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Comparative Effects of Generative Learning Strategies and 5E Strategies on Pre-Service Teachers' Achievement of Integrated Science Concepts

Yao Donusem Asamoah[1], Eric Appiah-Twumasi[1], John Bosco Kwasi Fiave[2], Daniel Mamudu[3]
[1]Department of Integrated Science Education, Faculty of Science Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong-Ashanti, Ghana
[2]Directorate of ICT Services, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong-Ashanti, Ghana
[3]Department of Science Education, St. John Bosco College of Education, Navrongo, Ghana

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ABSTRACT

Purpose of the study: This study aims to investigate the comparative effects of generative learning strategy (GLS) and 5E strategy (5E-IS) on the academic achievement of pre-service teachers in integrated science. This study addressed two research questions and test one hypothesis at .05 level of significance.

Methodology: The research employed a non-equivalent pre- and post-tests design followed by semi-structured interviews. A sample of 157 pre-service teachers were selected from two intact programmes of study. The main data collection instruments were pre- and post-tests, and interview schedule. Data was analysed using mean scores, adjusted means, percentages and with Analysis of Covariance (ANCOVA). Interview results were analysed using narratives.

Main Findings: There was relative improvement in pre-service teachers' performance taught with GLS and 5E-IS. Moreover, pre-service teachers instructed using generative learning strategies demonstrated superior performance compared to those in 5E strategy group (effect size = 0.32, p = 0.000, < 0.05). The interview data reveals that both generative and 5E strategies were perceived as beneficial and adaptable approaches that enhance understanding, retention, knowledge transfer across various contexts, and ultimately motivating learners throughout the learning process.

Novelty/Originality of this study: The effectiveness of GLS and 5E-IS hold significant implications for curriculum design, instructional practices, and teacher preparation programmes. Understanding pedagogical approach which yields superior learning outcomes, enhances retention of scientific concepts, and teacher efficacy is key. Insights from this study may contribute to the on-going discourse surrounding best practices in science education, fostering continuous improvement and innovation in instructional methodologies.

Corresponding Author:
Yao Donusem Asamoah,
Department of Integrated Science Education, Faculty of Science Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong-Ashanti, Sunyani Rd, Kumasi, Ghana
Email: yaoasamoah@aamusted.edu.gh

1. INTRODUCTION

Instructional strategies, the methodologies educators employ to deliver lessons effectively, play a pivotal role in facilitating learning. According to Persuad, these strategies transition into learning strategies when educators judiciously select and implement them [1]. Further posits that students can achieve their learning objectives when appropriate instructional strategies are chosen and implemented effectively. Kizlik, argues that the suitability and effectiveness of instructional strategies for a specific lesson hinge on various factors, including students' age, cognitive development, existing knowledge, learning needs, subject matter, student interest, and lesson objectives [2].

Consequently, a good instructional strategy should allow students to learn more effectively and efficiently by adjusting to their learning styles and actively engaging them in the teaching and learning processes [3]. Bigelow, emphasises that such strategies should foster independence in learning, assist students in attaining educational goals, and develop essential skills [3]. The effectiveness of instructional strategies relies on the synergy between teachers' subject expertise and instructional skills, as highlighted in educational literature. Despite the pivotal role of teachers in imparting knowledge, students' academic records often reveal gaps in skills and competencies attributed to ineffective instructional strategies. To address this issue, science educators must employ effective instructional strategies that align with curricular goals.

Many science teachers, however, struggle to incorporate instructional strategies that resonate with students, resulting in a curriculum that may seem disconnected from students' realities. This suggests that many science teachers appear stagnant with instructional strategies that do not facilitate student understanding and learning of required skills. Appiah-Twumasi, notes that contemporary science education emphasises student-centred teaching methods [4]. Therefore, it is imperative to ground Integrated Science educational methodologies in both theoretical and empirical foundations supporting student-centred learning.

Numerous studies highlight generative learning and the 5E instructional strategies as effective tools for enhancing science students' comprehension and retention of scientific concepts [5]-[9]. While existing literature underscores the effectiveness of these instructional approaches, there is a gap in empirical research comparing these strategies and elucidating students' perceptions of their benefits. Based on the empirical gap, this paper addressed the following research questions and hypothesis:

1. What is the effect of generative learning strategies and 5E instructional strategies on the achievement of pre-service teachers in integrated science concepts?
2. How do pre-service teachers perceive the importance of generative learning strategies and 5E instructional strategies in teaching integrated science?

The following null hypothesis was formulated and tested at .05 level of significance:

H_0: There is no statistically significant difference between the effects of generative learning strategies and 5E instructional strategies on pre-science teachers' achievement in integrated science concepts.

2. LITERATURE REVIEW

The theoretical foundation of this study rests upon the constructivist paradigm, which posits that students actively create their own representations and incorporate new information into their pre-existing knowledge when they interact with the world and reflect on it. Hence, in constructivist learning environments, students are expected to constantly interact with the world around them in an attempt to make meaning out of their interaction. A typical attribute of constructivist-minded instruction is that students construct knowledge in the constructivist classroom rather than passively taking in information. Therefore, constructivist adherents advocate active and interactive classroom engagement as students typically obtain information by getting involved in the teaching and learning processes.

Kroll, intimated that in the constructivist classroom, students should be able to construct for themselves an articulated vision of learning, teaching, development, and knowledge [10]. According to the literature Kirschner et al and Powell & Kalina, an active classroom in which teachers and students communicate effectively is dependent on the use of constructivist strategies, tools, and practices [11], [12]. Students' construction of knowledge by themselves is central to constructivism. This is done through active participation in the learning task. In the constructivist classroom, the teacher only acts as a facilitator, not a provider of knowledge. In a typical constructivist learning classroom, soliciting prior students' knowledge, creating cognitive dissonance, applying knowledge with feedback, and reflecting on learning activities are the key stages of teaching and learning enterprises facilitated by the instructor. The underlying idea is that a student must actively create knowledge and abilities and that information dwells within these built constructs rather than in the external environment, with the assumption that the individual's response to stimuli is the most important factor.

Constructivism emphasises the value of an individual's knowledge, beliefs, and skills in the learning process. These values are based on Piaget's ideas and emphasise the learner's active role in engaging with the environment, either alone or with others [13], [14]. According to Kola, constructivist classrooms promote active and engaged learning, which is indicative of real learning [15]. As a result, the teacher should encourage learners to participate in order for them to study effectively. Through student interactions, a constructivist teacher must use cooperative teaching underpinnings, respect the exchange of ideas, and provide learning assignments.

The core of constructivism paradigm is student learning. In other words, the constructivist model revolves around the learner. The teacher comes to class because of the students, regardless of the instructional strategy used, the students are prioritised. As a result, past student knowledge serves as a springboard for the students' learning process. Students make connections between new material and prior knowledge on their own or while interacting with a peer or the teacher. Any science learning is most effective when the science teacher is aware of the students' past knowledge. Consequently, the science teacher should be aware of students' prior knowledge of the topic under discussion. However, majority of students are unable to connect new knowledge provided by the teacher to their previously learned concepts, probably because of the instructional strategy selected and implemented by the teacher. As a result, confusion creeps in, and many students resort to memorisation to address their problems [15]. It is on this basis that science teachers are encouraged to use some pedagogical strategies, such as Generative Learning and 5E instructional strategies, to bridge this gap.

The processes involved in using the generative learning strategy are subject to differing opinions. For example, George divides generative learning into two categories: To begin, students are urged to create an organisational structure that includes the title, concentration, questions, objectives, a summary, graphs, location, and important ideas [16]. Second, the students are asked to create metaphors, such as analogies, interpretations, paraphrases, and conclusions, to create integrated links between what they see, hear, and understand. Pappas, on the other hand, described the generative learning strategy as having four primary fundamental principles that instructors can use depending on the learners' requirements and the teaching and learning materials available [17]. The four concepts proposed by Pappas, are recall, integration, organisation, and elaboration. In the recall, the student retrieves information stored in the long-term memory to aid learning [17]. This may involve the regular repetition of a concept. In the integration phase, the learner combines new information with those already stored in the long term to create new knowledge. This may involve the use of analogies to make concepts clearer to the student. Also in the organisation state, the student reorganises knowledge through critical analysis of concepts. This may facilitate the creation of related concepts. Finally, in the elaboration phase, the student is taught to connect new knowledge to existing ones to create expanded knowledge. This may also be accomplished by critiquing existing knowledge.

The Biological Sciences Curriculum Study (BSCS) team Bybee et al created the 5E instructional model to enhance and deepen the Science Curriculum Improvement Study (SCIS) instructional model. Following that, the group created a five-phase educational paradigm for teachers [18]. The 5Es instruction paradigm (engage, explore, explain, elaborate, and evaluate) is a research-based teaching model that is both learner-centred and inquiry-based. During the engagement phase, students are activated and their prior knowledge is tested. Its goal is to grab students' attention, identify their interests, and identify their misconceptions. During the exploration phase, the imbalance of engagement is resolved by students' actions in their various groups; their cognitive and physical talents are developed. The teacher supervises activities, provides proper resources, and corrects any misconceptions. During the explain phase, Ergin, stated that students present and explain their findings. The teacher acts as a shock absorber, directing students' attention to crucial features of previous phases and using their explanations to clarify scientific topics [19]. The elaboration phase is where learners' comprehension is enhanced with additional problems or real-life scenarios. Lastly, during the evaluation phase, students examine their learning and receive feedback on their adequate progress and competence, which assists the teacher in making the appropriate decision [20].

In summary, this study delves into the efficacy of generative instructional strategies and 5E strategies on pre-service teachers' achievement. Despite the recognition of these strategies' effectiveness in literature, empirical research comparing them and exploring students' perceptions of their benefits appears to be lacking.

3. RESEARCH METHOD

The study employed action research, utilising both quantitative and qualitative data collection methods from pre-service teachers enrolled in B.Ed. Upper Primary Education and B.Ed. Early Grade Education programmes at the Department of Educational Studies, Akenten Appiah-Menkah University of Skills Training and Entrepreneurial Development (AAMUSTED), Ghana, during the second semester of the 2021–2022 academic year. Non-equivalent pre-test and post-test followed by semi-structured interviews were conducted with the two groups pre-service teachers to assess the comparative effects of generative learning and 5E instructional strategies on their achievement of concepts in selected topics in integrated science. In order to avoid class disintegration of the pre-existing composition of participants in their respective programmes of study, random assignment to experimental groups was not feasible. Therefore, a non-equivalent pre-test and post-test design were employed using the two intact programmes of study.

A total of 157 pre-service teachers were included in the study, drawn from two distinct group of programmes. The distribution of pre-service teachers across the two groups was as follows: Bachelor of Education (B.Ed.) Upper Primary Education (n = 75.00) and Bachelor of Education (B.Ed.) Early Grade Education (n = 82.00). The age range of participants was between 18 and 28 years (SD = 0.120), with a mean age of 22 years (SD = 1.100). The entry characteristics was determined for both groups of pre-service teachers using their pre-test scores as depicted in Table 1 below.

Table 1. Independent Sample t-test Results for Entry Characteristics

	Group	N	Mean	Std. Dev.	Df	T	P
Pretest	GLS	75	5.55	2.189	155	4.623	0.00*
	5Es	82	7.33	2.601			

*p < 0.05

As presented in Table 1, entry characteristics test of the participants conducted via an independent sample t-test prior to the introduction of the GLS and 5Es showed significant difference in understanding of the Integrated Science concepts between both pre-service teachers exposed to GLS (M=5.55; SD=2.189) and 5Es (M=7.33, SD=2.601; $t_{(155)}=4.623$, $p < 0.05$). This indicates that the two groups were not equivalent in their achievement of Integrated Science concepts before the implementation of respective instructional strategies. However, the difference in entry characteristics was catered for by the ANCOVA (see Table 4). Any further change in the groups' achievement in Integrated Science concepts after instruction may be attributed to a particular instructional strategy used for respective groups. Throughout the intervention phase, participants in all two groups actively engaged in the teaching and learning processes, aligning with the constructivist paradigm adopted for the study. This approach encouraged collaboration among participants, documentation of their work and progress, and fostering personal responsibility for learning. All two groups received instruction using the same teaching materials, exercises, and assignments to ensure consistency in the teaching and learning experience.

For this comparative study, the main instruments employed were tests and interview schedules. In order to ensure consistency and standardisation of test items, a self-constructed Integrated Science Achievement Test (ISAT) was developed comprising a 20-item test for pre-test and a corresponding reshuffled 20-item achievement test for post-test. These tests aimed to assess pre-service teachers' comprehension of selected concepts in integrated science, covering topics in biology, chemistry, and physics. All questions were presented in a multiple-choice format, with four options provided to each question. The 20-item test and the reshuffled 20-item achievement test administered before and after the interventions respectively were introduced to the two groups.

To ensure quality of the instruments, experts in science education independently inspected the interview schedules and test items on the ISAT to ensure that domains of integrated science concepts were adequately covered. Their feedback was used to modify the instruments. The instruments were field tested with participants having similar characteristics with those in the main study. Items with difficulty indices below 0.20 were excluded due to being overly challenging, while those with difficulty indices exceeding 0.90 were discarded for being too straightforward [21]. The internal consistency of the test items on ISAT was determined using Cronbach's alpha correlation and found to be 0.77, indicating high reliability [22]. Furthermore, interviews were conducted to gather insights from pre-service teachers regarding the perceived benefits of both generative and 5Es instruction strategies.

4. RESULTS AND DISCUSSION

The Effect of Generative Learning Strategies and 5E Instructional Strategies on the Achievement of Pre-Service Teachers in Integrating Science Concepts

The effect of GLS and 5E instructional strategies on pre-service teacher participants' achievement in integrated science concepts was determined using total mean scores and their relative percentages of the pre-test and post-test scores of the pre-service teachers' performance on the ISAT test (see Tables 2 and 3 respectively). Table 2 shows the range of scores, total scores, and percentage of the pre-service teachers' ISAT conducted before and after the introduction of the GLS.

Table 2. Percentage of Pre-service Teachers' Performance in Pre-test and Post-test of GLS

Range of Scores	Pre-test		Post-test	
	Total	%	Total	%
16 – 20	6.00	8.00	15.00	20.00
11 – 15	7.00	9.30	24.00	32.00
06 –10	37.00	49.30	26.00	34.70
00 – 05	25.00	33.30	10.00	13.30
∑	75.00	100.00	75.00	100.00

As depicted in Table 2, the number of pre-service teachers scoring between 16 and 20 in the pre-test increased from 6 (8.00%) to 15 (20.00%) in the post-test. Similarly, those scoring between 11 and 15 in the pre-test rose from 7 (9.53%) to 24 (32.00%) in the post-test. Conversely, the proportion of students scoring between 6 and 10 in the pre-test decreased from 37 (49.30%) to 26 (34.70%) in the post-test. Additionally, the percentage of students scoring between 00 and 05 in the pre-test decreased from 25.00 (33.30%) to 10 (13.30%) in the post-test.

Furthermore, the impact of the 5E strategy on pre-service teachers' achievement in integrated science concepts was assessed using total mean scores and their relative percentages from the pre-test and post-test scores in the ISAT. Table 3 presents the score ranges, total scores, and percentages of pre-service teachers' ISAT results before and after the implementation of the 5Es strategy.

Table 3. Percentage of Pre-service Teachers' Performance in Pre-test and Post-test of 5Es

Range of Scores	Pre-test		Post-test	
	Total	%	Total	%
16 – 20	7.00	8.54	11.00	13.41
11 – 15	23.00	28.05	34.00	41.46
06 – 10	34.00	41.46	30.00	36.59
00 – 05	18.00	21.95	7.00	8.54
∑	82.00	100.00	82.00	100.00

As indicated in Table 3, the number of pre-service teachers scoring between 16 and 20 in the pre-test increased from 7.00 (8.54%) to 11.00 (13.41%) in the post-test. Similarly, pre-service teachers scoring between 11 and 15 in the pre-test rose from 23.00 (28.05%) to 34 (41.46%) in the post-test. Conversely, pre-service teachers scoring between 06 and 10 in the pre-test decreased from 34.00 (41.46%) to 30.00 (36.59%) in the post-test. Additionally, pre-service teachers scoring between 00 and 05 in the pre-test decreased from 18 (21.95%) to 7 (8.54%) in the post-test after receiving instruction with the 5E-IS.

To determine whether the difference in the effects of GLS and 5E on the pre-service teachers' achievement in integrated science concepts was statistically significant, research question one was formulated into a null hypothesis and tested at .05 level of significance. Consequently, it was hypothesised that:

H_o*: *There is no statistically significant difference between the effects of Generative and 5E strategies on the pre-science teachers' achievement in integrated science concepts.

It is important to note that there was a difference in the initial understanding of Integrated Science concepts (as shown in Table 1) between pre-service teachers enrolled in B.Ed. Upper Primary Education programme before the introduction of GLS and those in the Early Grade Education programme before the introduction of 5E-IS. However, this initial difference was accounted for using one-way ANCOVA. Consequently, any subsequent variations in the groups' achievement in Integrated Science concepts after the instruction can be attributed to the specific instructional strategies employed for each group. As a result, instructional strategy was taken as a fixed factor, pre-test scores as a covariate, and post-test scores of the dependent variable as a predictor. The results of the one-way ANCOVA are presented in Table 4.

Table 4. One-Way ANCOVA Results on Post-test Scores Between 5E Group and GLS Group

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	951.688[a]	2	475.844	66.568	.000	.464
Intercept	569.974	1	569.974	79.736	.000	.341
Pre-test	753.881	1	753.881	105.463	.000	.406
Method	517.235	1	517.235	72.358	.000	.320
Error	1100.834	154	7.148			
Total	22075.000	157				
Corrected Total	2052.522	156				

a. R Squared = .464 (Adjusted R Squared = .457)

A significant difference was found between pre-service teachers taught with GLS and those taught with 5Es as shown in Table 4 ($F_{(1, 154)}$ =72.358, $p < 0.05$). From Table 4, an effect size (using partial eta squared) for teaching method was also found to be 0.32 indicating a large effect size according to Pallant [22]. This means that 32.0% of the variance of the teaching methods was explained by post-test scores. Hypothesis one was therefore rejected. To ascertain which instructional strategy favoured the significant difference, references were made to Tables 5 using the adjusted mean scores and their respective standard errors after controlling for the effect of the pre-test scores on the post-test scores.

Table 5. Adjusted Means and Standard Errors of Post-test Scores

Group	Adjusted Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
GLS	13.320[a]	.337	12.654	13.985
5Es	9.443[a]	.312	8.826	10.059

a. Covariates appearing in the model are evaluated at the following values: Pre-test = 6.48.

After controlling for the pre-test scores on the post-test scores, the results as indicated in Table 5 showed that pre-service teachers exposed to GLS had a higher adjusted mean score of 13.320(SD = 0.337) while their counterparts exposed to 5E obtained an adjusted mean score of 9.443(SD = 0.312). The results presented in Table 5 indicate that the significant difference as shown in Table 4, favoured pre-service teachers exposed to GLS.

The study's results demonstrate enhanced achievement in integrated science concepts following the implementation of generative learning strategies (GLS) and 5E instructional strategies. Specifically, the post-test ISAT scores of pre-service teachers in the generative class surpassed their pre-test scores. For instance, the number of pre-service teachers scoring between 16-20 marks increased from 6.00 in the pre-test to 15.00 in the post-test. These findings align with previous research by Ahmad et al. [6], Appiah-Twumasi [7], and Al-Mutlaq [8], which also observed improved student performance after instruction with GLS. Ogunleye [23] similarly found that students exposed to GLS in physics achieved significantly higher post-test scores compared to those taught using traditional methods. GLS encourages students to engage actively with information, facilitating the formation of connections between new and existing knowledge in a constructivist setting through activities such as summarisation, analogy creation, and question generation. By fostering active involvement in the learning process, students are more likely to retain information over the long term [24].

Similarly, the second group, instructed with the 5E approach, exhibited improved achievement, as evidenced by their post-test scores. For instance, the number of students scoring between 16-20 in the ISAT increased from 7.00 in the pre-test to 11.00 in the post-test. These findings are consistent with the research of Abdul-Majeed [5] and Appiah-Twumasi et al. [9], who observed enhanced student performance with the 5E instructional strategy. The 5E model facilitates the provision of experiences necessary for conceptual change and inquiry learning in a constructivist classroom environment, as outlined by Bybee [25] and Campbell [26]. This is achieved through self-reflection and interaction with peers and the environment. However, such changes are not solitary; students must engage in discussion, debate, and sharing with others to solidify their thoughts and explanations, fostering success in science classrooms.

Pre-Service Teachers View the Benefits of Generative Learning Strategies And 5E Instructional Strategies in Teaching Integrated Science

This aspect of the research solicited feedback from the pre-service teachers on the perceived benefits of the implementation of generative and 5E instructional strategy's themes such active participation, retention on information and critical thinking emanated from the interview results. Specifically, out a total of 30 pre-service teachers selected for interview, majority (N = 22) of the pre-service teachers stated that they actively participated in the lesson. Moreover, 24 of the pre-service teachers stated that they could retain the teaching content they learned. Also, 21 of the pre-service teachers claimed that the teaching strategies foster critical thinking skills.

Some representative statements (all names are pseudonyms) about the benefits of the two teaching strategies are as follows:

Amina (a 23-year-old female) said that "*generative learning strategies provide a platform for promoting student learning by integrating new material with previous experience to create new connections and promote knowledge transfer"*. Justine (a 26-year-old male) also said that "*the combination of new and previous information encourages students to express their own actions, consequently promoting deeper understanding".* Amoah (a 25-year-old male) also said *"students participate actively in teaching and learning processes, either in the physical or cognitive aspects, through generative learning activities".* He added that *"generative learning strategy can help students organise new content and integrate it into meaningful and structured knowledge, thereby promoting deep learning".*

Afua (a 26-year-old female) also contended that *"5E encourages students to become interested in the topic and to ask questions. She furthered that "5E teaching strategy help students to increase their motivation to learn and become actively involved in the teaching and learning phases". She concluded that "5E strategy allow students to build their own understanding of the topic through hands-on activities and discussions".*

Furthermore, the interview results indicated that pre-service teachers perceive generative and 5E instructional strategies as beneficial for student understanding of teaching content, retention of learned information, transferability to different contexts, and engagement in all phases of teaching and learning. These views echo findings from authors such as Fiorella and Mayer [27], Ahmad et al. [6], and Al-Mutlaq [8], who reported similar benefits associated with these instructional strategies.

It is worth noting that teachers employ a range of teaching methods to promote student persistence and learning outcomes, potentially integrating active learning strategies to make the learning experience both effective and enjoyable for students [28]-[31]. The unique aspect of this study, in contrast to earlier research, is its emphasis on the effectiveness of GLS and 5E-IS has important consequences for curriculum development, teaching methods, and teacher training programmes. Identifying the pedagogical strategies that lead to better learning outcomes, improve retention of scientific concepts, and increase teacher effectiveness is crucial. The findings from this research could advance the ongoing discussion about optimal practices in science education, promoting ongoing progress and innovation in teaching approaches. However, the adoption of non-equivalent pre- and post-tests design along with semi-structured interviews was specific to pre-service teachers from the Akenten Appiah-Menkah University of Skills Training and Entrepreneurial Development (AAMUSTED), limiting its generalisability. Consequently, the results may not be applicable to all higher education institutions in Ghana with similar structures and programmes. It is therefore recommended that pre-service teachers should be instructed using a combination of GLS and 5E-IS to enhance comprehension and retention of scientific concepts.

5. CONCLUSION

Based on the outcomes of this investigation, it can be inferred that pre-service teachers exhibited improved performance when instructed using generative learning strategies compared to 5E instructional strategies in understanding integrated science concepts. Additionally, both generative learning and 5E instructional strategies facilitated pre-service teachers' grasp of content, retention of acquired knowledge, transferability across contexts, and notably enhanced the integration of teaching and learning in integrated science concepts. Among the two instructional approaches assessed (Generative Learning Strategies and 5E Instructional Strategies), it can thus be deduced from this study that both GLS and 5E are learner-centred instructional methods suitable for diverse learners, yet GLS appears to offer greater benefits compared to the 5E instructional strategy. It is important to highlight that the conclusions drawn from this study are specific to pre-service teachers enrolled at AAMUSTED during the 2021–2022 academic year, focusing on those pursuing B.Ed. Upper Primary Education and B.Ed. Early Grade Education programs. Consequently, the implications of these findings are confined to pre-service teachers engaged in similar programmes at AAMUSTED.

The study suggests the following recommendations based on its findings and conclusions: Comparative studies on the effectiveness of generative learning strategies and 5E instructional strategies should be conducted in different academic disciplines, involving students at lower educational levels. This broader examination will provide a comprehensive understanding of their impact on education. Further research is recommended to explore alternative student-centred instructional strategies, allowing teachers to make informed decisions when selecting the most suitable approach for their lessons. Pre-service teachers should receive guidance on integrating generative learning strategies and 5E instructional strategies, enhancing their ability to grasp integrated science concepts effectively. Teacher training institutions should arrange in-service training sessions such as workshops, conferences, and seminars. These sessions will equip tutors and science educators with the skills necessary to incorporate generative learning strategies into the teaching of integrated science across various institutions in Ghana.

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