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Integrating Inquiry-Based Learning within the 5E-Framework: Implications for Preservice Science Teacher Education

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Abstract

Understanding abstract science concepts such as density remains challenging for many preservice teachers. This study examines the effect of a 5E-guided blend instructional model on enhancing conceptual understanding and critical thinking skills in the topic of density among pre-service teachers at Bagabaga College of Education, with attention to gender differences. Using a one-group pretest-posttest design, data were collected from Level 200 pre-service teachers, with 52 complete responses used for the final analysis using SPSS. Results showed no statistically significant difference in normalized gain scores between males (mean NG = -0.045) and females (mean NG = -0.044); $t(50) = 0.965$, $p > .05$. However, significant gender differences were found in critical thinking dimensions: analysis ($p = .000$, $\eta^2 = .221$) and logic ($p = .005$, $\eta^2 = .129$). These findings suggest that while the 5E-guided blend model is effective in supporting general learning gains in science concepts like density, differences in specific cognitive skills remain.

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INTRODUCTION

Science is a universal discipline that underlies the development of modern technology, plays a crucial role in various fields and disciplines, and advances the power of human thought (Abdulazeez et al., 2024; Kurniashih et al., 2018). Science also helps in advancing human knowledge and our understanding of the natural world. All aspects of life employ science to solve problems, making it an essential tool in professions like engineering, medicine, and social sciences. According to Meidawati (2014), learning Integrated Science is fundamentally about understanding facts and relationships. It goes beyond individual subject content to foster a holistic scientific understanding, as emphasized by Gouvea et al. (2013). Therefore, the role of the Integrated Science teacher extends beyond merely imparting knowledge. It encompasses nurturing intellectual skills and igniting the passion for learning Integrated Science. Achieving this goal according to this author, necessitates the ability to guide pre-service teachers towards experiencing meaningful learning. Such a process unfolds when students are actively engaged.

Hawkins and Williams (2020) argued that traditional classroom settings, with their typical lesson designs, often fail to foster twenty-first century skills in pre-service teachers. These environments generally lack opportunities for critical thinking, collaboration, problem-solving, and connecting new information with real-world experiences. The authors proposed that instructional strategies which engage pre-service teachers, foster inductive reasoning, and stimulate their inquiry skills can boost their autonomy and improve learning outcomes. Research (Noor et al., 2025; Sudria et al., 2018; Saldo & Walag, 2020) recommended using diverse innovative learning models like guided-inquiry, problem-based, and project-based learning, tailored to the material and thinking patterns, for effective science education. These authors noted that while no single strategy suits all situations, integrating the 5E learning model with guided-inquiry can optimize learning outcomes. Appiah-Twumasi et al. (2021) emphasized that Integrated Science teachers, after assessing their pre-service teachers' needs, should select instructional strategies like integrating the 5E learning model with guided-inquiry to optimize learning outcomes.

Pre-service teachers at Bagabaga College of Education struggle with the concept of density, impacting their course performance and practical applications. Their assignments, quizzes, and presentations reveal issues such as misunderstandings of the definition of density, difficulty with mathematical calculations, inadequate practical experience, and misconceptions about the relationship between mass and volume. These challenges highlighted the need for improved teaching methods and more hands-on practice to enhance their understanding. Almuntasheri et al. (2016) noted that understanding the concept of density is challenging due to its reliance on proportional reasoning. The complexity lies in its abstract nature; density is a ratio of mass to volume, not a directly observable property, and requires calculation from an object's mass and volume. Xu and Clarke (2012) posited that density poses a challenge due to its non-perceptible nature, requiring comprehension solely through calculations.

The observations highlight the need for Integrated Science teachers to adopt a learner-centered approach for teaching density. Few studies have examined how classroom interactions affect preservice teachers' understanding of density, indicating a gap in research that needs to be addressed to improve teaching strategies and student comprehension. Nisa et al. (2018) suggested using instructional strategies that enhance pre-service teachers' learning outcomes, like the 5E inquiry blend model, to help them understand density and its related topics. Azizmalayeri et al. (2012) also indicated that inquiry-based teaching leads to better scientific understanding, improved academic achievement, and enhanced critical thinking.

Although previous studies have examined guided inquiry and the 5E learning model independently in science education, limited research has explored the integration of the 5E framework with guided inquiry to enhance preservice teachers' conceptual understanding and critical thinking, particularly in challenging concepts such as density. Furthermore, few studies have examined how such an integrated instructional approach influences gender differences in learning outcomes among preservice teachers in the Ghanaian context. This study therefore investigates the use of a 5E-guided blend instructional model to enhance preservice teachers' conceptual understanding and critical thinking in the topic of density. Specifically, the study examines whether the integration of inquiry-based learning within the 5E framework improves learning outcomes and whether gender differences exist in preservice teachers' conceptual understanding and critical thinking skills.

By examining these relationships within a College of Education context in Ghana, the study contributes to the growing body of literature on inquiry-based science instruction and offers practical insights for improving the teaching of abstract science concepts such as density in teacher education programmes.

5E-Guided blend in Density

The 5E instructional model is an approach to science teaching and learning which consists of five phases: engagement, exploration, explanation, elaboration, and evaluation (Ruiz-Martín & Bybee, 2022). According to Açışlı et al. (2011), each phase of the 5E instructional model serves a distinct purpose in facilitating coherent instruction by the teacher and fostering students' comprehension of scientific concepts, attitudes, and skills. These authors explained that the first phase, which is engagement, motivates students through real-life scenarios, leading them to exploration where students make observations and test hypotheses. The teacher guides inquiry, addressing misconceptions. In the explanation phase, students use data to create scientific explanations and learn relevant vocabulary. The elaboration phase offers additional problem-solving opportunities. The last phase, evaluation ensures students grasp concepts and can apply them in different contexts. The 5E learning model complements guided inquiry learning by incorporating its five key phases: engagement, exploration, explanation, elaboration, and evaluation. While various learning cycle models exist, Duran and Duran (2004) emphasized that the 5E instructional model effectively supports guided inquiry-based learning.

Building on this, Nicol et al., (2020) highlighted that when well-planned and effectively implemented, the 5E model aligns with the constructivist goals of guided inquiry-based learning. Taylor et al. (2006), as cited in Adauyah and Aznam (2024), noted the alignment between the steps of the inquiry phase and the 5E learning model. The 5E model includes engaging students' interest, allowing them to explore through hands-on activities, explaining their findings, elaborating on their understanding by applying it to new situations, and evaluating their comprehension and skills. This structured approach effectively guides preservice teachers through an inquiry process, promoting deep understanding and engagement with scientific concepts. According to Adauyah and Aznam (2024), guided inquiry-based learning encourages students to engage in learning through problems or tasks and explore scientific phenomena (Hwang et al., 2015) and improve students' critical thinking abilities (Uum et al., 2017).

Understanding the concept of density poses challenges for pre-service teachers due to its abstract nature. Density involves the amount of mass within a certain volume (Xu & Clarke, 2012), which can be difficult to understand without concrete examples and hands-on experiences. This concept entails compounding variables that change simultaneously and requires the understanding of ratio or proportion. Moreover, density is not directly perceivable but must be comprehended through calculation. Almuntasheri et al. (2016) noted that pre-service teachers' difficulties with density often stem from its complexity, including required mathematical knowledge, and misconceptions.

The traditional method of instruction contributes to pre-service teachers' difficulties in understanding density by focusing heavily on equations and formulas, favoring problem-solving over conceptual comprehension. Smith et al. (1997) highlighted that this approach often overlooks opportunities for interactive reasoning about the phenomena, resulting in a lack of conceptual understanding and scientific explanations of density. Conversely, within the 5E-Guided blend instructional approach, inappropriate teaching methods can impede students' comprehension of density in several ways. If the Engage phase fails to capture students' interest, their motivation may wane. Moreover, limited hands-on exploration during the Explore phase hinders active investigation, impeding critical thinking development. Shallow conceptual explanations in the explain phase may hinder deep understanding construction, while inadequate opportunities for application and problem-solving in the Elaborate phase restrict knowledge transfer.

Finally, misaligned evaluation methods in the Evaluate phase may inaccurately assess students' density proficiency. To effectively support preservice teachers' comprehension of density, integrated science teachers must ensure that teaching methods across all 5E-Guided blend phases foster engagement, enable exploration, facilitate explanation, encourage elaboration, and promote evaluation, this framework strengthens conceptual understanding and application.

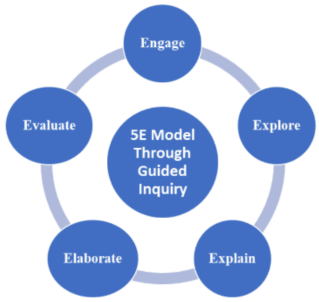

Figure 1. application of the 5E-Guided Blend Model in teaching

Table 1 presents the application of the 5E-Guided Blend Model in teaching density to pre-service teachers, emphasizing inquiry-based learning activities and teacher facilitation throughout the entire learning process. The incorporation of guided inquiry methodologies within the 5E paradigm facilitates proactive engagement, critical thinking, and conceptual understanding among pre-service teachers in the study of density and related concepts.

Table 1. 5E-guided blend model in teaching density to pre-service teachers

Stage	E-Approach	Researcher's Role	Guided Inquiry Approach
Engage	Pose compelling questions to activate prior knowledge and stimulate curiosity about density.	Provide materials and activities that allow students to explore density through experimentation, such as measuring mass and volume of objects. Encourage small-group discussions and questions.	Encourage pre-service teachers to share their thoughts and experiences related to density, setting the stage for exploration and learning
Explore	Provide hands-on materials and guided questions to investigate density changes (e.g., solid to liquid).	Facilitate student exploration and experimentation with density concepts. Encourage group collaboration and hypothesis formation.	Guide pre-service teachers through inquiry activities focused on density transitions and related phenomena. Encourage critical thinking and data analysis.
Explain	Initiate discussions on observed phenomena and introduce formal definitions and formulas (e.g., density = mass/volume).	Lead class discussions to connect hands-on experiences to theoretical concepts. Provide	Support pre-service teachers in understanding density principles through guided explanations and connections between theory and practice.

		explanations and clarify misconceptions.	
Elaborate	Engage in discussions applying density knowledge to various scenarios (e.g., states of matter).	Pose challenging questions and scenarios requiring application of density concepts. Foster critical thinking and problem-solving skills	Encourage pre-service teachers to extend their understanding of density by applying concepts to diverse contexts and real-world situations
Evaluate	Implement assessments to gauge understanding and mastery of density concepts	Administer quizzes, presentations, or projects to assess learning outcomes. Provide feedback and support based on assessment results	Assess pre-service teachers' proficiency in density concepts and provide constructive feedback to enhance learning and development

The main research questions that directed this study were:

1. What is the mean gain achievement scores of male and female preservice teachers taught density with 5E-guided blend method?
2. Is there difference in critical thinking of preservice male and female teachers?

METHOD

The study adopted a quantitative approach utilizing a one-group pretest-posttest research design. This design was chosen to ensure that the 5E-guided blend intervention was applied consistently to every participant, thereby enhancing the reliability of the study's findings. Additionally, the use of a one-group design ensures that all participants receive the benefits of the 5E-guided blend intervention, aligning with ethical considerations and maximizing the intervention's impact on conceptual understanding in density.

The study focused on Level 200 College of Education students enrolled in upper primary courses across the Northern Region of Ghana. The population consisted of 100 Level 200 students (60 males and 40 females). Using a stratified sampling method, 80 students were initially selected from the population to ensure representation of both male and female students. For the purpose of this study, an accessible population was drawn from Bagabaga College of Education, comprising Level 200 students. From this group, 60 students (36 males and 24 females) were selected through stratified sampling to participate in the intervention. However, during data analysis, only 52 complete responses were retained because some participants had incomplete test responses. Therefore, the final analysis was conducted using data from 52 pre-service teachers. This approach aimed to provide an in-depth understanding of the specific context while ensuring representation across different student characteristics.

To evaluate the efficacy of the intervention (5E-guided blend) and comprehensively assess learning outcomes over time, pre and post-test measures were employed. The pre-test served to establish baseline levels of understanding and critical thinking skills related to density among participants before the intervention. Subsequently, the post-test measured immediate changes in learning outcomes following the intervention, providing insights into its initial impact. A critical thinking skills (CTS) test, based on Shahzadi and Khan's (2020) adaptation, comprises 30 multiple-choice items categorized into three dimensions: analysis, evaluation, and logic, with each dimension containing ten items. Each set of critical thinking post-test items within these dimensions was scored independently, using a binary scoring system where correct answers receive a score of 1 and incorrect answers receive a score of 0. This scoring method allows for the individual assessment of critical thinking skills across the specified dimensions.

Additionally, a delayed post-test enables the examination of long-term retention and transfer of knowledge, providing insights into the sustainability and lasting effects of the intervention beyond the immediate post-intervention period.

In this study, data gathering involved three key assessments: a critical thinking pre-test and post-test to evaluate participants' conceptual understanding and critical thinking in density. The critical thinking pre-test establishes baseline levels before the 5E-Guided blend intervention is applied. Following the intervention implementation, a critical thinking post-test immediately assessed changes in learning outcomes.

Both descriptive and inferential statistics were employed to analyze the data in this study. The researcher utilised Microsoft Excel and The Statistical Package for Social Sciences (SPSS version 22.0) for data analysis. The findings were accurately explained, with tables utilized to provide detailed answers to the research questions.

RESULTS AND DISCUSSION

Is there any difference in normalized gain achievement of preservice male and female teachers?

Table 2. Normalized gain achievement scores of male and female preservice teachers

Gender	N	Mean	Std. Deviation	Std. Error Mean
Normalized Gain	32	2.5188	.97051	.17156
	20	2.5313	1.00646	.22505

Table 2 analyses the normalized gain scores among male and female preservice teachers taught density using the 5E-guided blend method. Both groups showed positive gains in understanding density, with male preservice teachers achieving a mean normalized gain of 2.5188 and female preservice teachers slightly higher at 2.5313. Despite this slight difference in mean scores, the variability in gains is lower among male preservice teachers compared to females, suggesting more consistent improvements within the male group. Additionally, the precision of the mean score estimate is higher for males, indicating that their observed gain is likely more representative of the overall population.

Table 3. Differences in normalized gain achievement between male and female preservice

	Gender	t	Df	Sig (2-tailed)	Mean Difference	Std. Error Difference
Normalised Gain	Male	-.045	50	.965	-.01250	.28058
	Female	-.044	39.355	.965	-.01250	.28299

Table 3 examined the differences in normalized gain achievement between male and female preservice teachers who were taught density using the 5E-guided blend method. The analysis involved an independent samples t-test to compare the gain scores of male and female preservice teachers. The findings revealed that there is no statistically significant difference [(50) = 0.965, p > .005] in normalized gain achievement between male (mean NG = -0.045) and female (mean NG = -0.044) preservice teachers. The mean difference in normalized gain scores between genders was minimal (-0.01250), suggesting that the instructional method is similarly effective for both male and female preservice teachers

Is there any difference in critical thinking of preservice male and female teachers?

Table 4. Mean score performance of students on critical thinking skill test (CTST)

Dimensions of Critical Thinking skill	Gender	Mean	Std. Deviation	N
Analysis	Male	3.75	.770	36
	Female	3.08	.282	24
Evaluation	Male	3.83	.655	36
	Female	3.71	.550	24
Logic	Male	3.83	.561	36
	Female	3.42	.504	24

The analysis of mean scores from (Table 5) the critical thinking skill test (CTST) reveals significant gender differences across various skill categories. Specifically, male preservice teachers consistently outperformed their female counterparts in critical thinking skills. The mean scores of the male preservice teachers ranged between 3.75 and 3.83 while those of their female counterparts ranged from 3.08 to 3,71. These findings illustrate a consistent pattern across different critical thinking domains, suggesting a gender-related advantage favouring male preservice teachers.

Table 5. Gender Differences in Critical Thinking Skill Categories

	Dimensions of Critical Thinking skill	Type III Sum of Squares	df	Mean Square	Sig.	Partial Eta Squared
GENDER	Analysis	6.400	1	6.400	.000	.221
	Evaluation	.225	1	.225	.444	.010
	Logic	2.500	1	2.500	.005	.129

Manova analysis was conducted to examine the influence of gender on performance across different critical thinking skill categories among preservice teachers, with a significance level of 0.05. The results revealed statistically significant differences in performance influenced by gender within specific skill domains.

In the analysis skill category, there was a highly significant difference ($p < .05$) between male and female preservice teachers, with a substantial effect size (Partial Eta Squared = 0.221). This suggests that gender significantly impacts analysis performance, with gender accounting for a significant amount of variance in scores. Similarly, in the logic category, a significant difference ($p = .005$) was observed between male and female preservice teachers, although with a slightly smaller effect size (Partial Eta Squared = 0.129) compared to analysis. This indicates that gender plays a significant role in determining logic performance among preservice teachers. Conversely, in the evaluation category, no statistically significant difference ($p > .05$) was found between male and female preservice teachers, with a negligible effect size (Partial Eta Squared = 0.010). This suggests that gender differences do not significantly impact evaluation performance. The results highlight the importance of considering gender as a factor in educational settings to address performance variations and promote equitable skill development.

The data from Table 2 comparing normalized gain achievement scores of male and female preservice teachers reveals a minimal difference in achievement between the two groups. The mean normalized gain score for male preservice teachers is 2.5188 (SD = 0.97051), while for female preservice teachers, it is slightly higher at 2.5313 (SD = 1.00646). The small standard error of the mean for both groups suggest consistency in the sample means. These findings indicate that male and female preservice teachers achieve similar levels of normalized gain, suggesting that gender may not be a significant factor influencing learning outcomes in this study. This similarity underscores the importance of effective teaching strategies and instructional methods that can benefit all preservice teachers equally, regardless of gender. It emphasized the need for inclusive and equitable approaches to teaching practices.

From Table 3, there is a negligible difference in normalized gain achievement between male and female preservice teachers. The mean differences in normalized gain between the two groups are similar, with high p-values suggesting non-significance and relatively small effect sizes. Male and female preservice teachers' normalized gains differ by a small amount (mean difference = -0.01250), and the corresponding t-values for both genders show that these differences are not statistically significant (p-values of 0.965). These results imply that gender had no noticeable impact on the study's normalized gain achievement. The lack of statistical significance underscores the importance of considering multiple variables beyond gender when interpreting educational outcomes. In conclusion, the data from Table 3 supports the notion that gender differences have minimal impact on normalized gain achievement among preservice teachers.

The data from Table 4 reveals significant gender differences in the mean score performance of students across different dimensions of critical thinking skills: analysis, evaluation, and logic. Male preservice teachers consistently demonstrated higher mean scores in these skill categories compared to female students. In the analysis dimension, male preservice teachers scored notably higher (M = 3.75, SD = 0.770) than female preservice teachers (M = 3.08, SD = 0.282), indicating stronger performance in analytical thinking. Similarly, in the evaluation dimension, male preservice teachers had a higher mean score (M = 3.83, SD = 0.655) compared to female preservice teachers (M = 3.71, SD = 0.550), showing a trend of better performance in evaluative skills among male preservice teachers. Furthermore, male students also exhibited higher mean scores in the Logic dimension (M = 3.83, SD = 0.561) compared to female preservice teachers (M = 3.42, SD = 0.504), suggesting stronger logical reasoning abilities among male preservice teachers. These findings underscore the influence of gender on critical thinking skills among preservice teachers.

The findings from Table 5 underscore the differential impact of gender on specific dimensions of critical thinking skills. Gender exerts a substantial influence on analysis skills, where male and female differences account for a significant portion of the variance in performance. This is supported by a study by Ramadani et al., (2021) which confirmed in their study that female students are less able to solve problems that require explanation of concepts. The study added that female students have lower mastery of concepts than male students, therefore, they cannot solve problems that require analysis.

In contrast, gender has a minimal impact on evaluation skills, with negligible differences between male and female performance. The influence of gender on logical reasoning skills falls somewhere in between, with a moderate effect size indicating notable gender-related disparities. Findings from Table 5 align with the study by Aliakbari and Sadeghdaghighi (2011), which identified a significant main effect for gender, with males consistently scoring higher. The T-test analysis revealed a statistically significant difference in critical thinking ability between males and females, concluding that males demonstrate stronger critical thinking skills. However, this finding contradicts previous research (Salahshoor & Rafiee, 2016; Bagheri & Ghanizadeh, 2016; Azizi et al., 2022), which suggested that gender has no significant influence on critical thinking ability or the use of critical thinking strategies.

Several studies (Al-Jasim & Al-Hamdan, 2012; Bart et al., 2015; Zetriuslita et al., 2016; Shubina & Kulakli, 2019) have examined the relationship between gender and critical thinking. For instance, Zetriuslita et al. (2016) found that gender differences are particularly significant at higher levels of critical thinking proficiency. These findings are further supported by Liu et al. (2019) and Otero et al.

(2024), who argued that masculinity plays a significant role in developing critical thinking skills. Additionally, Atmatzidou and Demetriadis (2016) noted that gender differences in critical thinking skills vary across specific areas, with female students often requiring additional time and practice to reach the same level of proficiency as their male counterparts.

CONCLUSION

This study advances science education by demonstrating the effectiveness of a 5E-guided blend model in improving preservice teachers' understanding of density, a concept that is often challenging to grasp. By embedding inquiry-based learning within the 5E framework, the study extends constructivist approaches and shows how abstract concepts can be taught more effectively. The use of pre-, post-, and delayed post-tests, together with the adaptation of the Critical Thinking Skills Test into analysis, evaluation, and logic dimensions, offers a methodological contribution that can be replicated in similar contexts.

The findings revealed significant and sustained gains in conceptual understanding for all learners. While overall achievement did not differ by gender, variations in specific critical thinking skills, particularly analysis and logic indicate the need for targeted instructional support to achieve balanced development. These outcomes provide practical guidance for teacher education, emphasizing strategies that promote both equity and effectiveness in science learning.
In sum, the study contributes to the literature on inquiry-based science education and offers actionable implications for curriculum design, classroom practice, and teacher preparation. By addressing persistent challenges in teaching density and highlighting areas for equitable skill development, it supports the broader goal of preparing teachers who are conceptually strong and capable of fostering higher-order reasoning in their future classrooms.

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