Momentum: Physics Education Journal
8 (2), 2024, 194-209
Available at: ejournal.unikama.ac.id/index.php/momentum
ISSN 2548-9127(print) | 2548-9135 (online)

Scaffolding as a cognitive load reduction strategy for teaching atomic and nuclear physics

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Received: 27 December 2023; Revised: 7 March 2024; Accepted: 12 March 2024

Abstract: This study investigated the effectiveness of scaffolding as a cognitive load reduction strategy for teaching Atomic and Nuclear Physics. This study was carried out with the participation of university physics students (n = 20) enrolled in the B.Sc. Physics Education Programme. A quasi-experimental one-group pre-test-post-test design was used to collect both quantitative and qualitative data on physics students' conceptual understanding and learning dispositions about Atomic and Nuclear Physics. The intervention consisted of a university academic calendar of one semester (2022-2023) using scaffolding as a cognitive load reduction strategy. The baseline assessment revealed that the respondents had incorrect, partial, and no knowledge of electron transition and radioactivity-related concepts. However, the post-test analysis revealed a mean score of 7.22 (SD = 0.31) that can be considered significant ($p < 0.05$) and a large effect of 0.79 on the conceptual understanding of the participants in Atomic and Nuclear Physics. The study findings also revealed that the participants' factual, conceptual, procedural, and meta-cognition about Atomic and Nuclear Physics improved after using scaffolding as a cognitive load reduction strategy. The results further revealed an improved learning disposition about Atomic and Nuclear Physics among the participants after the intervention. The participants articulated, among others, that the use of scaffolds as a cognitive load reduction strategy stimulated their interests, made the topic more enjoyable, and reduced their sense of hopelessness. The author accordingly recommends scaffolding as a cognitive load reduction strategy to physics educators for effective teaching and learning in the context of Atomic and Nuclear Physics.
Keywords: Scaffolding; Cognitive Load; Atomic Nuclear and Physics; Learning Disposition

How to Cite: Appiah-Twumasi, E. (2024). Scaffolding as a cognitive load reduction strategy for teaching atomic and nuclear physics. *Momentum: Physics Education Journal*, *8*(2), 194-209. https://doi.org/10.21067/mpej.v8i2.9580

Introduction

During the past century, atomic and nuclear physics applications have enormously affected humankind, some beneficial (Jóźwik, 2017) and some catastrophic (Williams, et al., 2015). Nonetheless, atomic and nuclear physics are still beneficial in today's world. It continues to produce technological advances and computer science, which are critical in the digital age (Hachiya & Akashi, 2016; Hon, 2022). Hon specifically argued that modern experiments in nuclear physics enable scientists, engineers, and other industry stakeholders to solve complex problems and increase life expectancy. Therefore, Hon concluded that it is important that physics students become more involved in nuclear physics in general and contribute significantly to the future.

Nuclear Physics Education is an excellent opportunity for students to become aware of the impact of modern science and its achievements on daily life (Elbanowska-Ciemuchowska & Giembicka, 2011). In addition, teaching nuclear physics enables students to understand the application of laboratory research results in the fields of medicine, technology, food conservation, and the energy industry. However, Elbanowska-Ciemuchowska and Giembicka (2011) contend that nuclear physics is perceived as a difficult subject to teach because the physics and mathematical apparatus required to describe it are very advanced. Therefore, this part of the physics content demands abstract thinking and frequently exceeds students' cognitive abilities. Rathore's (2016) study findings affirm these negative attributes of Nuclear Physics, as highlighted by Elbanowska-Ciemuchowska and Giembicka. Specifically, Rathore's findings showed that students face many common challenges related to the concepts of radioactivity, half-life, nuclear force, and binding energy.

A study (Muhakeya & Maseko, 2022) found that even after comprehensive training, students in the university's introductory and advanced physics classes struggle to demonstrate an understanding of some fundamental concepts in Atomic and Nuclear Physics. This perceived difficulty may be attributed to the traditional nature of the teaching pedagogies employed by physics educators. In traditional physics classrooms, the focus is on solving problems that require students to calculate a precise quantitative solution and on equations, manipulating them, and calculating an answer (Abraham & Barker, 2023). This traditional pedagogical approach to physics teaching, rather than promoting strong conceptual understanding, promotes rote memorisation with a consequential effect on student academic performance.

A theoretical paradigm for instructional design, Cognitive Load Theory (CLT) addresses how the human brain processes and stores information (Main 2022). CLT argues that humans will find it difficult to perform tasks if the cognitive load exceeds the processing capacity. Based on its underlying theory, the CLT explains how humans learn by utilising the properties of working memory and long-term memory, as well as their interactions. As such, the CLT helps to understand how people absorb and retain new knowledge as well as the kinds of instructional strategies that promote learning (Likourezos and Kalyuga, 2021). According to CLT, learning is impeded when learning tasks require more working memory than can be handled. These characteristics of CLT align with those of CLT proponent John Sweller, who believes that optimal learning occurs in settings that match students' cognitive capacities.

The adoption of CLT in the classroom has helped improve students' understanding and performance in learning domains; therefore, it has been implemented in the classroom. In 2023, Pečiuliauskienė, for example, studied the clarity of instruction in physics lessons and student motivation and self-confidence. Pečiuliauskienė found supporting evidence that cognitive load theory positively influences student learning outcomes. The findings led Pečiuliauskienė to recommend that physics educators reduce the heavy intrinsic load associated with physics and increase instructional clarity in physics lessons by providing explanations using signalling and redundancy (Pečiuliauskienė, 2023).

Scaffolding is a classroom teaching strategy in which instructors deliver lessons in distinct segments, providing less and less support as students master new concepts or material (McIsaac, 2019). McIsaac added that similar to scaffolding in a building, this technique is designed to provide students with a framework for learning as they build and strengthen their understanding. Subsequently, in the application of the scaffolding strategy in the classroom, when students have achieved the desired level of comprehension or mastery, the teacher can take a step back and gradually remove their support (Mulvahill, 2023).

Consequently, scaffolding attempts to help students disperse their learning into manageable parts as they progress toward greater understanding and, ultimately, independence. As introduced by psychologist Lev Vygotsky, scaffolding refers to the assistance or support provided to learners as they work towards the acquisition of new knowledge or skills (Mcleod, 2023). McLeod further stated that the concept of scaffolding was precisely articulated by Lev Vygotsky, who referred to the perceived gap in learners' minds that must be filled by an experienced person. As a result, scaffolds can be used to bridge the gap between students' current cognitive abilities, improve their general conceptual understanding, and consequently promote students' positive learning dispositions in any domain of learning.

The learning disposition of students is another factor that affects their learning outcomes. To be successful future-focused lifelong learners, students will need a complex blend of dispositions, skills, values, and attitudes. Consequently, authors such as Dowd et al. (2019) have demonstrated that students’ learning is influenced by their intrapersonal competencies, specifically their motivation, self-efficacy, and intellectual beliefs. For this reason, the development of appropriate learning dispositions in students must be done in the institutions of learning to ensure students’ success in their future endeavour and their development to become respected scientific literate.

Educators' major goals in physics should be to assist students in building dispositions that will allow them to engage with information purposefully and to honestly explain their knowledge and opinions in all subject areas (Weinstock et al., 2017), utilising their conceptual understanding. Despite the perceived benefits of students’ learning disposition, it appears that undergraduate physics students’ learning disposition, particularly in the context of Atomic and Nuclear Physics teaching and learning, has not been researched and presents a gap in this domain of research. Therefore, to improve the conceptual understanding and learnin g dispositions of undergraduate physics students about Atomic and Nuclear Physics and to fill this identified gap, scaffolding was adopted as a cognitive load reduction strategy. Consistent with the foregoing, this study specifically sought to answer the following questions.

1. What prior conceptual understanding do undergraduate physics students hold on Atomic and Nuclear Physics concepts?
2. What is the effect of scaffolding as a cognitive load reduction strategy on undergraduate physics students' conceptual understanding of Atomic and Nuclear Physics?
3. Does scaffolding as a cognitive load reduction strategy enhance undergraduate physics students’ factual, conceptual, procedural, and meta-cognition knowledge of Atomic and Nuclear Physics?
4. How does scaffolding as a cognitive load reduction strategy enhance undergraduate physics students' learning disposition towards Atomic and Nuclear Physics?

Method

Research Design

The researcher employed a one-group pre-test-post-test quasi-experimental design. In this type of quasi-experimental design, as proposed by Reichardt (2019) and presented in Table 1, the researcher measures the outcome of interest twice, once before and once after exposing a non-randomised group of participants to a certain intervention or treatment.

Table 1. The One-Group Pretest-Post-test Design

O	X	O
Pre-intervention measurement	Intervention	Post-intervention measurement

With this adopted design, pre-intervention measures were conducted using baseline assessment instruments. This measure was intended to establish the prior conceptual understanding of Atomic and Nuclear Physics by the research participants and their learning dispositions towards Atomic and Nuclear Physics. Following this phase, the treatment was introduced, which was scaffolding as a cognitive load reduction strategy, and a subsequent postintervention measurement that measured participants' conceptual understanding as well as participants' factual, conceptual, procedural, and metacognition knowledge in Atomic and Nuclear Physics. The last measure was the participants' new learning dispositions toward Atomic and Nuclear Physics.

Measures

Three research instruments—a baseline assessment test, an Atomic and Nuclear Physics Test, and Learning Dispositions about Atomic and Nuclear Physics—were used for the data collection for the study.

Baseline Assessment Test

The baseline assessment consisted of four open-ended items comprising concepts from Atomic and Nuclear Physics, namely electron transition and radioactivity. The baseline assessment instruments are used to evaluate the conceptual understanding of undergraduate Physics students in Atomic and Nuclear Physics, especially to answer research question one of this study. The detailed structure of the baseline assessment instrument is shown in Table 2.

Table 2. Baseline Assessment

Concept	Questions
Electron Transition	A lithium atom emits energy to move from its ground state to an excited state. Explain whether this statement is true or false.
	Explain why an electron in the ground state of hydrogen cannot absorb a photon of energy less than 13.6 eV for excitation to occur.
	Explain why an electron of an atom requires a much greater energy of -12.07 eV to be excited from the ground state (n=1) to the third energy level (n=3) but another electron of the same atom requires an energy of -1.88 eV to transition from the second energy level (n=2) to the third energy level (n=3).
Radioactivity	Using the nucleon number, how can you determine if an isotope is radioactive or stable?

Atomic and Nuclear Physics Test

The *Atomic and Nuclear Physics Test (ANPT) was used to answer research questions two and three. ANPT* consisted of 25 multiple-choice items on selected concepts in Atomic and Nuclear Physics. The selected topics included atomic models, energy levels, nuclear stability and radioactivity, photoelectric effects, as well as wave-particle duality based on PHY 247 (Atomic and Nuclear Physics) for B.Sc. Physics Education at AAMUSTED-M. ANPT items were constructed in line with the revised Bloom's Taxonomy as factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge, as seen in Table 3.

Table 3. Atomic and Nuclear Physics Test Specification

Knowledge	Questions	Sample of the Questions
Factual	1, 2,4, 17, 18, 19, and 22	The duality of matter implies that matter….. exists as a particle of dual composition has momentum and energy has both wave and particle properties is made up of dual material Which photon is more energetic: A red one or a violet one? Both Red Violet Neither
Conceptual Knowledge	3, 5, 8, 15, 16, 21, and 25	Which of the following statements is an assumption of the radioactive decay law? Alpha particles are released Beta particles are released Charges are not conserved Mass number is conserved Why are alkali metals most suitable as photo-sensitive metals? High frequency Zero rest mass High work function Low work function
Procedural Knowledge	6, 9, 10, 11, 12, 13, 14, and 23	The energy of an electron in the first Bohr's orbit of a hydrogen atom is -2.18×10^{-18}J. Its energy in the second orbit will be

Knowledge	Questions	Sample of the Questions
		-1.09×10^{-19}J -4.36×10^{-19}J -5.45×10^{-19}J -8.72×10^{-19}J
Meta-cognition Knowledge	7, 20, and 24	The energy of an electron in the first Bohr orbit of hydrogen is $-13.6\ eV$. The possible energy value(s) of the excited state(s) for the electron in the Bohr orbits of hydrogen is $-10.2\ eV$ $-3.4\ eV$ $-1.51\ eV$ $-0.85\ eV$ I only I and II only I, II, and III II, III, and IV

The ANPT items were validated using expert judgement by drawing experts from the AAMUSTED-M campus. The test-retest reliability analysis using second-year Chemistry students of the same campus who were doing similar course content revealed Cronbach's alpha reliability coefficients of 0.76, which was interpreted as a very satisfactory level of acceptance.

Learning Dispositions about Atomic and Nuclear Physics

The Atomic and Nuclear Physics Learning Disposition Survey assesses undergraduate physics students' learning dispositions regarding atomic and nuclear physics. The participants responded to each of the 7 items by selecting one of the following responses: strongly agree (4), agree (4), disagree (2), or strongly disagree (1). Negatively worded items were scored in reverse: strongly disagree (1), disagree (2), agree (3), and strongly agree (4). Accordingly, negative questionnaire items 2, 3, and 6 were scored inversely to produce consistent values between positively and negatively worded items. That is, it would produce high scores for those high and low scores for those low in the Atomic and Nuclear Physics learning disposition. The minimum score on the scale is 1, and the maximum score is 28. Table 4 presents the detailed structure of the Atomic and Nuclear Physics learning disposition survey.

Table 4. Atomic and Nuclear Physics Learning Disposition Survey

S/N	Learning Dispositions	Item
1	Interest	I am interested in learning about atomic and nuclear physics.
2	Frustration	While learning Atomic and Nuclear Physics, I felt frustrated.
3	Learning boredom	I become bored when studying Atomic and Nuclear Physics.
4	Study management	I usually study in places where I can concentrate.
5	Learning enjoyment	I enjoy the challenge of learning about atomic and nuclear physics.
6	Learning hopelessness	I feel hopeless when studying Atomic and Nuclear Physics.
7	Learning persistence	When studying atomic and nuclear physics, I keep going over and over until I understand them.

Participants

A total of 20 intact-class undergraduate physics students participated in this study. Participants were selected from students from Akenten Appiah-Menkah University of Skills and Entrepreneurial Skills and Development in the academic year group 2022-2023. The respondents were between the ages of 18 and 26, with a standard deviation of 1.23 years. Because the one-group design was adopted, all participants were subjected to the same treatment of using scaffolding as a cognitive load reduction strategy to teach Atomic and Nuclear Physics to undergraduate students. The participants were assured of the anonymity of any information they provided. Therefore, pseudonyms were used in the study.

Research Procedure

The main principle of cognitive load theory is that when teachers align their instruction with students' cognitive structures, students' learning will improve (Sweller, 2020). The premise is that students have a working memory that can hold only a certain amount of knowledge for a limited period and an infinite long-term memory. Therefore, purposeful integration and preservation of knowledge in students' long-term memory can help them function beyond their limited working memory with the correct scaffold intervention from an experienced person. Sweller subsequently proposed seven scaffolding effects that teachers can apply to help reduce their students' cognitive load, including the worked examples effect, self-explanation effect, completion problems effect, and goal-free effect. Other effects include variability, imagination, and the collective working memory effect. Five of the scaffolding effects proposed by Sweller were adapted for this study. Figure 1. presents a detailed description of the effects of the adapted scaffolds used, including the researcher's role and that of the students.

Data Analysis

The set of data collected was analysed both quantitatively and qualitatively. The quantitative part was analysed using SPSS version 23, where paired sample t-text, effect size analysis, percentages, and graphs were employed to analyse research questions two and three. The qualitative data analysis was done to solicit undergraduate Physics students' prior conceptual understanding and their learning dispositions about Atomic and Nuclear Physics to answer research questions one and four. In this regard, the students' explanations and views on some selected concepts in Atomic and Nuclear Physics and their learning dispositions about Atomic and Nuclear Physics through a semi-structured interview were sorted, coded, and categorised. To reveal their prior conceptual understanding and learning disposition, students' responses to the semi-structured interview questions were analysed under themes and categories.

Figure 1. Atomic and Nuclear Physics Teaching and Learning Scaffolding Activities

Results and Discussion

Students' Prior Conceptual Understanding of Atomic and Nuclear Physics Concepts

To assess the respondents' prior conceptual understanding of Atomic and Nuclear Physics concepts, 8 respondents labelled A-H were selected through a systematic sampling from the 20 undergraduate participants used for the study. Their responses to the selected questions asked on Atomic and Nuclear Physics revealed that the respondents before the introduction of scaffolding as a cognitive load reduction strategy had an incorrect, partial, and no understanding of the questions asked on some selected concepts in Atomic and Nuclear Physics. Their responses to the various questions are presented as follows:

Researcher: A lithium atom emits energy to move from its ground state to an excited state. Explain whether this statement is true or false.

Expected answer: Before a lithium atom makes a transition from the ground state to an excited state, the Lithium atom must absorb energy. Therefore, the statement is false.

Student A's response:

"The statement is true. This is because, at ground state, the atom possesses a greater amount of energy than expected. Therefore, the lithium atom must give out some energy before it can move from a lower energy level to a higher energy level".

Student A response revealed incorrect knowledge concerning the answer to question one. A careful analysis of student A's response reveals that the student misunderstood the concept of ground state and excited state.

Student B's response:

"The statement is a false statement. This is because, the lithium atom naturally is unstable. Therefore, to move from its ground state to an excited state, it must absorb energy".

However, student B demonstrated partial knowledge of the answer to question one. Student B identified the statement as a false statement; however, the student confused the electron configuration of lithium with the energy level of the electrons of lithium.

Researcher: Explain why an electron in the ground state of hydrogen cannot absorb a photon of energy less than 13.6 eV for excitation to occur.

Expected response: For an electron to move from the ground state to a higher energy level, it must absorb a photon of energy that is equal to the energy difference between the two levels. If the photon's energy is less than 13.6 eV, the electron will not be able to absorb it and move to a higher energy level. If the photon's energy is greater than 13.6 eV, the electron can absorb it, and it will excite to a higher energy level.

Student C's response:

"13.6 eV is an energy limit for all energy transitions within the hydrogen atom. Therefore, once the energy absorbed is less than 13.6 eV, the electron cannot move from the ground state to an excited state".

Student C demonstrated partial knowledge about answering question two. The fact that the energy threshold of 13.6 eV precisely relates to the energy differential between the ground state and the first excited state was overlooked by Student C.

Student D's response:

"The electron cannot absorb energy less than 13.6 eV because it cannot reach a higher energy level".

Student D's response also revealed wrong knowledge in answering question two. Student D assumed that the electron in the hydrogen atom is fixed. Therefore, from the student's response, no amount of energy could cause the electron to be excited.

Researcher: Explain why an electron of an atom requires a much greater energy of -12.07 eV to be excited from the ground state ($n = 1$) to the third energy level ($n = 3$) but another electron of the same atom requires an energy of -1.88 eV to transition from the second energy level ($n = 2$) to the third energy level ($n = 3$).

Expected response: The ground state of an atom is the lowest energy level where the atom is most stable. The electron located in the ground state therefore requires that a greater amount of energy be absorbed to move it electron from the ground state to the third allowed state. However, as one moves up the energy levels, stability reduces. As a result, the energy required for the transition from $n = 2$ to $n = 3$ is comparatively lower than that for the $n = 1$ to $n = 3$.

Student E's response:

"The distance between the electron in the second energy level and the third energy level is shorter compared to the distance between the ground state and the third energy level. As a result, the electron in the ground state will require greater energy than the electron in the second energy level".

The response from student E revealed that the student demonstrated incorrect knowledge regarding item 3. One could decipher from the student's response that the student mistakenly believed that energy levels are evenly spaced or linear in their distribution. Student E thought the energy required for each successive level should increase by a consistent amount, leading to an incorrect understanding of why the energy jump from $n = 1$ to $n = 2$ is significantly larger than the jump from $n = 2$ to $n = 3$.

Student F's response:

"Since the electron in the ground state is located at the last energy level, it will require a greater amount of energy to excite it to the third energy level, compared to the electron in the second energy level".

Also, the response from student F to item 3 revealed that the student demonstrated partial knowledge. Student F failed to add that the electron is located at the last energy level, making the atom stable, which will require a greater amount of energy to excite the electron compared to the electron in the second energy level, which is located at an unstable energy level.

Researcher: Using the nucleon number, how can you determine if an isotope is radioactive or stable?

Expected response: Isotopes with a balanced neutron-to-proton ratio are more likely to be stable, while those with an imbalance in this ratio tend to be radioactive.

Student G's response:

"Isotopes with less neutron-proton ratio are more radioactive than isotopes with high neutron-proton ratio".

Student G's response to question four revealed that the student demonstrated incorrect knowledge. The student rather answered in the opposite.

Student H's response:

"The greater the number of nucleons in an isotope, the more stable the isotope and the less radioactive the isotope"

Student H also demonstrated no knowledge in answering question four. The student showed no knowledge of neutron-proton ratio in determining the stability of an isotope.

The findings of the study showed that undergraduate Physics students demonstrated "incorrect knowledge", "partial knowledge" and "no knowledge" in Atomic and Nuclear Physics concepts. Previous findings such as those of the studies of Im and Kim (2014), Ejigu (2014), as well as Muhakeya and Maseko (2022), found that undergraduate and pre-service teachers had incorrect knowledge about concepts of Atomic and Nuclear Physics.

Effect of scaffolding as cognitive reduction strategy Conceptual Understanding

This research question was analysed using paired samples t-test with pre and post-test scores of Atomic and Nuclear Physics Knowledge Tests. Table 5 presents the results of the paired-sample t-test with an effect size value on conceptual understanding before and after the introduction of scaffolding as a cognitive reduction strategy.

Table 5. Paired Sample Test Results with Effect Size

Variable	Group	M	SD	MD	SD-MD	df	t	p	η^2
Pre-test score	One	6.12	0.38	7.22	0.31	19	-12.96	0.03	0.79
Post-test score		13.34	0.23						

N=20, p<.05; M: Mean; SD: Standard deviation; MD: Mean difference; & SD-MD: Standard deviation of mean difference.

The results shown in Table 5 show a statistically significant difference between the post-test score (M = 13.34, SD = 0.23) and the pre-test score (M = 6.12, SD = 0.38); t (19) = -12.96, p < 0.05, 95% CI [32.50, 41.15]. Also, the overall mean score increases by 7.22 with a slightly smaller spread in standard deviation (SD = 0.31). This indicates that the mean increase in undergraduate physics student's overall conceptual understanding of Atomic and Nuclear Physics after the introduction of scaffolding as a cognitive reduction strategy can be considered significant by the Sig (2-tailed) value of 0.03 and a large effect size value of 0.79 (Cohen et al., 2018).

The finding represents that the utilisation of scaffolding as a cognitive load strategy in the teaching and learning of Atomic and Nuclear Physics increased B.Sc. Physics Education students' comprehension and mastery of concepts, demonstrating improved conceptual understanding of undergraduate Atomic and Nuclear Physics concepts. Researchers such as Alake and Ogunseemi (2013), Alrawili et al. (2015), Joda (2019), Mohammed (2019), and Bileya et al. (2021), in agreement with this study, found the use of scaffolding as an effective instructional strategy to enhance students' academic performance in science, which can be extrapolated to mean enhanced conceptual understanding.

Factual Knowledge, Conceptual Knowledge, Procedural Knowledge, and Meta-Cognition Knowledge

This research question assesses participants' factual, conceptual, procedural, and meta-cognition knowledge in Atomic and Nuclear Physics before and after the integration of scaffolding into CLT. Pre-test frequency counts and post-test frequency counts of each question of the ANPT were converted into percentages and used to answer this research question.

In the ANPT factual knowledge domain, undergraduate physics students' knowledge of terminology and specific details about Atomic and Nuclear Physics concepts is assessed. The factual knowledge items of the ANPT, as presented in Figure 2, were 1, 2, 4, 17, 18, 19, and 22. The item pre-test frequency counts ranged from 3.00 to 10.00, with corresponding percentages between 15.00% and 50.00% and an overall percentage of 31.43% for the pre-test. In addition, the frequency counts of the post-test items ranged from 14.00 to 16.00, with corresponding percentages between 70.00% and 80.00% and an overall percentage of 75.71%. These results indicate that the participants improved their factual knowledge of atomic and nuclear physics after the integration of scaffolding into CLT.

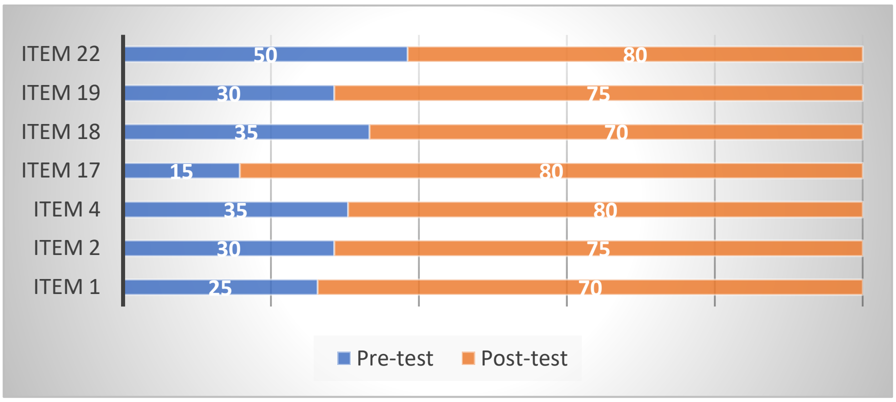

Figure 2. Pre-test and Post-test Percentage Distribution of Factual Knowledge Items

The conceptual knowledge domain of the ANPT assesses the knowledge of undergraduate physics students about classification, category principles, generalisations, theories, models, and structures of Atomic and Nuclear Physics concepts. The conceptual knowledge items of the ANPT as presented in Figure 3 were 3, 5, 8, 15, 16, 21, and 25. The item pre-test frequency counts ranged from 5.00 to 11.00, with corresponding percentages between 25% and 55% and an overall percentage of 40.00% for the pretest. Similarly, the frequency counts of the post-test items ranged from 12 to 17, with corresponding percentages between 45% and 75% and an overall percentage of 74.28%. The results indicate that the participants have improved their conceptual knowledge of Atomic and Nuclear Physics after the integration of scaffolding into CLT.

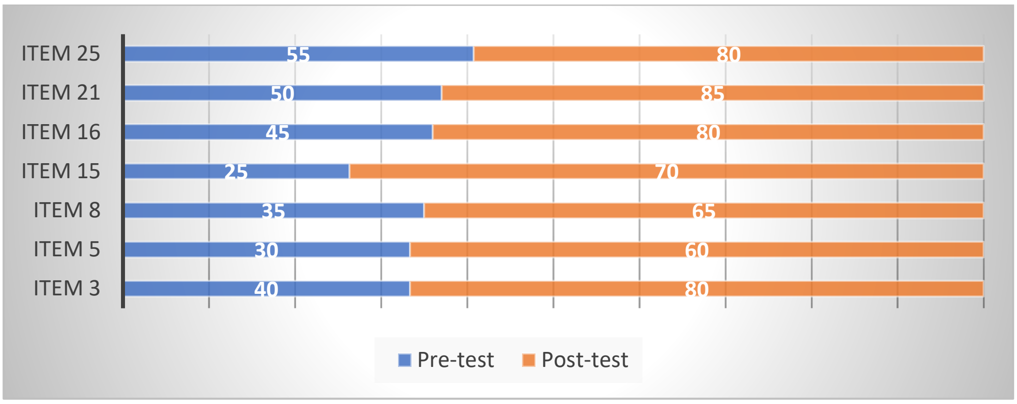

Figure 3. Pre-test and Post-test Percentage Distribution of Conceptual Knowledge Items

The procedural knowledge domain of the ANPT assesses the knowledge of undergraduate physics students about subject-specific methods and the criteria to determine when to use appropriate procedures of the concepts of Atomic and Nuclear Physics. Procedural Knowledge items of the ANPT as presented in Figure 4 were 6, 9, 10, 11, 12, 13, 14, and 23. The procedural knowledge item pre-test frequency counts ranged from 4.00 to 12.00, with corresponding percentages between 20% and 60% and an overall percentage of 41.88 % for the pre-test. Also, the frequency counts of the post-test items of the post-test items ranged from 12 to 17, with corresponding percentages between 60% and 85 % and an overall percentage of 75.00%. These results indicate that the participants have improved their procedural knowledge of Atomic and Nuclear Physics concepts used for the study after the integration of scaffolding into CLT.

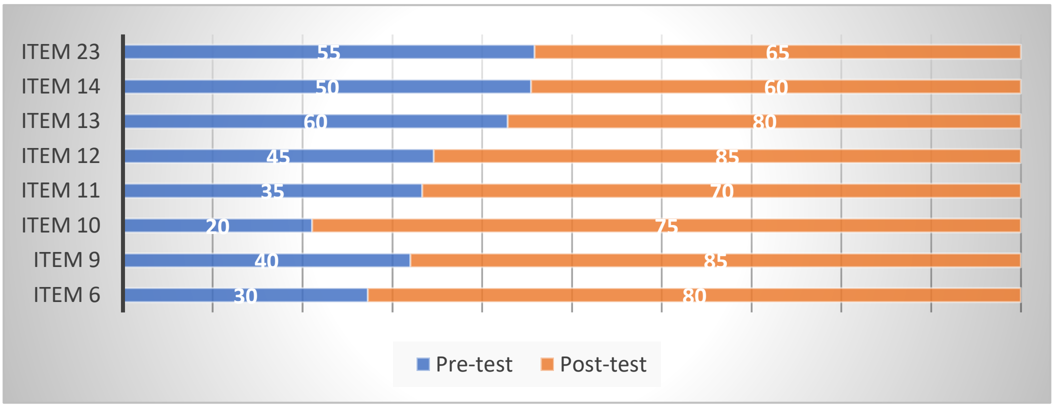

Figure 4. Pre-test and Post-test Percentage Distribution of Procedural Knowledge Items

The meta-cognition knowledge domain of the ANPT measures the metacognition knowledge of undergraduate physics students' knowledge about cognitive tasks, including contextual and conditional knowledge of Atomic and Nuclear Physics concepts. Meta-cognition knowledge items of the ANPT as presented in Figure 5 were 7, 20 and 24. The meta-cognition knowledge item pre-test frequency counts ranged from 6.00 to 8.00, with corresponding percentages between 30.00 % and 40.00 % and an overall percentage of 35.00 % for the pre-test. Also, the frequency counts of the post-test items ranged from 14 to 16, with corresponding percentages between 70.00% and 80 % and an overall percentage of 75.00%. These results can be interpreted as indicating that the participants have improved their meta-cognition Knowledge of Atomic and Nuclear Physics concepts used for the study after the integration of scaffolding into CLT.

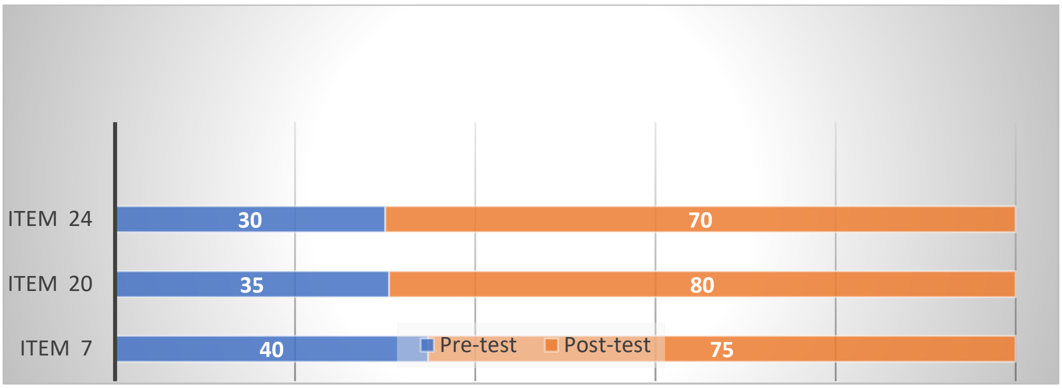

Figure 5. Pre-test and Post-test Percentage Distribution of Meta-cognition Knowledge Items

this findings on students' factual, procedural, conceptual, and meta-cognition knowledge, researchers including Wang et al. (2021), Midun et al. (2020), and Abdul-Aziz (2016) found the use of scaffolding to enhance student metacognitive and procedural knowledge. Ahmad et al., (2019) posit that scaffolding gives students the organised help, direction, and clarity they need to approach problems methodically, fostering comprehension, developing abilities, and instilling the self-assurance required for academic achievement. Furthermore, in the view of Ahmad et al. (2019), using real-world examples and models of concepts and problem-solving techniques helps decrease the cognitive stress and uncertainty related to abstract or new tasks.

Physics Students' Learning Dispositions Towards Atomic and Nuclear Physics

The effectiveness of using scaffolding as a cognitive load reduction strategy on the learning dispositions of undergraduate Physics students toward Atomic and Nuclear Physics was examined both quantitatively and qualitatively. The quantitative part was descriptively analysed by examining the responses of the pre-and post-learning disposition of the respondents from the questionnaire. The results are presented in Table 6.

Table 6. Descriptive Statistics of the Learning Disposition with Effect Size

Learning Disposition Domain	Pre-Survey		Post-Survey		Effect Size	Effect Size Interpretation
	M	SD	M	SD	η^2	
Interest	1.19	0.91	2.85	1.11	1.63	Large
Frustration	2.81	1.23	1.98	1.20	0.68	Medium
Learning Boredom	2.57	0.78	2.00	1.89	0.68	Medium
Study Management	2.01	1.23	3.01	1.32	0.92	Large
Learning enjoyment	1.89	0.17	2.98	1.07	0.95	Large
Hopelessness	2.10	1.23	1.52	1.45	0.43	Small
Learning Persistence	1.11	1.90	3.45	2.00	1.19	Large
Overall	1.95	1.06	2.54	1.13	0.93	Large

$M = Mean, SD = Standard\ Deviation, \eta^2 = Effect\ sizet$

In the pre-survey analysis on the learning disposition domains, the mean scores of the items ranged from 1.11 to 2.81, with an overall mean score of 1.95 (SD = 1.06). These results can be interpreted to indicate that undergraduate physics students used for the study had a negative learning disposition towards the learning of Atomic and Nuclear Physics before the introduction of scaffolding as a cognitive load reduction strategy. However, post-survey analysis revealed that the mean scores of the elements range between 1.52 and 3.45, with an average mean score of 2.54 (SD = 1.13), suggesting that the undergraduate physics students used for the study have developed a positive learning disposition towards Atomic and Nuclear Physics after the introduction of the scaffold as a cognitive load reduction strategy. The positive learning disposition developed is also supported by the calculated large effect size value, $\eta^2 = 0.93$ (Cohen et al., 2018).

The opinions of the students after the use of scaffolding as a cognitive load reduction strategy were also solicited to provide a complete understanding of their dispositions towards the teaching and learning of concepts of Atomic and Nuclear Physics. In this regard, the researcher asked the respondents, selected through a systematic sampling from the 20 undergraduate physics students and labelled as A-H for a face-to-face interview. The respondents were asked to briefly explain a learning experience that they felt had a particularly significant or influential outcome during the teaching and learning of Atomic and Nuclear Physics. The researcher also asked the respondents to explain the difficulties they encountered, their approach, how they maintained their motivation as they studied, and how they were able to accomplish the learning objectives. The results of the face-to-face interview are presented in Table 7.

Table 7. The results of the Face-to-Face Interview

Respondent	Response	Identified Learning Disposition
A	The real-life examples helped me to understand the practical applications of X-rays and the photoelectric effect. For instance, I understood that the shorter wavelength of X-rays makes it possible for them to be used as a diagnostic tool in medicine to detect fractures of bones and foreign bodies like bullets and stones in the body. My interest in these topics was piqued by the sufficient process of reducing difficult problems into manageable steps, even though it was initially difficult.	Interest
B	The use of conceptual analogies to relate carbon dating phenomena to everyday experiences made the subject more enjoyable. Making links between unfamiliar situations and abstract concepts made it easier for me to understand the details of carbon dating, and I now enjoy seeing those connections.	Learning enjoyment
C	These strategies used to teach Atomic and Nuclear Physics have encouraged autonomous learning. The resources and guidance provided during the learning process empowered me to explore additional materials and deepen my understanding of half-life independently. It is like I have developed a toolkit for tackling similar complex scenarios regarding half-life on my own. For instance, I can determine the half-life of substance using $N=N_O e^{-\lambda t}$ to find the decay into $T_{\frac{1}{2}} = \frac{0.693}{\lambda}$.	Study Management
D	Now using these strategies has helped me understand that learning is a process, and it is okay not to grasp everything immediately. Breaking down the material into smaller, manageable parts allowed me to focus on mastering one concept at a time, reducing the sense of hopelessness.	Learning hopelessness
E	These techniques you used helped break down the challenges of solving carbon dating problems using the decay law into manageable steps. For example, I can determine the original amount of a substance after it has decayed for some time. I can also determine the age of a substance, all by rearranging the equation $N=N_O e^{-\lambda t}$. Instead of feeling overwhelmed, I could focus on one concept at a time, which motivated me to persist and gradually build a solid understanding of the subject.	Learning persistence
F	The regular feedback allowed me to address my misconceptions and errors early on. Previously I exchanged the meaning of nuclear fusion for nuclear fission, especially when solving problems regarding applications of fission and fusion. Getting prompt feedback on my understanding helped prevent frustration from escalating. It turned mistakes into opportunities for learning and improvement.	Frustration

Respondent	Response	Identified Learning Disposition
G	The collaborative nature of lectures in atomic and nuclear physics, especially when working with peers in discussions, made the learning experience more interactive. Sharing ideas, debating concepts, and learning from each other kept me interested and prevented the monotony that could come with studying alone.	Boredom

Supporting the findings presented in Tables 6 and 7, researchers such as Annisa and Sutapa (2019) and Weinstein and Preiss (2017) stated that the use of scaffolding increases students' interest and further said that scaffolding improves students' learning autonomy. In this study, participants articulated that the use of the scaffolding strategy encourages them to take charge of their learning. This aspect of the finding is consistent with Cardullo et al. (2018), who acknowledged that the application of scaffolding in the classroom provides a structured framework. This structured framework subsequently reduces students' feelings of overwhelm and promotes a sense of competence and achievement by breaking down difficult activities into manageable steps.

Conclusion

This study examines the effectiveness of scaffolding as a cognitive load reduction strategy in the teaching and learning context of Atomic and Nuclear Physics. The baseline assessment revealed that the majority of the B.Sc. Physics Education students had difficulties relative to Atomic and Nuclear Physics concepts. However, after employing scaffolding as a cognitive load reduction strategy, undergraduate physics used for the study's conceptual understanding of Atomic and Nuclear Physics was enhanced.

Similarly, the factual, conceptual, procedural, and meta-cognition knowledge of undergraduate physics students was enhanced after using scaffolding as a cognitive load reduction strategy. Also, both quantitative and qualitative measures revealed that the use of scaffolding as a cognitive load reduction helps undergraduate physics students develop positive learning dispositions towards the teaching and learning of Atomic and Nuclear Physics. Based on these findings, the author concludes that using scaffolding as a cognitive load reduction strategy effectively promotes the teaching and learning of Atomic and Nuclear Physics in the context of undergraduate physics studies.

Recommendations

Based on the results of this study, it is recommended that undergraduate physics lecturers consider the use of scaffolding to reduce the cognitive load of students, which increases their conceptual understanding of the teaching and learning of Atomic and Nuclear Physics. Additionally, in an attempt to change students' learning dispositions, it is recommended that undergraduate physics lecturers employ scaffolding as a cognitive load reduction strategy in the teaching and learning of Atomic and Nuclear Physics.

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