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Effect of E-learning Self-directed Interactive Module (E-SelfIMo) on Students' Understanding of Earth Science Concepts

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ABSTRACT

This study sought to determine the effect of using a researcher-developed e-learning self-directed interactive module (E-SelfIMo) in enhancing the conceptual understanding of selected earth science concepts by senior high school students in the STEM strand of Sorsogon National High School. The study used a mixed-methods approach, consisting of an explanatory sequential research design and a randomized pretest-posttest control group, to compare the conceptual understanding levels of an experimental group of 30 students exposed to E-SelfIMo with 30 students in a control group. An unpaired t-test revealed no significant difference between the initial (pretest) levels of conceptual understanding of the two groups [t(58) = 0.2445, p = 0.40]. After exposure to E-SelfIMo, After exposure to E-SelfIMo, the experimental group demonstrated a significantly higher level of conceptual understanding ($\bar{x}$ = 129.8, SD = 7.35) than the control group ($\bar{x}$ = 112.63, SD = 9.84), t(58) = 7.66, p = 0.0001. This result was also supported by the large effect size, with a Cohen's d value of 1.996. Qualitative analysis also supported the quantitative findings, reporting significant knowledge gains, improved learning skills, greater engagement, enhanced understanding, and positive overall learning experiences among participants due to the interactive simulations, multimedia content, and self-directed nature. The study concludes that students exposed to E-SelfIMo demonstrated significantly higher levels of conceptual understanding, indicating its positive effect on learning outcomes.

RESUMEN

Este estudio tuvo como objetivo determinar el efecto del uso de un módulo interactivo autodirigido de aprendizaje electrónico desarrollado por el investigador (E-SelfIMo) en la mejora de la comprensión conceptual de conceptos seleccionados de ciencias de la Tierra por parte de estudiantes de educación media superior del área STEM en la Sorsogon National High School. El estudio utilizó un enfoque de métodos mixtos, compuesto por un diseño de investigación secuencial explicativo y un grupo de control con pretest y postest aleatorizado, para comparar los niveles de comprensión conceptual de un grupo experimental de 30 estudiantes expuestos al E-SelfIMo con 30 estudiantes en un grupo de control. Una prueba t para muestras independientes no reveló diferencias significativas entre los niveles iniciales (pretest) de comprensión conceptual de los dos grupos [t(58) = 0.2445, p = 0.40]. Después de la exposición al E-SelfIMo, el grupo experimental demostró un nivel significativamente más alto de comprensión conceptual ($\bar{x}$ = 129.8, DE = 7.35) que el grupo de control ($\bar{x}$ = 112.63, DE = 9.84), t(58) = 7.66, p = 0.0001. Este resultado también fue respaldado por un tamaño del efecto grande, con un valor d de Cohen de 1.996. El análisis cualitativo también respaldó los hallazgos cuantitativos, informando mejoras significativas en el conocimiento, habilidades de aprendizaje mejoradas, mayor compromiso, mejor comprensión y experiencias de aprendizaje positivas en general entre los participantes, debido a las simulaciones interactivas, el contenido multimedia y el carácter autodirigido del módulo. El estudio concluye que los estudiantes expuestos al E-SelfIMo demostraron niveles significativamente más altos de comprensión conceptual, lo que indica su efecto positivo en los resultados del aprendizaje.

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Introduction

Education equips learners with the knowledge, skills, and values necessary to navigate real-life challenges and contribute meaningfully to society (Munna & Kalam, 2021). In an increasingly complex world, where issues such as environmental degradation and sustainability demand informed action, science education plays a pivotal role. Among the scientific disciplines, Earth Science offers essential insights into the planet's dynamic systems and finite resources (Orion, 2017). A strong conceptual grasp of these systems enables learners to make informed decisions, engage critically with environmental issues, and adopt sustainable practices.

Yet, despite its significance, Earth Science education in many secondary schools—particularly in the Philippines—remains underdeveloped in both scope and pedagogy. Traditional instruction continues to rely on static, print-based modules that do little to promote deep conceptual understanding. Vasconcelos and Orion (2021) emphasized the global underrepresentation of Earth Science in curricula, while Landicho (2021) highlighted the urgent need to recalibrate Earth Science education in the Philippines to align with global scientific literacy and to diversify instructional modalities. These challenges reveal a pressing need to explore innovative, learner-centered approaches that enhance students' conceptual engagement with complex scientific ideas.

In such cases, leveraging technological advances to foster interactive and self-directed learning (SDL) could help improve the learning process (Gestiada et al., 2025; Lasala, et al., 2025; Loberes et al., 2025; Haleem et al., 2022). In recent years, instructional technology has emerged as a powerful tool to enhance learning outcomes in various subject areas, including the sciences. Instructional technology tools such as e-learning modules allow students to engage in interactive, self-paced, and meaningful learning experiences (Kokoç, 2019).

These modules are usually packed with multimedia elements, audiovisual study aids, and simulations that cater to diverse learning goals and requirements. By integrating technology in an educational context, educators can also foster SDL. As students learn how to direct their learning process, they become more engaged, accountable, and independent in their studies (Lasala, 2024; Robinson & Persky, 2020). Self-directed learners know how to seek, select, and evaluate resources and apply knowledge and skills to real-life situations.

Artman and Crow (2022) asserted that SDL and instructional technology are a dynamic duo that facilitates effective learning. The authors highlighted the mutual importance of using instructional technology in cultivating self-directed learners by placing more responsibilities on them. An example of such a combination is an e-learning module using Kotobee interactive e-book software. Lasala (2023a) developed eight e-learning self-directed interactive modules (E-SelfIMo) using Kotobee to integrate technology and foster SDL in teaching earth science in senior high school (SHS). The modules include multimedia learning resources to facilitate effective and interactive learning. The eight modules cover earth science topics such as the characteristics of the earth (E-SelfIMo 1), earth subsystems (E-SelfIMo 2), rocks and minerals (E-SelfIMo 3 & 4), formation of fossil fuel (E-SelfIMo 5), geothermal and hydroelectric powerplants (E-SelfIMo 6), water resources and factors that affect them (E-SelfIMo 7), and soil degradation and conservation (E-SelfIMo 8).

However, it is important to acknowledge that SDL is not a panacea. Its effectiveness hinges on students' motivation, digital literacy, and access to supportive learning environments. Learners who lack metacognitive strategies or sufficient scaffolding may find SDL overwhelming (Artman & Crow, 2022). Therefore, it is essential to design SDL tools that embed structured guidance while preserving learner autonomy.

The E-learning Self-directed Interactive Module (E-SelfIMo), developed by Lasala (2023a), seeks to meet this challenge by combining SDL principles with instructional technology. Created using Kotobee interactive e-book software, the E-SelfIMo series comprises eight multimedia-rich modules covering core Earth Science topics—ranging from Earth's subsystems and rocks and minerals to energy resources and conservation strategies. These modules were designed to foster engagement through interactivity, embedded assessments, visual aids, and accessibility features such as a text-to-speech AI bot. Upon validation by content and design experts following DepEd's standards for non-printed instructional materials, the E-SelfIMo series received a reliability coefficient of **0.91**, indicating high internal consistency.

While previous research demonstrated the perceived effectiveness of E-SelfIMo among students during its pilot implementation, there remains a lack of empirical evidence on its actual impact on measurable learning outcomes, particularly students' conceptual understanding in Earth Science. In this context, the researchers conducted the present study to determine the effect of E-SelfIMo developed by Lasala (2023a) on SHS students' conceptual understanding of selected earth science topics. The E-SelfIMo developed by Lasala (2023a) was enhanced based on the validation results from the initial study. The present study continues Lasala (2023a) by further exploring the effects of E-SelfIMo on the conceptual understanding of students in the science, technology, engineering, and mathematics (STEM) strand at SNHS, Sorsogon City, Philippines.

This study evaluates the effectiveness of the researcher-developed E-SelfIMo in improving the conceptual understanding of SHS students in earth science. Specifically, it aims to answer the following research questions: What are the initial levels of conceptual understanding of the control and experimental groups based on their pretest scores? Is there a significant difference between the initial levels of conceptual understanding of the control and experimental groups? What are the levels of conceptual understanding of the control and experimental groups after the instructional period based on their posttest scores? Is there a significant difference between the levels of conceptual understanding of the control and experimental groups after the instructional period?

This study addresses the question: To what extent does the exposure to E-SelfIMo improve the SHS students' conceptual understanding of the selected earth science topics? The study tested the following hypothesis:

H_0: There is no significant difference in conceptual understanding between students exposed to E-SelfIMo and those taught using DepEd learning modules.

H_1: Students exposed to E-SelfIMo exhibit significantly higher conceptual understanding compared to those taught using DepEd learning modules.

By integrating instructional technology with SDL, this study investigates whether E-SelfIMo can serve as an effective tool to promote deep learning and overcome the limitations of traditional Earth Science instruction.

Methodology

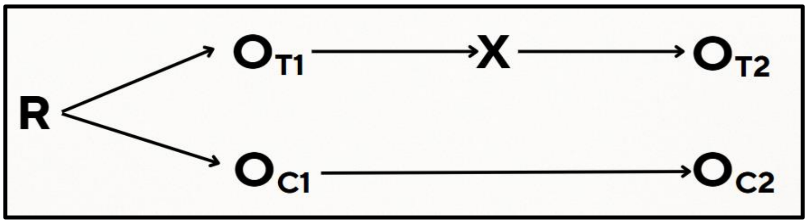
A mixed-method approach was used in this study, combining both quantitative and qualitative techniques. Specifically, it employed an explanatory sequential design, a methodology characterized by the sequential collection of quantitative data followed by qualitative data, with the latter serving to support and elaborate upon the findings derived from the former (Toyon, 2021). This approach allows the researcher to test hypotheses using quantitative and qualitative data for comprehensive data exploration. Quantitative methods assess the results of the pretest and posttest conceptual understanding tests, while qualitative techniques support the quantitative findings.

Likewise, the study employed a randomized pretest-posttest control group design to assess the efficacy of the E-SelfIMo in enhancing students' conceptual understanding. Two Grade 11 STEM strand classes were divided into experimental and control groups through random assignment. The experimental group underwent a pretest, received the intervention (exposure to E-SelfIMo), and then completed a posttest. Similarly, the control group also took a pretest but did not receive the intervention; instead, they used the learning module provided by the Philippine DepEd, followed by a posttest.

The content of the selected topics for both the experimental and control groups is based on the curriculum guide provided by the DepEd. The only distinguishable difference is the delivery of content. This was performed through the E-SelfIMo platform for the experimental group and with an electronic copy of the learning module for the control group. Data collection involved analyzing students' performance in both the pretest and posttest. This research design ensures a rigorous evaluation of the intervention's effect on the conceptual learning outcomes. The research design is shown in Figure 1:

Figure 1.

Randomized Pretest-Posttest Control Group Design



Where R represents the randomization of the participants into experimental and control groups, T is the treatment or experimental group participating in the intervention, C is the control group not participating in the intervention, and X is the introduced treatment or intervention (researcher-developed E-SelfIMo). O_{T1} denotes the experimental group pretest, and O_{T2} denotes the experimental group posttest. O_{C1} denotes the control group pretest, and O_{C2} denotes the control group posttest. All quantitative data were taken from the pretest and posttest results of the two groups. The students in the experimental group were also asked to complete a journal log entry at the end of each lesson module. Qualitative data were analyzed using thematic analysis.

The study involved 69 Grade 11 STEM students from two intact classes at Sorsogon National High School, Philippines. One class consisted of 34 students and the other 35. To ensure equal group sizes, 30 students were randomly selected from each class and assigned to the experimental and control groups. The final sample size of 30 participants per group was guided by recommendations in educational research methodology. According to Vasileiou et al. (2018), a sample of 30 participants per condition is considered sufficient for detecting moderate to large effect sizes (Cohen's $d \approx 0.5–0.8$) at 80% power and $\alpha = 0.05$, especially in controlled experimental settings.

To further strengthen internal validity, the researchers conducted a preliminary review of the students' prior academic performance in science subjects from the previous academic year. Descriptive comparisons showed no significant disparities between the two groups in terms of their general science grades. Moreover, both groups were taught by the same Earth Science teacher, which helped reduce teacher-related instructional variation. These measures ensured that the experimental and control groups were academically comparable at baseline, beyond the pretest results alone.

It is important to note that the sample and context of this study may be limited, considering that the samples came from only one school. The researcher employed this approach as this study focused on obtaining localized insights into the effectiveness of E-SelfIMo in earth science education for initial implementation in a localized setting. The discussion and conclusion sections present recommendations for addressing the limitations of this study.

In adherence to ethical guidelines, prior to data collection, approval was obtained from the school principal, and informed consent was secured from both the students and their parents or guardians through formal communication. Participants were explicitly informed that their participation in the study was voluntary and that they could withdraw from the study at any point without facing any academic penalty or disadvantage. They were also informed of the minimal risks involved, such as screen fatigue or occasional technical difficulties associated with the digital format of the instructional materials. All information gathered from the participants was treated with strict confidentiality and used solely for research purposes. Participation in the study had no bearing on students' grades or academic standing, ensuring that no coercion or undue influence affected their involvement.

A set of eight validated E-SelfIMos covering various earth science subtopics was used in this study. These were the same e-learning modules used in the initial study of Lasala (2023a), and they were refined based on the validators' suggestions. The modules encompassed topics such as Earth characteristics and subsystems, rocks and minerals, energy resources (fossil fuels, geothermal, and hydroelectric), and waste generation and management.

The control group relied on the earth science learning modules from the Philippine DepEd containing the same concepts for the topics but in electronic PDF format. The module contents for both groups were aligned with the MELC outlined by DepEd for the SHS earth science subject. Preceding the intervention's commencement, the control and experimental groups underwent a pretest assessment to gauge their baseline conceptual understanding of earth science concepts. Throughout the eight-week intervention, based on the prescribed instructional timeframe outlined in the DepEd MELC, the experimental group received weekly instruction using the designated E-SelfIMo. In contrast, the control group was given the learning module for the week. After the instructional period was completed, the posttest was given to both groups to measure the efficacy of the instructional interventions, specifically using E-SelfIMo.

Table 1

Interpretation Table For Levels of Conceptual Understanding

Performance level (%)	**Descriptive equivalent of mastery level**	**Descriptive interpretation**
92% and above	Full Mastery	Complete understanding
83%–91%	Near Full Mastery	High understanding
75%–82%	Mastery	Moderate understanding
51%–74%	Near Mastery	Partial understanding
25%–50%	Low Mastery	Faulty understanding
24% and below	No Mastery	No understanding

The conceptual understanding pretest and posttest used in this study consisted of 50 multiple-choice questions, each aligned with the learning competencies from the DepEd curriculum guide in Earth Science. The test items were grouped according to major content areas addressed in the instructional modules, such as Earth's characteristics, subsystems, rock and mineral types, fossil fuel formation, renewable energy sources, water resources, and soil conservation. The number of questions per category was determined based on the relative emphasis and breadth of each topic in the curriculum and the modules, resulting in a proportional distribution of test items across content domains. Each test item was scored on a three-point scale to assess not only the correctness of the response but also the reasoning process indicated in the students' chosen justifications, which were embedded in the multiple-choice options. Thus, the total score possible was 150 points across 50 items. This scoring approach allowed for a more nuanced measurement of conceptual understanding, capturing both content knowledge and depth of reasoning.

The 50-item pretest and posttest administered to both groups had the same contents. A panel of experts validated the test items before implementation. In addition, the Kuder-Richardson Formula 20 reliability metric of the tests reported a statistical value of 0.7153, indicating high reliability on the tests' internal consistency. The conceptual understanding levels of the participants were determined by computing their performance level and using Table 1, adapted from Lasala (2023b), for the interpretation.

Furthermore, reflective journaling activities were incorporated post-lesson for participants from the experimental group to augment data collection and gain insights into the students' learning experiences using E-SelfIMo. Writing prompts for the reflective journals such as "What have you learned from the lessons?" and "How does the E-SelfIMo help you understand the topic? Elaborate your answer" and "How did you find the lesson using the E-SelfIMo in earth science?" were included. Qualitative data from the journal logs were encoded, word for word, for thematic analysis. The qualitative data provided valuable context and a nuanced understanding of the instructional dynamics within the classroom setting.

Mixed-method techniques and quantitative and qualitative data analysis strategies were used throughout the analysis and interpretation of the data. Appropriate statistical treatments were employed to analyze quantitative data. Frequency counts, weighted means, and percentages were analyzed to determine the participants' level of conceptual understanding during the pretest and posttest. In this study, the weighted mean was used to ensure a more accurate representation of students' conceptual understanding by accounting for the varying number of test items across different topics. Each topic's mean score was weighed according to its proportional representation in the total test. Thus, topics with more test items had a greater impact on the final weighted mean. This method provided a balanced evaluation of students' performance across all assessed content areas. Additionally, unpaired t-tests were used to determine whether there was a significant difference between the levels of conceptual understanding of the two groups in both the pretest and posttest.

Warne (2020) explained that an unpaired t-test enables researchers to compare the means of two independent data sets or unrelated groups to determine whether there is a statistically significant difference between the two. The effect size was calculated and analyzed using Cohen's d value. This step determines the magnitude of the relationship between the variables on a numeric scale. According to Foster et al. (2018), reporting effect sizes allows researchers to communicate the strength of the effect in a standardized manner, which can help explain the practical and statistical significance of the results. In this case, the effect size helped the researcher determine the substantial statistical difference between the two participant groups.

The second phase of the study dealt with collecting and analyzing qualitative data gathered from the reflective journal logs of the participants in the experimental group. For qualitative analysis, this study employed deductive thematic analysis at a latent level with reflexive thinking. Proudfoot (2023) described deductive thematic analysis as a type of qualitative analysis that uses predetermined themes. This approach is particularly appropriate when the study's clear objectives and the theoretical framework are well-established. In this study, the hypothesis and objectives of the study were already presented, and a theoretical framework was established. For the deductive thematic analysis, the researcher started with predetermined themes such as learning outcomes, understanding enhancement, and E-SelfIMo perception. The researcher then organized the transcribed journal logs into codes and grouped them under specific themes. The data analysis is presented in the discussion of the results based on the objectives of the study.

Result and Discussion

Conceptual knowledge is the understanding of core principles and the relationships among them (Hurrell, 2021). This suggests that with conceptual understanding, students can apply their knowledge and skills to new contexts. Measuring students' conceptual understanding is also a way of determining their academic performance. If students' conceptual understanding improves, it also suggests that expected competencies are being achieved or increasingly achieved; thus, the main objective of this study is to determine the effect of using E-SelfIMo on the conceptual understanding of earth science topics by SHS students.

The researcher determined the students' conceptual understanding level using the weighted mean of their pretest and posttest results. The study also aims to determine if there is a significant difference between the levels of conceptual understanding of the control and experimental groups based on their pretest and posttest averages. It is also important, however, to note that some of the findings of this study may not be applicable to the general population of SHS-STEM, considering that the study focused on a limited sample size in one locale. Recommendations to improve the generalizability of the findings are presented in the latter section of this paper. The recommendations include replicating the study setup and investigating the long-term effects of E-SelfIMo and its applicability to other subjects and grade levels.

Level of conceptual understanding based on pretest achievement scores

Before the intervention or actual teaching, the experimental and control groups were given a pretest to determine their baseline conceptual understanding of this study's selected earth science topics. Table 2 presents the participants' baseline performance level and the unpaired *t*-test results for the level of conceptual understanding of the control and experimental groups based on the pretest achievement scores.

Table 2 reveals that the control and experimental groups exhibit a similar level of conceptual understanding concerning the earth science topics specified in this study. This is supported by the similar weighted means and performance levels of both groups. The control group had an overall weighted mean of 83.94 and an average performance level of 56.0%, interpreted as near mastery. The experimental group had an 82.71 overall weighted mean and 55.1% performance level, which was also interpreted as near mastery. The results suggest that the participants partially understood the selected earth science topics. Partial conceptual understanding also implies that students have gained some understanding of the topics to be undertaken but need help to correctly express or explain their understanding (Braithwaite & Sprague, 2021).

Table 2.

Participants' Pretest Levels of Conceptual Understanding

Topic	**Number of items**	**Number of points**	**Control group (n = 30)**			**Experimental group (n = 30)**		
			Weighted mean	**PL (%)**	**Interpretation**	**Weighted mean**	**PL (%)**	**Interpretation**
Earth characteristics & subsystems	10	30	18.56	61.9	NM	17.94	59.8	NM
Rocks and minerals	10	30	15.62	52.1	NM	15.60	52.0	NM
Fossil fuels	7	21	12.76	60.8	NM	12.71	60.1	NM
Geothermal & hydroelectric energy	16	48	24.02	50.0	LM	24.26	50.1	LM
Water & soil conservation	7	21	12.97	61.8	NM	12.20	58.1	NM
Overall	50	150	83.94	56.0	NM	82.71	55.1	NM

Notes: PL: Performance Level; LM: Low Mastery; NM: Near Mastery.

Based on the social and cognitive constructs of the learning process, these results suggest that the two groups share similar learning backgrounds and perspectives regarding the selected earth science topics before the actual instructional period. Both groups of participants demonstrated a near mastery or partial understanding of topics such as earth characteristics and subsystems, rocks and minerals, energy resources (fossil fuels), and waste generation and management, as indicated by the weighted means and performance levels. This implies a higher potential for the participants to perform better and understand these topics more efficiently during the instruction period because they already partially understand the concepts related to the topic.

This also supports the researcher's choice of using the samples to avoid experimental bias, as the participants come from homogenous classes. Both groups of participants also displayed a lower mastery level concerning geothermal and hydroelectric energy resources, which implies a low level of understanding of the concepts and misconceptions. The performance levels and weighted averages of the control and experimental groups for each earth science topic signify their conceptual understanding level, as suggested by the interpretation. Higher weighted mean and performance levels suggest a higher conceptual understanding among the students.

Additionally, the study sought to determine if there is a significant difference between the participants' levels of conceptual understanding, as indicated in their performance in the pretest. Table 3 compares the levels of conceptual understanding of the control and experimental groups using an unpaired *t*-test (one-tailed) set at the 0.05 significance level (α) to determine if there is a significant difference between the two. Table 3 also presents the value of effect size (Cohen's *d*) to determine the practical significance of the outcome.

Table 3

Unpaired t-Test Results for the Participants' Pretest Achievement Scores

	Control group (n = 30)	**Experimental group (n = 30)**
Mean ($\bar{x}$)	83.94	82.71
Standard deviation (*SD*)	19.84	19.12
Degrees of freedom (*df*)	58	
t-statistic (*t*)	0.2445	
p-value	0.40	
Effect size (Cohen's *d*)	0.06	

One of the aims of this study is to determine if there is a significant difference between the levels of conceptual understanding of the control and experimental groups. The statistical results for the difference between the control and experimental groups obtained using the unpaired *t*-test shown in Table 3 indicate no significant difference between the initial levels of conceptual understanding of both groups of participants, $t(58) = 0.2445$, $p = 0.40$, despite the control group ($\bar{x} = 83.94$, $SD = 19.84$) attaining higher pretest scores than the experimental group ($\bar{x} = 82.71$, $SD = 19.12$). The Cohen's *d* value of 0.06 confirms that the effect size is very small, suggesting that the difference in the pretest achievement scores between the control and experimental groups is negligible.

The results show that both groups of participants had some conceptual understanding that could help them better understand the topics to be taught and prepare them for what they would be learning. Van Riesen et al. (2018) stated that even minimal prior knowledge can be an advantage to students in their learning process, as the instructions and learning materials can stimulate or accelerate learning. Since the participants had prior knowledge about the topics, it can be expected that with instruction, their knowledge and understanding of earth science concepts can still be improved. This challenges the instructional models and materials utilized in this study (E-SelfIMo for the experimental group and DepEd learning modules for the control group) to activate students' prior knowledge and correct misconceptions on the selected topics to facilitate and accelerate learning.

Level of conceptual understanding based on posttest achievement scores

The instructional period of the study lasted eight weeks and was divided into five topics. To determine the effect of E-SelfIMo on students' conceptual understanding of selected earth science topics, the learning materials used during the instructional period differed for the two groups of student participants. As treatment or intervention for the experimental group, the participants used the E-SelfIMos for the selected earth science topics. In contrast, the control group used the DepEd learning modules. At the end of the instructional period, both groups were given a posttest to determine their levels of conceptual understanding. Table 4 summarizes the posttest achievement scores of the control and experimental groups.

Table 4 shows the posttest average of the control and experimental groups for each earth science topic selected for this study. The table shows that the overall conceptual understanding of each group improved after the instruction period, as indicated by the increase in the groups' overall weighted mean and performance level. Calhoun et al. (2021) argued that regardless of the form of delivery, instruction can help students learn; the difference in the impact of an instructional tool or strategy lies in how much the students learn. The higher scores obtained by both groups of participants support the authors' argument. Regardless of the instructional tool used, both groups scored higher than their pretest scores, implying that both tools helped students better understand earth science concepts.

Table 4

Participants' Posttest Levels of Conceptual Understanding

Topic	Number of items	Number of points	Control group (*n* = 30)			Experimental group (*n* = 30)		
			Weighted mean	PL (%)	Interpretation	Weighted mean	PL (%)	Interpretation
Earth characteristics & subsystems	10	30	22.50	75.1	NM	26.80	89.2	NFM
Rocks and minerals	10	30	21.94	73.1	M	26.50	88.4	NFM
Fossil fuels	7	21	16.24	77.3	M	18.10	86.2	NFM
Geothermal & hydroelectric energy	16	48	35.21	73.3	LM	40.10	83.6	NFM
Water and soil conservation	7	21	16.74	80.0	NFM	18.30	87.3	NFM
Overall	50	150	112.63	75.8	M	129.80	86.9	NFM

Notes: PL: Performance Level; LM: Low Mastery; NM: Near Mastery; M: Mastery; NFM: Near Full Mastery.

The posttest achievement scores of the control group indicate that the control group has moved from the near mastery to mastery level of conceptual understanding based on the interpretation of the group's overall weighted mean (112.63) and performance level (75.8%). The learning modules used by the control group enabled the students to learn the concepts and better understand the subject matter. This shows an increase to another level through digitalized modular instruction. The overall increase in conceptual understanding also implies that the DepEd learning modules effectively cultivate and enhance students' conceptual understanding.

In comparison, the experimental group achieved an overall weighted mean of 129.80 and 86.9% performance level, interpreted as near full mastery. This means that the students in the experimental group progressed to higher levels of conceptual understanding. The experimental group had higher average scores than the control group in all topics, implying better performance or conceptual understanding in favor of the experimental group. This shows that, like the learning modules of the control group, the use of E-SelfIMo was also able to improve students' conceptual understanding of the selected earth science topics. The experimental group scores for each topic and the overall posttest score signal better performance than the control group, although both improved.

Tables 1 and 4 clearly show that, while there is an increase in the weighted average and performance level in both groups of participants, the experimental group achieved greater improvement in their conceptual understanding level. The results presented in Table 4 is consistent with existing studies on interactive e-learning modules.

Errabo and Ongoco (2024) found that using interactive mobile learning modules is better than traditional instructional tools as it gives more equitable access to learning and engaging materials to help students better comprehend science lessons. The use of E-SelfIMo allows students to access their lessons in interactive formats that can be opened on their smartphones, laptops, computers, and tablets to better support their learning.

Lubiano (2018) also observed higher posttest scores among students who used an interactive e-learning portal in his study. The author asserted that the learning support features in the portal helped students understand science concepts better than traditional classroom instruction. E-SelfIMo also contains learning and language support tools such as an AI bot and buttons for study help. The interactive nature of E-SelfIMo and its different functionalities help students understand earth science concepts better than the traditional form of learning modules.

To further examine the difference in the levels of understanding between the control and experimental groups and test the study's hypothesis, the researcher also applied an unpaired *t*-test to the posttest data. The results are given in Table 5.

Table 5

Unpaired t-Test Results for the Participants' Posttest Achievement Scores

	Control group (*n* = 30)	**Experimental group (*n* = 30)**
Mean ($\bar{x}$)	112.63	129.80
Standard deviation (*SD*)	9.84	7.35
Degrees of freedom (*df*)	58	
t-statistic (*t*)	7.66	
p-value	0.0001	
Effect size (Cohen's *d*)	1.996	

An unpaired *t*-test was conducted to compare the levels of conceptual understanding of the control and experimental groups. Results show a significant difference in the levels of conceptual understanding of the control ($\bar{x}$= 112.63, *SD* = 9.84) and experimental groups ($\bar{x}$= 129.80, *SD* = 7.35), $t(58) = 7.66$, $p = 0.0001$ after the instructional period. This means that the null hypothesis is rejected in favor of the experimental group, which achieved higher posttest achievement scores than the control group. This is also supported by the reported Cohen's *d* value of 1.996, indicating a considerable effect size. It can be inferred that the differences between the control and experimental groups are statistically significant and practically significant.

Meanwhile, a paired sample t-test was conducted to compare the experimental group's pretest and posttest scores. This is to evaluate the intervention's (E-SelfIMo) actual effectiveness further. The result was shown in Table 6;

Table 6 revealed a statistically significant improvement in students' conceptual understanding following the intervention. The mean pretest score was M = 82.71 (SD = 19.12), which significantly increased to M = 129.80 (SD = 7.35) in the posttest, $t(29) = 15.44$, $p < .001$. The corresponding effect size was large (Cohen's d = 3.25), suggesting that the use of E-SelfIMo had a substantial and practically significant impact on learners' mastery of Earth Science concepts. This finding confirms that the interactive and self-directed features of E-SelfIMo effectively enhanced students' understanding of the targeted content areas.

Table 6

Paired t-Test Results for the Experimental Group's Pretest and Posttest Achievement Scores, with Corresponding Mean Gains and Normalized Gains

Topic	Experimental group (n = 30)								
	Pretest mean score	**Standard Deviation**	**Posttest mean score**	**Standard Deviation**	**Mean Gain**	**Norm. Gain**	**Interpretation**	**Effect Size**	**Interpretation**
Earth characteristics & subsystems	17.94	8.55	26.80	3.29	8.86	0.73	HG	1.37	H
Rocks and minerals	15.60	8.55	26.50	3.29	10.9	0.76	HG	1.68	H
Fossil fuels	12.71	7.15	18.10	2.75	5.39	0.65	MG	1	H
Geothermal & hydroelectric energy	24.26	10.82	40.10	4.16	15.84	0.67	HG	1.93	H
Water and soil conservation	12.20	7.15	18.30	2.75	6.10	0.69	HG	1.13	H
Overall	**82.71**	**19.12**	**129.80**	**7.35**	**47.09**	**0.7**	**HG**	**3.25**	**H**
Degrees of freedom (df)	**29**								
t-value	**15.44**								
p-value	**0.00**								

Notes. Paired-sample t-test was used to compare the pretest and posttest scores of the experimental group (n = 30).
Norm. Gain = Normalized Gain; calculated as Mean Gain divided by the maximum possible gain.
HG = High Gain (≥ 0.7); MG = Medium Gain (0.3–0.69).
Effect size was calculated using Cohen's d; H = Huge effect (d ≥ 0.8).
**p* < .05 for all comparisons.*

The experimental group, which received the E-SelfIMo treatment, scored significantly higher than the control group in the posttest, which measured their level of conceptual understanding. Using E-SelfIMo significantly improved the students' conceptual understanding. Comparing the experimental group's level of conceptual understanding from pretest to posttest, it can be inferred that the E-SelfIMo, like other self-directed and interactive e-learning materials, helped the students activate their prior knowledge and correct misconceptions, leading to improved conceptual understanding of the topics (Lasala, 2023a).

Qualitative analysis of the effect of E-SelfIMo on participants' conceptual understanding of earth science concepts

This research unveils the potential of E-SelfIMo as a valuable tool for enhancing students' conceptual understanding. The analysis of the pretest and posttest results from the experimental group revealed noticeable improvements in the average scores across topics following exposure to E-SelfIMo. As part of the mixed-methods approach of this study, qualitative data were gathered from the journal logs of the participants in the experimental group. Only the experimental group was asked to keep a reflective journal and be interviewed by the researcher, as the purpose of the qualitative data is to support the findings from the quantitative data analysis. This study employed a deductive thematic analysis of the participants' journal logs. The qualitative data were coded according to four major themes: Efficacy of E-SelfIMo, Learning Gains, Student Engagement, and Technology Integration. These themes guided the discussion of qualitative analysis. Table 6 presents the organization of the codes into themes for thematic analysis.

The qualitative data gathered from the experimental group participants' journal logs provide insight into the reasons behind the observed quantitative improvement of the experimental group's conceptual understanding levels. Thematic analysis revealed two main aspects of the efficacy of using E-SelfIMo: knowledge gain and skill development. All 30 participants in the experimental group reported that using E-SelfIMo helped them gain knowledge about the selected topics. With 53 transcripts for this code, students consistently expressed significant knowledge gains, particularly on complex topics such as Earth's subsystems, terrestrial planets, physical and chemical characteristics of rocks and minerals, and energy sources.

Participants often gave comments such as "*Ganun pala yun*" ["Oh, that is how it is"], "Now I know," and "I haven't encountered this before" during the lessons. Seshan et al. (2021) explained that these types of sentiments reflect knowledge development, as they depict a sort of "eureka" moment for students. Transcripts like the sample quote from Participant 29 (P29) suggest that using E-SelfIMo effectively facilitated learning new earth science concepts on the selected topics for this study.

Another participant shared in his study journal: "I just knew before that hydrothermal power plants are not really environment-friendly, but with the videos I watched from the module, I came to understand how it depletes the surrounding with resources that should have been available for other biological processes" (P11). These quotes from students align with the expected learning outcome of improved understanding. The students using the multimedia resources in E-SelfIMo were able to connect their prior knowledge to new learning materials on their own. This made their understanding of a particular earth science concept deeper and more complete.

Additionally, participants not only gained new knowledge, but they could also connect their newfound knowledge to their lives. For example, one participant noted, "I have learned what a mineral is and how you would determine if the said crystal is real or a fake. I also learned the importance of minerals to our society and lives" (P23). This quote demonstrates that participants were able to connect the concepts they had learned using E-SelfIMo to their society and practical activities, which further supports their improved level of conceptual understanding. Hussein and Csíkos (2023) asserted that recognizing the connections of concepts to the natural world is an essential part of conceptual understanding; effective e-learning material helps learners gain knowledge about the topic and use multimedia meaningfully (Adawiyah et al., 2021).

Furthermore, using E-SelfIMo also aided in the skills development of the participants. The sample quote from P6 in Table 6 emphasizes the ability of E-SelfIMo to improve participants' learning and self-study skills. One key feature of the researcher-developed E-SelfIMo is its self-directed nature, see Tabe 7.

Table 7
Coding for Thematic Analysis

Theme	Number of participants contributing (*n* = 30)	Number of transcript excerpts assigned	Sample quote
Theme 1: Efficacy of E-SelfIMo			
Acquisition of New Knowledge	30	53	"I learned that geothermal energy is cleaner, more efficient, and more cost-effective than burning fossil fuels." (P29)
Development of Self-Directed Learning Skills	9	12	"E-SelfIMo helped me improve self-study and learning skills." (P6)
Theme 2: Learning Gains			
Clarification of Difficult Concepts	27	59	"The highlighted text was also a great help in clarifying and providing extra insight about the topic at hand." (P14)
Integration with Prior Knowledge	34	52	"I already had ideas about geothermal energy, but E-SelfIMo made me understand how it really works in our environment. " (P14)
Theme 3: Student Engagement			
Improve Motivation to Learn	26	39	"E-SelfIMo motivates me to learn more about the topic because it is not dull, and it levels up my interest to focus and learn more." (P27)
Increased Enjoyment and Active Participation	28	51	"The module was interactive, and the activities were more enjoyable to answer as a result." (P12)
Theme 4: Technology Integration			
Feedback on Features of E-SelfIMo	23	41	"The video there [E-SelfIMo] also helped me understand the concept more easily and quickly." (P15)
Feedback on using E-SelfIMo	26	50	"The E-SelfIMo felt futuristic and advanced. I felt like a proper 21st-century student when using it." (P19)

When learners have autonomy in their learning process, they can discover learning skills and self-regulation strategies that benefit their study. Mujiono and Herawati (2019) asserted the effectiveness of self-directed e-modules in fostering self-study skills and self-regulation in students. Another participant wrote, "I was not really a techy person, but with Blithe's (AI bot) assistance, I was able to listen to the lesson. I now know how to use text-to-speech features in applications or portals" (P21). This reflection shows that as the students interact with E-SelfIMo, they also learn technical and practical skills that can help them learn more effectively. This aligns with the principles of SDL, as it focuses on how learners use available materials to aid their learning.

Oates (2019) also emphasized that when instruction helps students develop skills, students learn to become lifelong learners. The search and listening skills the student gained through using the AI bot feature (text-to-speech language assistance) of E-SelfIMo help not only in understanding the lessons in the module but also in finding other learning materials for their other subjects and needs. In this way, E-SelfIMo helps students become more independent learners. The use of E-SelfIMo in selected earth science lessons can help students gain more knowledge and skills to aid their learning.

Another recurring theme emerging from the students' journal reflections highlights the cognitive benefits they experienced from using E-SelfIMo. These learning gains were evident in two key areas: the clarification of complex concepts and the integration of new knowledge with prior understanding. Many students described how E-SelfIMo helped make challenging earth science topics more understandable.

Twenty-seven participants (with 59 transcript excerpts) specifically indicated that the module helped clarify complex ideas, thanks to features like highlighted text, integrated videos, AI-powered text-to-speech support, graphs, and visuals. For instance, Participant 14 noted, "The highlighted text was also a great help in clarifying and providing extra insight about the topic at hand." Similarly, Participant 13 reflected, "The E-SelfIMo provided me with activities and answer keys that helped me better understand the lesson." These features not only presented information in multimodal formats but also offered immediate feedback, which supported students in identifying and correcting misconceptions.

This observation resonates with Halim et al. (2021), who emphasized the role of narrative feedback in improving learners' conceptual processing during interactive module-based activities. Likewise, Delıta et al. (2022) affirmed that e-modules can clarify abstract concepts more effectively by catering to various learning preferences—whether textual, visual, or auditory. Beyond clarifying isolated concepts, students also demonstrated the ability to connect new information with their existing knowledge.

Thirty-four participants mentioned how E-SelfIMo helped reinforce or reframe what they already knew, which deepened their overall understanding. As Participant 14 shared, "I already had ideas about geothermal energy, but E-SelfIMo made me understand how it really works in our environment." This indicates that E-SelfIMo not only delivered content but also enabled students to restructure and expand their existing cognitive frameworks. As emphasized by Hussein and Csíkos (2023), the ability to meaningfully relate new ideas to real-world systems is a crucial indicator of conceptual understanding. Together, these reflections suggest that E-SelfIMo facilitated more than surface-level learning; it actively supported the cognitive restructuring needed for deeper conceptual mastery

The use of E-SelfIMo was also observed to improve students' engagement by fostering both motivation to learn and enjoyment in participating in learning activities, thus improving their conceptual understanding. Several participants noted that the interactive features of E-SelfIMo—such as embedded videos, quizzes, simulations, and prompts for collaboration—contributed to a more dynamic learning experience. As Participant 27 (P27) remarked, "E-SelfIMo motivates me to learn more about the topic because it is not dull, and it levels up my interest to focus and learn more." This sentiment was echoed widely among respondents, indicating that the multimedia-rich format of E-SelfIMo played a key role in stimulating intrinsic motivation. Likewise, students also expressed heightened enjoyment and a more active approach to their learning.

For instance, Participant 12 (P12) shared, “The module was interactive, and the activities were more enjoyable to answer as a result.” Such feedback points to a learning experience that is not only informative but also engaging and emotionally positive. Features like peer collaboration prompts, real-world application tasks, and autonomy-supportive design elements contributed to this sense of enjoyment and participation. As Munna and Kalam (2021) mentioned in their study, as the students are given more options to learn and become aware of the relevance of their lessons, they become more interested and willing to learn. Comprehension comes more easily when students are willing to learn for themselves. The various features and functions embedded in E-SelfIMo make the lessons more attractive, appealing, and engaging to the participants.

The last recurring theme from the qualitative data provides context on how Technology Integration on E-SelfIMo achieved the improvement in the participants' level of conceptual understanding observed in the quantitative data. The last theme consisted of feedback by the participants in the experimental group on the features of E-SelfIMo and their experiences using it. Positive feedback was given by 23 participants (41 transcripts) on the multimedia functionality of E-SelfIMo. The sample quote from P15 highlights the advantage of using video to explain concepts so that learners can understand better and faster. Another participant stated, “The lesson was interesting and fun to learn, especially with the videos, graphs, and robots that are in the module” (P9).

This statement highlights the diversity of the learning materials in E-SelfIMo. The diverse media in E-SelfIMo can cater to more students by matching their learning styles. Zhu et al. (2022) found that including videos in e-learning modules makes them more interactive. Videos can hold students' attention longer than textual content, which is why they are effective in enhancing students' memory and understanding, especially those of younger students. These statements suggest that the multimedia elements of E-SelfIMo facilitate comprehension. Such feedback underscores the effectiveness of multimedia tools and the integration of instructional technology in enhancing learning.

Twenty-six participants (50 transcripts) also shared feedback on their overall experience using E-SelfIMo in learning earth science concepts. The sample quote from P19 in Table 6 implies the participants' high regard for the appropriateness and relevance of E-SelfIMo to their learning needs, capacities, and time demands. This aligns with Martin (2018), who stated that learning materials should match learners' needs and capacities to facilitate learning more effectively. Another participant commented, “The E-SelfIMo was very interactive and 'all-in-one'” (P25). Other participants stated that using E-SelfIMo had made their learning fun as it caters to their learning styles, whether visual, auditory, tactile, or textual. This feedback suggests the comprehensiveness and effectiveness of E-SelfIMo in providing a positive learning experience to students and, consequently, improving their learning outcomes.

On the other hand, some participants expressed their challenges in using E-SelfIMo to learn earth science concepts. Participants shared that "using the e-pub [E-SelfIMo through the Kotobee app] gets irritating and annoying sometimes because it takes a grueling amount of time to open," "functions not working properly take out the fun in it" (P21), and "[it] was a little strange at first" (P27). However, the positive feedback on using E-SelfIMo outweighs the negative comments. Participants shared, "Students with different learning preferences can comfortably learn the way they want, at the pace they want, and at the level of effort that they want through E-SelfIMo" (P22), and "Overall, the experience with the E-SelfIMo learning process is better than my setup with the regular modules" (P4). These results emphasize that while using E-SelfIMo to improve students' conceptual understanding is promising, there is still a need to improve technology integration in learning tools. Further studies could focus on the elements, features, and functionality of E-SelfIMo that contribute to enhanced learning outcomes.

Findings from the qualitative data analysis support the quantitative results regarding the improvement of conceptual understanding among participants in the experimental group. The reflective journal data provided rich contextual insights that helped interpret the statistically significant difference observed between the control and experimental groups. While both groups demonstrated gains in conceptual understanding, students exposed to E-SelfIMo achieved more substantial improvements, highlighting the module's effectiveness as a self-directed, interactive e-learning resource for Earth Science.

This finding reinforces the pedagogical value of integrating multimedia-enriched and learner-centered tools in science instruction, particularly those that align with self-directed learning principles and support diverse cognitive and engagement needs. As such, E-SelfIMo presents practical implications for instructional design and curriculum development. Its successful implementation suggests that digital modules embedded with multimodal content—such as video, AI-driven support, and interactive simulations—can enhance not only students' comprehension of abstract concepts but also their motivation and autonomy in learning. Educators may consider adapting similar strategies to complement traditional teaching, especially in contexts where learner independence and technology readiness are critical.

However, several limitations of this study must be acknowledged. The research was conducted with a relatively small sample size drawn from a single institution, which limits the generalizability of the findings. Additionally, the intervention was implemented over a short duration, and long-term effects on retention or knowledge transfer were not assessed. Technical issues such as slow loading times and unfamiliarity with the platform were also reported by some participants, which may have influenced their learning experience. These challenges underscore the need for further refinement of the module's usability and accessibility features to ensure more inclusive and seamless learning experiences.

Future studies may address these limitations by replicating the research with a larger and more diverse population across multiple educational settings. Longitudinal investigations could also explore whether the observed gains are sustained over time and whether E-SelfIMo can be effectively adapted for other STEM domains.

Moreover, examining how the integration of digital modules influences students' metacognitive development, problem-solving abilities, and performance in applied tasks would offer deeper insight into their broader educational value. Ultimately, while the results of this study affirm the potential of E-SelfIMo in enhancing conceptual understanding, ongoing iterative development and evidence-based scaling are essential to maximize its impact across varied learning contexts.

Conclusion

This study aimed to determine whether the use of the E-SelfIMo significantly improved the conceptual understanding of SHS students in selected earth science topics. Drawing from both quantitative and qualitative strands, the findings affirm that E-SelfIMo is an effective instructional tool that supports deeper, more meaningful learning.

The first objective—determining the extent of conceptual understanding following exposure to E-SelfIMo—was met through significant improvement in post-instruction scores and supported by strong qualitative evidence of knowledge construction.

The second objective—analyzing how E-SelfIMo promotes conceptual understanding—was addressed through journal reflections that revealed gains in content knowledge, clarification of complex topics, integration with prior knowledge, and the development of self-directed learning skills.

The third objective—identifying the experiential and technological affordances of E-SelfIMo—was supported by themes of increased motivation, student enjoyment, and effective integration of multimedia and AI-assisted features.

The implications of this study are multifaceted. Pedagogically, E-SelfIMo provides a model for integrating self-directed learning and multimedia tools in science education, offering teachers a robust alternative to traditional modules. Instructional designers may draw from this model to develop context-sensitive, interactive modules that support conceptual change and active engagement. At the policy level, the findings provide empirical support for DepEd's efforts to integrate platforms like Kotobee into mainstream instruction, affirming that digital tools—when well-designed—can elevate student learning even in resource-constrained settings. For teacher practice, E-SelfIMo exemplifies how learner-centered, autonomous, and digitally mediated instruction can cultivate both cognitive and affective gains.

However, this study also has its limitations. Its findings are bound by the short intervention period, the use of a purposive sample, and a focus on a single subject area. These limitations suggest caution in generalizing results. Future research should explore long-term impacts through longitudinal studies and test the adaptability of E-SelfIMo to other disciplines and learner demographics. Investigating how such modules influence metacognitive development, problem-solving skills, and sustained academic performance would also offer valuable insights.

Finally, the integration of E-SelfIMo into Earth Science instruction holds promise for enhancing students' conceptual understanding by merging technological innovation with learner autonomy. It demonstrated through both measurable outcomes and lived experiences—points toward a viable and scalable path forward for 21st-century science education..

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