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Self-Directed Learning as a Strategy to Enhance Students Science Concept Mastery

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Abstract

Self-Directed Learning (SDL) is a teaching approach that emphasizes autonomy, self-control, and active student involvement in the learning process. In the context of science education, SDL has the potential to improve concept mastery through self-investigation experiences, experimental activities, and deeper meaning-making. This study aims to evaluate the effectiveness of the self-directed learning approach through the Self-Directed Science Experiment Module (SDSEM) in enhancing students' concept mastery for the topic of methods of separating mixtures in the Form One Science subject. The study employed a quasi-experimental design with a non-equivalent control group (pre-test–post-test), involving 78 students in a Government-Assisted Religious School (GARS). The treatment group followed lessons using SDSEM, which involved conducting experiments independently, while the control group followed conventional teaching based on group experiments using standard laboratory apparatus. The Concept Mastery Test (CMT) instrument consisted of 20 multiple-choice items covering the entire topic. The findings showed that there was a significant effect on science concept mastery when self-directed learning was applied. Overall, this study demonstrates that the self-directed learning approach through SDSEM is effective in improving students' concept mastery and is appropriate to be applied as an alternative teaching strategy in science education.

Keywords: Self-Directed Learning, Concept Mastery, Module, Science Education, Learning Strategy

Introduction

Mastery of science concepts refers to the mental structures that enable students to construct a systematic understanding of natural phenomena through processes of observation, interpretation, and meaning-making (Faridah, Mohd & Suhailah 2019). It also encompasses the ability to relate abstract ideas to observable events, thereby forming a coherent cognitive framework that supports deeper conceptual understanding (Goldwater & Schalk 2016). This foundation is crucial as it underpins students' ability to comprehend more complex scientific topics and apply their knowledge meaningfully in real-life contexts (Wan & Lilia 2016).

Therefore, strengthening concept mastery is essential in efforts to enhance the overall quality of science education.

In the context of science education in Malaysia, issues related to students' weaknesses in concept mastery have long been identified. International assessment reports such as TIMSS and PISA consistently show that Malaysian students record low levels of conceptual understanding, particularly in the domains of reasoning, interpretation, and application of scientific knowledge (Education Policy Planning and Research Division, 2016; 2023). Most students still practise memorisation without understanding the relationships between concepts, causing them to struggle to solve real-world problems and fail to connect science learning with everyday life experiences. This indicates that the weaknesses do not only stem from cognitive factors but are also influenced by pedagogical approaches that do not sufficiently support meaningful construction of science concepts.

One of the main factors contributing to this issue is teacher-centred teaching practices, the use of memorisation without understanding, time constraints, as well as limited implementation of experimental activities (Hasmiza et al. 2023; Zaitul et al. 2022). Such methods limit students' opportunities to explore, make decisions, communicate, and take responsibility for their learning. As a result, students become passive, lack initiative, and fail to develop metacognitive skills needed to understand science concepts in depth. Although the curriculum emphasises active learning, studies that systematically integrate student autonomy in science experiments, especially in rural schools, are still lacking.

Findings from previous studies also show that students face difficulties in mastering science concepts when learning does not emphasise exploration, hands-on activities, and lacks approaches towards exploring relationships between science concepts and real-world situations (Fatin et al. 2014; Siti & Lilia 2021; Zaitul et al. 2022). Such an approach exposes students towards forming autonomous learning and at the same time builds good conceptual understanding. Lack of autonomy in the learning process causes students to build only basic knowledge and fail to achieve deeper understanding as outlined in the science curriculum. Therefore, there is a need to introduce teaching strategies that provide space and autonomy for students to control their own learning.

Self-Directed Learning (SDL) is one of the approaches that has the potential to support concept construction through active student engagement, autonomy, and the decision-making process. According to Grow (1991), SDL enables students to set goals, choose strategies, explore learning materials, and assess their own progress. In science education, SDL provides opportunities for students to conduct experiments, test ideas, and relate concepts to real-world experiences in a more authentic way. This approach can also overcome the limitations of conventional experimental practices by providing space for students to construct meaning through self-directed exploration.

This study was conducted in a Government-Assisted Religious School (SABK) located in a rural area that typically faces limitations in facilities and experimental materials (Rozita et al. 2021). To address this issue, this study applies a self-directed experimental approach using simple and easily accessible materials while still aligning with the Malaysian science curriculum. This context is significant because rural religious schools rarely become the focus in innovative pedagogical research, especially studies involving self-directed experiments based on SDL.

The purpose of this study is to evaluate students' mastery of science concepts when they conduct experiments in a self-directed manner using everyday materials that are easily obtained. Students carry out experiments individually without sharing materials, thereby giving them full autonomy in the experimental process. This approach not only nurtures independent learning but also develops science process skills holistically. It also allows the effectiveness of SDL to be evaluated in real learning contexts.

Through the implementation of SDL using the Self-Directed Science Experiment Module (SDSEM), this study contributes to the literature related to hands-on activities in the context of self-directed learning. It also offers practical guidance to teachers, especially in rural schools that face limitations in laboratory equipment. The use of materials that are not from formal laboratories proves that meaningful science learning can still be achieved even in limited-resource conditions.

The uniqueness of this study lies in its focus on Form One students in rural religious schools. This target group is less given attention in SDL-based learning research in particular. This study also introduces a unique pedagogical framework through the integration of Grow's SDL Model and the 5E model, which provides a structured approach to foster student autonomy in science learning. In addition, the use of everyday materials familiar to students' lives adds authenticity to this approach, enabling them to conduct experiments individually while mastering science concepts and science process skills more effectively

This study offers three main contributions to the field of social science and science education. First, from the aspect of new pedagogical design, the Self-Directed Learning Science Experiment Module is developed in a structured manner by integrating simple materials that are easily obtained, thus providing a practical inquiry learning approach. Second, this study provides a contextual contribution by offering empirical evidence in the GARS context, which is still under-explored, thereby enriching the literature on science learning in educational environments based on religious schools. Third, this study also contributes theoretically through the integration of constructivism principles, SDL and science process skills, and presents a comprehensive model that shows how SDL can enhance concept mastery in the practical implementation of science experiments.

Literature Review

Self-Directed Learning (SDL) refers to the process in which students take the initiative in planning, implementing, and evaluating their own learning (Knowles, 1975). SDL emphasises autonomy, intrinsic motivation, self-reflection, and active engagement, differing from traditional learning that relies more on teacher direction. Candy (1991) states that in SDL, students act as active learning agents who make decisions regarding resources, strategies, and methods for completing learning tasks. The theoretical foundation is associated with constructivist theory, which emphasises that individuals must construct their own knowledge through active learning. In the context of self-directed learning, constructivist theory supports the notion that students should build their understanding independently.

In addition, Grow (1991) introduced the Staged Self-Directed Learning Model (SSDL), which outlines the stages of students' development of autonomy. It involves four main stages of self-directed learning:

a) Stage 1 (Dependent Learner): Students depend entirely on the teacher, requiring clear instruction and strict structure. The teacher acts as a coach.
b) Stage 2 (Interested Learner): Students begin to show interest and respond to guidance. The teacher acts as a motivator.
c) Stage 3 (Involved Learner): Students participate actively and engage in planning their learning. The teacher acts as a facilitator.
d) Stage 4 (Self-Directed Learner): Students achieve full autonomy and are able to make learning decisions independently. The teacher acts as a consultant at this stage.

In this study, the SDSEM was developed based on Grow's principles as well as the 5E instructional model, particularly at Stage Four of SDL, where students are given the space and opportunity to conduct self-directed experiments using everyday materials while following the provided guidelines. The teacher functions as a consultant rather than the main instructor, thereby encouraging students to progress towards learning autonomy.

The Self-Directed Learning Approach in Teaching and Learning
Self-directed learning (SDL) has been widely recognised as an instructional approach that offers substantial benefits, particularly in supporting students' cognitive development (Hind 2014; Adenan & Nazri 2018). Empirical studies by Ahmad et al. (2019), Adenan and Nazri (2018), and Arshad et al. (2019) consistently report that SDL contributes positively to students' academic performance, cognitive readiness, and learning engagement.

Despite these advantages, several studies highlight that some students perceive SDL as demanding and time-consuming compared to conventional teacher-centred instruction, which they view as more straightforward (Abraham et al. 2016; Mohd Mokhzani et al. 2017; Kwan & Ester 2018). Some students also prefer teacher-centred approaches due to negative prior experiences with SDL, which they felt did not yield successful learning outcomes (Maimunah & Hashimah 2017).

Challenges in implementing SDL are often attributed to insufficient teacher guidance, rigid instructional structures, and classroom environments that lack flexibility (Robotham 2000). Although many teachers acknowledge the value of SDL, they continue to favour teacher-centred practices because they feel uncertain or inadequately prepared to design SDL-oriented lessons (Arshad et al. 2019). This reinforces the need for structured learning modules that can guide both teachers and students in implementing SDL effectively. Radin et al. (2020) similarly advocate the development of SDL modules to ensure equitable access to quality learning opportunities. In line with these recommendations, the SDSEM approach in this study addresses these concerns by providing guided, module-based support for students undertaking self-directed science learning activities.

Student-centred approaches within SDL have been shown to promote greater learner responsibility and seriousness towards learning tasks (Yap, Neo & Neo 2014). While SDL has been integrated into subjects such as Malay Language, English Language, History, and

Mathematics (Adenan & Nazri 2018; Kleden 2013; Hind 2014; Kaviza 2020), its application in science education remains relatively limited. Therefore, this study adopts a self-directed learning module specifically tailored for science to strengthen students' SDL competencies, particularly in conducting independent experimental activities.

Research Gap and Rationale

Despite the well-documented benefits of Self-Directed Learning (SDL), existing studies predominantly focus on higher education contexts, high-performing or smart schools, and selected subject areas. Empirical evidence on the impact of SDL among students in Government-Assisted Religious Schools (GARS), particularly those located in rural environments, remains limited. Furthermore, there is an absence of structured, self-directed experimental modules tailored for science education, especially for conducting hands-on experimental activities.

To address these gaps, the present study introduces the Self-Directed Science Experiment Module (SDSEM), a structured SDL-based module that integrates independent experimental tasks, fundamental science process skills, and assessment components within the understudied context of Form One religious secondary schools. This study provides empirical evidence on the effectiveness of SDL in enhancing students' mastery of science concepts, thereby establishing the pedagogical rationale for implementing self-directed experimental learning in rural GARS settings.

Methodologi

Research Design

This study employed a quasi-experimental design with a non-equivalent control group involving a pre-test and post-test (nonequivalent control group pre-test post-test design). This design was chosen because random assignment of students into groups could not be carried out due to school constraints. Therefore, existing classes were randomly selected as the treatment group and control group. This approach is aligned with Chua (2011), who stated that a quasi-experimental design is appropriate when full randomisation cannot be implemented but group comparisons are still required.

The treatment group received instruction using the Self-Directed Science Experiment Module (SDSEM), while the control group received conventional teaching. Both groups completed a pre-test before the intervention and a post-test after the intervention. The duration of the study was seven weeks. Weeks one and seven involved the administration of the pre-test and post-test. The total duration for the self-directed experimental activities was six weeks, involving six self-directed experimental activities for the topic of mixture separation in Form One Science.

Instrument

Students' concept mastery was measured using a Concept Mastery Test comprising 20 multiple-choice items. The instrument was administered to both the treatment and control groups during the pre-test phase and again after the intervention.

Multiple-choice items were chosen because they allow broad coverage of learning objectives (Ebel 1979), assess various cognitive levels (Higgins & Tatham 2003; McDonald 2002), reduce grading inaccuracies (Blerkom 2008), and eliminate examiner subjectivity due to fixed-response formats (Kjoernsli & Jorde 1992). Ramesh et al. (2005) also note that multiple-choice assessments are widely used and encourage higher student participation, particularly in school settings.

Data Analysis

This section reports the analytical procedures used to evaluate the impact of the Self-Directed Science Experiment Module (SDSEM) on students' conceptual understanding of mixture separation methods. Both descriptive and inferential analyses were conducted, including Repeated Measures ANOVA to examine the interaction effects between groups over time. Ethical considerations were strictly observed, and all respondent information was kept confidential with no personal identifiers included in the reporting.

Finding

To evaluate the effectiveness of the self-directed learning approach on students' science concept mastery, the pre-test and post-test scores were analysed using the *Statistical Package for the Social Sciences* (SPSS).

Descriptive Statistics

Table 1 presents the descriptive statistics for concept mastery scores across the control and treatment groups. At the pre-test level, both groups showed comparable scores, with the control group (M = 10.84, SD = 3.51) and the treatment group (M = 10.63, SD = 3.14) demonstrating similar baseline understanding. This indicates that both groups started at an equivalent level.

Following the intervention, the treatment group recorded a substantial improvement (M = 16.68, SD = 2.34), outperforming the control group (M = 12.61, SD = 3.05). The increased post-test mean score in the treatment group reflects the positive effect of the SDSEM intervention on students' conceptual mastery. Figure 1 graphically illustrates the comparative trends of the two groups across testing periods.

Table 1
Descriptive Statistic for Concept Mastery Scores by Group

Test	**Group**	**N**	**Mean (M)**	**Standard Deviation (SD)**
Pre-test	Control	38	10.84	3.51
	Treatment	40	10.63	3.14
Post-test	Control	38	12.61	3.05
	Treatment	40	16.68	2.34

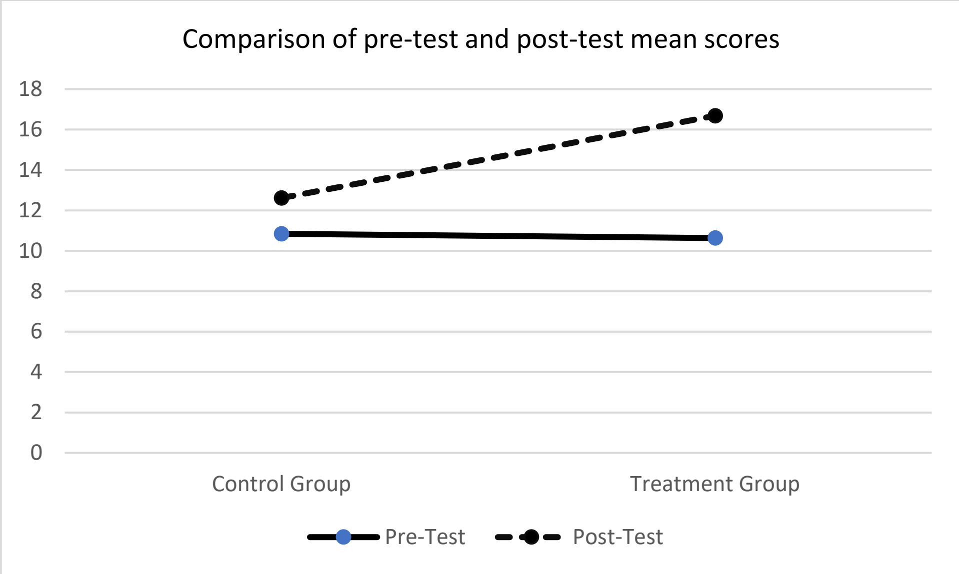

Figure 1 Comparison of mean concept mastery scores by group and test time

Comparison of Science Concept Mastery between Control and Treatment Groups
A two-way ANOVA was conducted to examine the effects of two factors, namely the independent variables on one dependent variable, as well as the interaction between both factors. In this study, the independent variables were time (pre and post) and group (control and treatment), while the dependent variable was concept mastery

The multivariate analysis results in Table 2 show a significant main effect of time on concept mastery, Pillai's Trace = 0.521, $F(1,76) = 82.584$, $p < 0.001$, with a large effect size (Partial $\eta^2 = 0.521$). This indicates that students' concept mastery improved significantly from pre-test to post-test.

A significant interaction effect between time and group was also found, Pillai's Trace = 0.246, $F(1,76) = 24.861$, $p < 0.001$, with a large effect size (Partial $\eta^2 = 0.246$). This demonstrates that the magnitude of improvement differed between groups, with the treatment group showing a substantially larger gain compared to the control group.

Table 2
Multivariate Test Results for Concept Mastery

Effect	**Pillai's Trace**	**F**	**df1**	**df2**	**p**	***Partial Eta Squared***
Masa	0.521	82.584	1	76	**0.00**	0.521
Masa*Kumpulan	0.246	24.861	1	76	**0.00**	0.246

Further analysis using within-subject effects (Table 3) supports these findings. There was a significant main effect of time on concept mastery scores, $F(1,76) = 82.584$, $p < 0.001$, Partial $\eta^2 = 0.521$, indicating strong overall improvement. Additionally, a significant time × group interaction, $F(1,76) = 24.861$, $p < 0.001$, Partial $\eta^2 = 0.246$, confirms that the treatment group improved at a substantially higher rate compared to the control group.

Table 3
Within-Subject for Concept Mastery Scores

Effect	Sum of Squares	df	Mean Square	F	P	*Partial eta Square*
Time	594.802	1	594.802	82.584	**0.000**	0.521
Time* Group	179.058	1	179.058	24.861	**0.000**	0.246

Overall, the results provide strong evidence that self-directed learning via the SDSEM significantly enhances students' science concept mastery. Despite using non-conventional, everyday materials instead of standard laboratory equipment, students in the treatment group demonstrated deeper understanding of the principles and procedures of mixture separation. Their substantial score gains suggest that the self-directed experimental approach encouraged active engagement, independent decision-making, problem identification, and hypothesis testing and it's a key process that support the development of meaningful conceptual understanding.

Discussion

The findings of this study show that self-directed learning provides a significant improvement in science concept mastery among Form One students. Overall, the results show that the self-directed learning approach leads to a substantial increase in students' understanding of the topic of mixture separation compared to conventional teaching methods.

In this study, the self-directed learning approach through the implementation of individually conducted experimental activities enabled each student to be directly involved in hands-on activities. This approach was intentionally used to address the common issue in group experiments, where a small number of students dominate the tasks while others only act as helpers, observers, or simply copy the results (Salasiah 2016; Suriyati 2020). Such imbalance in participation limits active engagement and meaningful learning experiences, which then contributes to uneven levels of conceptual understanding (Nurzatulshima & Lilia 2009). Therefore, the implementation of individual experiments for each student is more effective in developing scientific reasoning, critical and creative thinking, motivation, content mastery, and conceptual understanding (Rambely & Paujian 2012; Kamarudin 2012; Ministry of Education Malaysia 2015a; Fazilah & Othman 2016; Norazilawati et al. 2017; Lilia & Tamby 2016; Prescilla & Kamisah 2017), in addition to creating meaningful experiences.

Meaningful learning experiences gained through self-directed experimental activities in SDSEM were found to contribute directly to students' conceptual understanding. According to Ausubel et al. (1978), meaningful learning occurs when new knowledge are connected with prior knowledge, forming deeper cognitive structures. The structured use of everyday materials familiar to students within this module is one of the ways used to help them make connections between prior knowledge and the context of science experiments. This aligns with the findings of Irish & Kang (2018), Gomes & Fleer (2019), Kadri et al. (2023), and Levy & Moore (2021), who reported that real-life experiences help students understand scientific concepts more deeply and form meaningful learning experiences. This study also found that students with strong prior knowledge demonstrated stronger conceptual understanding. This is consistent with the findings of Preston (2019), Stammes et al. (2023), and Mason et al. (2019), who found that strong prior knowledge helps develop good concept mastery.

The SDSEM approach, which is based on self-directed experimental learning, also provides autonomy and active involvement to students. These two elements are important in shaping good conceptual understanding. The findings of Ware et al. (2019) showed that active learning can enhance science concept mastery. Other studies also support these findings, including Salome et al. (2023), Yusmail & Sabariah (2021), and Sshana & Abulibdeh (2020), who found that intensive and independent involvement in experimental activities leads to improved academic achievement and conceptual understanding. Sshana & Abulibdeh (2020) also suggested that students should be given sufficient opportunities to engage in experiments and that schools should ensure that science laboratories are adequately equipped.

In conclusion, the implementation of individually conducted experimental activities provides significant advantages in developing science concept mastery. Providing students with autonomy, ownership and active responsibility in managing their learning is aligned with the principles of self-directed learning. The findings of this study clearly show that self-directed learning is an effective pedagogical approach for improving students' science concept mastery.

Conclusion

The findings of this study clearly demonstrate that the self-directed learning module offers significant advantages over conventional teaching methods. Through SDSEM, students are provided with opportunities to engage actively in independent experiments, utilise easily accessible environmental materials, and apply science process skills throughout the activities. The combination of these features has been shown to support the development of deeper, stronger, and more meaningful conceptual understanding.

In addition, the self-directed approach embedded within SDSEM enhances students' learning autonomy, strengthens their problem-solving abilities, and fosters scientific thinking that aligns with the aspirations of 21st-century learning. Overall, this study provides empirical evidence that self-directed learning–based science modules represent an effective instructional strategy with strong potential for wider implementation in secondary school science education.

For future research, it is recommended that the self-directed learning module be further improved by applying SDSEM to additional science topics, as well as involving larger and more diverse sample sizes. Conducting studies across multiple schools or districts may also provide a more comprehensive understanding of the module's effectiveness. Furthermore, incorporating digital components such as videos, animations, or interactive simulations is suggested to enhance conceptual understanding and facilitate students' independent revision

Overall, this study affirms the effectiveness of SDSEM as a self-directed learning strategy capable of enhancing students' science concept mastery. The module (SDSEM) not only provides an innovative instructional teaching and learning but also holds strong potential as a foundation for the development of alternative science learning materials that are more flexible, autonomous and student-centred based on self-directed learning strategy.

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