-intervention phase, the average score for the experimental group was 3.917, with a standard deviation of 0.823, while post-intervention, the average score for the same group increased to 4.415, with a standard deviation of 0.363. For the control group, the results concerning motivation regulation were as follows: the pre-intervention score averaged 3.719, with a standard deviation of 0.809, while post-intervention, the average score was 3.842, with a standard deviation of 0.584. The observed discrepancy in the change pattern of motivation regulation scores between the intervention and control groups is deemed to have a moderate effect, as indicated in **Table 7** and **Table 8**, respectively.

Figure 4 depicts the mean scores for motivation regulation along with the standard error of the mean for both the intervention and control groups before and after the intervention.

The graph indicates that motivation regulation scores were comparable for both groups during the pre-measurement phase. However, following the intervention period, motivation regulation scores markedly increased for the intervention group while remaining consistent with initial values for the control group. This suggests that exposure to formative assessment enhances motivation regulation.

The mixed between-within ANOVA has unveiled a significant interaction effect for the highlighting strategy, as delineated in **Table 9** and **Table 10**. In the pre-intervention phase, the average score for the experimental group was 3.822, with a standard deviation of 0.849, whereas post-intervention, the average score surged to 4.492, with a standard deviation of 0.473. For the control group, the pre-intervention average score stood at 3.719, with a standard deviation of 0.666, while post-intervention, the average gain score was 3.807, with a standard deviation of 0.531. The observed disparity in the change pattern of highlighting strategy scores between the intervention and control groups is considered to have a substantial effect, as indicated in **Table 9** and **Table 10**.

Table 7. Pre-intervention comparison of learners' self-regulation skills in term of **motivation regulation** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	3.917	0.823	0.000	0.079	Medium
Control	57	3.719	0.809			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 8. Post-intervention comparison of learners' self-regulation skills in term of **motivation regulation** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	4.415	0.363	0.000	0.079	Medium
Control	57	3.842	0.584			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 9. Pre-intervention comparison of learners' self-regulation skills in term of **highlighting strategy** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	3.822	0.849	0.000	0.167	Large
Control	57	3.719	0.666			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 10. Post-intervention comparison of learners' self-regulation skills in term of **highlighting strategy** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	4.492	0.473	0.000	0.167	Large
Control	57	3.807	0.531			

Note. *Pearson correlation is quite significant with p-value of 0.000

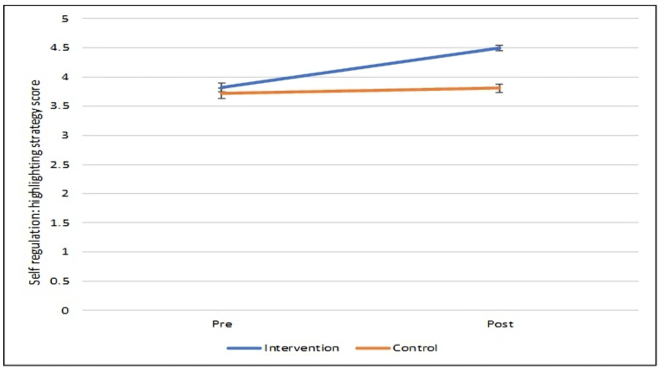

Figure 5. Pre- and post-self-regulation: highlighting strategy rating for intervention and control groups (Source: Authors' own elaboration)

Figure 5 exhibits the mean scores for the highlighting strategy alongside the standard error of the mean for both the intervention and control groups before and after the intervention.

The graph indicates that scores for the highlighting strategy were comparable for both groups during the pre-measurement phase. However, after the intervention period, the intervention group shows a rise in highlighting strategy scores, while the control group maintains scores like those observed during the pre-measurement phase. This implies that exposure to formative assessment enhances the utilization of the highlighting strategy.

The mixed between-within ANOVA has unveiled a significant interaction effect for various strategies, as delineated in **Table 11** and **Table 12**.

In the pre-intervention phase, the average gain score for the experimental group was 3.383, with a standard deviation of 0.658, while post-intervention, the average gain score surged to 4.453, with a standard deviation of 0.279. For the control group, the pre-intervention average score stood at 3.620, with a standard deviation of 0.613, whereas post-intervention, the average score was 3.769, with a standard deviation of 0.432. The observed disparity in the change pattern of various strategies scores between the intervention and control groups is considered to have a very large effect, as highlighted in **Table 11** and **Table 12**.

Figure 6 depicts the mean scores for various strategies alongside the standard error of the mean for both the intervention and control groups before and after the intervention. The graph indicates that scores for various strategies were similar for both groups during the pre-measurement phase. However, following the intervention period, the intervention group shows a rise in various strategies scores, while the control group maintains scores like those observed during the pre-measurement phase. This implies that exposure to formative assessment enhances the utilization of various strategies.

The mixed between-within ANOVA has revealed a significant interaction effect for planning, as delineated

Table 11. Pre-intervention comparison of learners' self-regulation skills in term of **various strategies** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	3.383	0.658	0.000	0.455	Very large
Control	57	3.620	0.613			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 12. Post-intervention comparison of learners' self-regulation skills in term of **various strategies** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	4.453	0.279	0.000	0.455	Very large
Control	57	3.769	0.432			

Note. *Pearson correlation is quite significant with p-value of 0.000

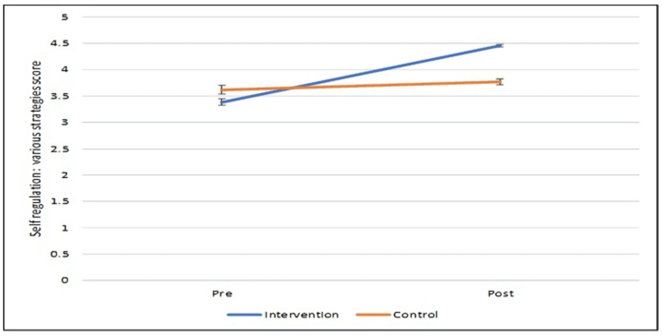

Figure 6. Pre- and post-self-regulation: various strategies rating for intervention and control groups (Source: Authors' own elaboration)

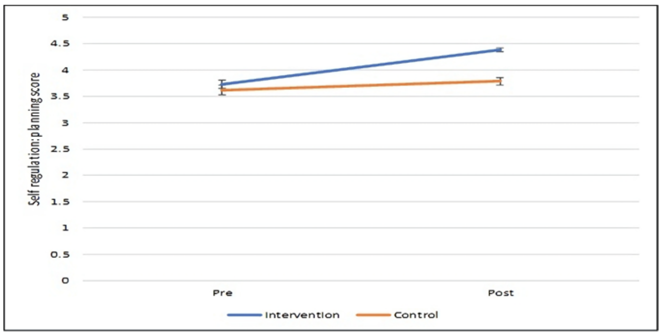

Figure 7. Pre- and post-self-regulation: planning rating for intervention and control groups (Source: Authors' own elaboration)

Table 13. Pre-intervention comparison of learners' self-regulation skills in term of **planning** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	3.729	0.815	0.000	0.139	Large
Control	57	3.620	0.711			

Note. *Pearson correlation is quite significant with p-value of 0.000

Table 14. Post-intervention comparison of learners' self-regulation skills in term of **planning** between the experimental and control groups

Groups	N	Average	Standard deviation	p-value	Eta squared	Effect size
Experimental	118	4.381	0.378	0.000	0.139	Large
Control	57	3.784	0.551			

Note. *Pearson correlation is quite significant with p-value of 0.000

in **Table 13** and **Table 14**. In the pre-intervention phase, the average score for the experimental group was 3.729, with a standard deviation of 0.815, while post-intervention, the average score surged to 4.381, with a standard deviation of 0.378. For the control group, the pre-intervention average score stood at 3.620, with a standard deviation of 0.711, whereas post-intervention, the average score was 3.784, with a standard deviation of 0.551. The observed disparity in the change pattern of planning scores between the intervention and control groups is considered to have a substantial effect, as highlighted in **Table 13** and **Table 14**.

Figure 7 illustrates the mean scores for planning along with the standard error of the mean for both the intervention and control groups before and after the intervention. The graph indicates that scores for planning were comparable for both groups during the pre-measurement phase. However, following the intervention period, the intervention group shows an elevation in planning scores, while the control group maintains scores like those observed during the pre-measurement phase. This implies that exposure to formative assessment enhances planning.

DISCUSSION

The research outcomes concerning the promotion of learners' SRL through formative assessment practices in physical sciences classrooms highlight several key points. Firstly, the intervention group exhibited superior performance compared to the control group across various facets of SRL, as outlined by Seyhan (2015), encompassing effort regulation, attention focus, motivation regulation, and planning. This suggests that formative assessment practices play a crucial role in enhancing learners' capacity to regulate their learning effectively.

Moreover, the findings underscored the significance of employing a conceptual framework to guide the study. By embracing Boekaerts' (1999) three-layered SRL model, the researchers structured their investigation and assessed the impact of formative assessment practices on different layers of SRL. This approach yielded a comprehensive understanding of how formative assessment intervention practices influenced learners' SRL behaviors and strategies. Additionally, the study identified specific strategies and actions implemented by the experimental group that contributed to their enhanced SRL outcomes. These strategies included adept use of highlighting, utilization of diverse learning strategies, and robust planning techniques. Concurrently, the actions involved providing quality feedback, fostering critical thinking through dialogue, clarifying learning objectives and success criteria, and integrating self and peer assessment. By pinpointing these strategies and actions, physical sciences teachers can better customize their instructional approaches to cultivate SRL in science classrooms.

In essence, the findings underscore the importance of integrating formative assessment practices into science classroom routines to foster SRL. Through the implementation of targeted intervention practices guided by conceptual frameworks such as Boekaerts' (1999) model, teachers can empower learners to take charge of their learning processes and achieve heightened academic success.

Recommendations

Based on the findings of the study, several recommendations are outlined:

Integration of formative assessment practices: Encourage physical sciences teachers to integrate formative assessment practices into their classroom routines. This could include providing regular feedback, clarifying learning objectives, promoting self and peer assessment, and fostering critical thinking dialogue.

Professional development: Provide professional development opportunities for physical sciences teachers to enhance their understanding and implementation of formative assessment practices. Workshops, seminars, and ongoing training sessions can help teachers effectively incorporate these strategies into their teaching methodologies.

Utilization of conceptual frameworks: Encourage teachers to utilize conceptual frameworks, such as Boekaerts' (1999) three-layered SRL model, to guide their instructional practices. This framework can help teachers understand the underlying mechanisms of SRL and tailor their interventions accordingly.

Promotion of metacognitive strategies: Emphasize the importance of metacognitive strategies in promoting SRL. Teachers should encourage students to reflect on their learning processes, monitor their understanding, and adjust their strategies as needed.

Differentiation of instruction: Recognize the diverse needs and learning styles of students in physical sciences classrooms. Teachers should differentiate their instruction to accommodate various levels of readiness, interests, and learning preferences, thereby promoting SRL among all students.

Collaborative learning opportunities: Foster collaborative learning environments where students can work together, share ideas, and support each other's learning. Collaborative activities can enhance students' self-regulation skills by promoting communication, teamwork, and problem-solving abilities.

Continuous evaluation and improvement: Encourage ongoing evaluation and reflection on the effectiveness of formative assessment interventions. Teachers should regularly assess student progress, solicit feedback from students, and adjust their instructional practices as necessary to continually enhance students' SRL.

By implementing these recommendations, educators can effectively enhance learners' SRL in physical sciences classrooms and contribute to improved academic achievement and lifelong learning skills.

CONCLUSION

This study has provided valuable insights into the enhancement of learners' SRL in physical sciences classrooms through the implementation of formative assessment intervention strategies. The findings underscore the effectiveness of formative assessment practices in promoting various aspects of SRL, including effort regulation, attention focus, motivation regulation, and planning. By adopting Boekaerts' (1999) three-layered SRL model as a guiding framework, the study elucidated the intricate interplay between formative assessment practices and learners' SRL behaviors. The intervention group demonstrated superior performance compared to the control group, emphasizing the pivotal role of formative assessment in empowering learners to regulate their learning effectively. Moreover, the study identified specific strategies and actions employed by the intervention group that contributed to their enhanced SRL outcomes. These included effective utilization of highlighting, diverse learning strategies, and robust planning techniques, coupled with quality feedback provision, critical thinking dialogue, and clear learning objectives clarification.

Overall, the findings highlight the importance of integrating formative assessment practices into physical sciences classrooms to foster SRL. By implementing targeted intervention strategies guided by conceptual frameworks like Boekaerts' (1999) model, educators can facilitate a conducive learning environment where learners actively engage in their learning processes, ultimately leading to improved academic achievement and lifelong learning skills.

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Ethical statement: This study was approved by the Faculty of Education Research Ethics Committee, under the approval reference number [Sem 1-2022-059], on [5 April 2022]. All research procedures adhered to the guidelines set forth by the committee, ensuring that the rights, privacy, and welfare of all participants were protected. Informed consent was obtained from all participants prior to their involvement in the study. Participants were fully briefed on the study's objectives, their voluntary participation, the confidentiality of their responses, and their right to withdraw from the study at any point without consequence.The authors further stated that sensitive or personal data collected during the study was anonymized to protect the identities of the participants. Data were securely stored in password-protected files, accessible only to the research team. All identifying information was removed to ensure confidentiality, and results were reported in aggregate form to prevent the identification of individual participants. No vulnerable populations were involved in this study. The research posed minimal risk to participants and complied with ethical standards for educational research. As such, no additional ethical approval was required beyond the institutional committee review.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: SELF-REGULATION SKILLS QUESTIONNAIRE

Self-Regulation Skills

This section includes questions measuring self-regulation skills. Please read each statement and then choose the response option which best represents your experience.

Please use a cross (X) to indicate your response.

Table A1. Questions

	Items	N	R	S	O	U	A
F1	While studying for a topic, I take a break when I don't understand something						
	While studying, I quit if I am bored						
	I quit studying if I don't understand the topic						
F2	On my desk, I only keep resources required for studying (books, notebooks etc.)						
	I switch off the television in order to concentrate while studying						
	I try to remove the things which distract me while studying						
	Before starting to study, I organize the environment in which I will study						
	I study in a quiet environment in order to concentrate						
F3	I use different resources when I study a topic						
	While studying for a topic, I combine the information I gather from different resources						
	While studying for a topic, I solve questions from test books other than course books						
F4	While studying, I remind myself that the topic will be necessary in my future life						
	I motivate myself to study more by thinking that I will get a high mark						
	I motivate myself to study in order to be loved by my teacher						
	I persuade myself that I need to study hard in order to learn the topic						
	While studying, I remind myself how important getting a good mark is.						
F5	While studying, I summarize the topic by drawing schemas						
	While studying, I summarize using my own sentences						
	While studying I will make a list of the concepts, I do not understand						
F6	I explain the method I used to solve a question to myself						
	While studying for a topic I explain the topic to myself						
	I ask myself questions in order to be sure that I understand the topic I study						
F7	I make a study plan before starting to study						
	I list what I should do before starting to study						
	Before starting a study, I determine what I should learn						
	Before starting to study, I decide what method I will use to study						
F8	While studying, I write down the definitions of important concepts						
	While studying for a topic, I underline the important points						
	While studying for a topic, I mark the important points with color markers						

Note. F1: Effort regulation; F2: Attention focusing; F3: Using additional resources; F4: Motivation regulation; F5: Summary strategy; F6: Self-instruction; F7: Planning; F8: Highlighting strategy; N: Never; R: Rarely; S: Sometimes; O: Often; U: Usually; & A: Always

APPENDIX B: EFA PATTEN MATRIX FOR SELF-REGULATION STATEMENTS

Table B1. EFA patten matrix for self-regulation statements

Item	1	2	3	4	5	6
SRS15 I persuade myself that I need to study hard in order to learn the topic	0.755	-0.138	-0.097	0.012	0.073	-0.038
SRS13 I motivate myself to study more by thinking that I will get a high mark	0.695	-0.095	0.161	0.000	0.016	-0.191
SRS12 While studying, I remind myself that the topic will be necessary in my future life	0.659	0.026	-0.131	-0.138	0.140	0.072
SRS16 While studying, I remind myself how important getting a good mark is.	0.489	0.132	0.147	-0.129	0.048	-0.318
SRS19 While studying I will make a list of the concepts, I do not understand	-0.156	0.649	-0.063	-0.181	0.058	-0.284
SRS17 While studying, I summarize the topic by drawing schemas	-0.118	0.562	-0.051	0.188	0.138	0.016
SRS9 I use different resources when I study a topic	-0.085	0.543	0.042	-0.273	-0.035	-0.048
SRS24 I list what I should do before starting to study	0.248	0.530	0.023	-0.011	0.007	0.014
SRS10 While studying for a topic, I combine the information I gather from different resources	0.400	0.508	0.183	0.073	-0.270	0.078
SRS23 I make a study plan before starting to study	-0.029	0.449	0.109	0.127	0.309	-0.028
SRS27 While studying, I write down the definitions of important concepts	0.065	0.082	0.801	-0.021	-0.081	0.319
SRS29 While studying for a topic, I mark the important points with color markers	-0.110	-0.011	0.757	-0.096	-0.063	-0.085
SRS28 While studying for a topic, I underline the important points	-0.076	-0.139	0.710	0.083	0.237	-0.146
SRS2 While studying, I quit if I am bored	-0.124	-0.136	-0.019	0.758	0.006	-0.022
SRS3 I quit studying if l don't understand the topic	-0.163	0.019	-0.086	0.574	-0.430	-0.206
SRS11 While studying for a topic, I solve questions from test books other than course books	0.318	0.288	-0.034	0.439	0.117	0.285
SRS5 I switch off the television in order to concentrate while studying	-0.004	-0.091	-0.105	-0.011	0.788	-0.114
SRS6 I try to remove the things which distract me while studying	0.162	0.075	0.127	-0.103	0.466	-0.014
SRS4 On my desk, I only keep resources required for studying (books, notebooks, etc.)	0.055	0.161	0.067	0.009	0.444	0.186
SRS8 I study in a quiet environment in order to concentrate	0.106	0.187	0.161	-0.050	0.386	-0.219
SRS20 I explain the method I used to solve a question to myself	0.170	0.265	-0.075	0.005	0.024	-0.680
SRS22 I ask myself questions in order to be sure that I understand the topic I study	0.167	0.048	0.152	0.188	0.354	-0.439
SRS21 While studying for a topic I explain the topic to myself	0.403	0.001	0.233	0.035	-0.033	-0.439