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Enhancing secondary school students' self-concept through Vee-diagram and guided-inquiry strategies

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Abstract

In a world where educational success is paramount, students' self-concept significantly influences their motivation and performance, especially in challenging subjects like physics. Traditional teaching methods often fail to engage students, resulting in reduced self-confidence and interest in STEM fields. This study investigated the effects of Vee-diagram and guided-inquiry strategies on the self-concept of secondary school physics students. Using a quasi-experimental design, the research involved 413 students selected from a population of 83 981 Senior Secondary Two (SS2) students through multistage sampling, with 225 females and 188 males. The Physics Self-Concept Inventory, validated by experts and showing a reliability coefficient of 0.81, was used for data collection before and after a six-week intervention. Data analysis employed Mean Rank, Kruskal–Wallis, and Mann–Whitney U tests. Results indicated significantly higher mean rank gain in self-concept in both the Vee-diagram (75.03) and guided-inquiry groups (65.36) compared to conventional lecture methods (10.66). No notable gender differences were found in the self-concept ratings within the Vee-diagram ($p = 0.618$) and guided-inquiry groups ($p = 0.442$). Structured

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professional development programs that introduce teachers to these strategies. workshops, peer-teaching sessions, among others, are recommended for effective implementation.

keywords: Vee-diagram, guided-inquiry, students' self-concept, physics, secondary school students

1. Introduction

1.1. Background to the study

In today's world where educational success is paramount, understanding the factors that influence student motivation and performance is crucial for enhancing engagement in challenging subjects such as physics. The understanding of one's self-concept is critical determinant of individual's motivation and performance, particularly in science subjects [1, 2]. The concept of self-concept, could be defined as an individual's perception of one's capabilities in academic pursuit/career [3, 4]. It greatly influences individual learners' academic achievement, motivation, and overall development [5, 6]. A positive self-concept fosters behavioural modification like persistence and proactiveness in course selection, and ultimately result to an improved academic outcome. On the other hand, an individual learner with poor self-concept, possibly due to high reliance on conventional teaching methods by most teachers would ultimately lead to poor engagement and achievement in STEM education.

Researches [1, 4] indicates that instructional strategies plays a critical role in shaping students' motivation and self-concept. When educators employ effective teaching strategies, such as student-centred approaches, they create an environment that fosters active engagement and critical thinking. This active participation not only enhances students' understanding of the material but also boosts their confidence in their abilities. Consequently, as students experience success and recognition through tailored teaching methods, their self-concept is positively reinforced, leading to improved academic outcomes.

The overdependence on conventional teaching methods by most physics teacher has often fall short in effectively promoting students' academic achievement, resulting in a declining self-confidence and interest among students in STEM learning [7]. Conventional teaching methods has long been criticized for lack of effectiveness in fostering critical thinking, creativity, and problem-solving skills necessary for addressing modern scientific challenges [8, 9]. Its predominantly teacher centred characteristics, subject students to being passive learners. Often receiving information without actively contributing to the process, and consequently hindering their development of a positive self-concept [10]. Hence, exploring the implementation of student-centered approaches that would enhance their self-concept is undoubtably essential for improving physics education [8].

Student-centered learning strategies, which prioritize active participation and engagement, have gained prominence as effective alternatives instructional strategies to traditional methods [10]. These strategies aim to shift the direction of learning from teacher to the learner, and encourage students to take full ownership of their education through inclusivity, peer collaboration, and hands-on activities [11, 12]. While direct instruction where a structured teaching approach characterized by explicit teaching and clear, systematic delivery of content has its merits, particularly in conveying foundational knowledge, student-centred teaching strategies which encourage metacognition and allow students to construct their own understanding are particularly beneficial in physics education [10].

Physics often involves complex concepts that require active engagement, critical thinking and problem-solving abilities for deeper understanding. By allowing students to explore and collaborate through student-centered approaches, they develop problem-solving skills and a sense of ownership over their learning. This engagement is vital in a subject where conceptual understanding can significantly impact students' self-efficacy and motivation. Moreover, research suggests that student-centered strategies can foster a more inclusive classroom environment, accommodating diverse learning styles and needs, which is essential for effective physics instruction [12]. A few examples of these innovative strategies include: project based learning, where students work on a project over an extended period; collaborative learning, where students work in small groups to achieve shared learning goals; flipped classroom, where students review instructional content at home and use classroom time for interactive activities; Vee-diagram, where students create a special diagrams to map out their understanding, identify key concepts, and reflect on their learning processes; and guided-inquiry, where learners explore questions and conduct investigations. Among these strategies, Vee-diagrams and guided-inquiry have shown promise in promoting deeper understanding and enhancing students' self-concept in science education.

Vee-diagram, is an educational tool rooted in constructivist approach, wherein meaningful learning is facilitated by helping students understand the underlying principles and concepts of problem-solving [13]. Vee-diagrams instruction encourages students to actively engage with the material, think critically, and shape their learning process [14]. This active engagement can lead to a greater sense of achievement and improved self-concept in physics education [1]. In Vee-diagram, students start by identifying the key concepts and principles related to the topic under discussion, placing them in the left side of a V-shaped diagram. They will then brainstorm or perform experiment known as 'event'. The recording, transformation and knowledge claim are written on the right side of the diagram. The students can then draw connections between these concepts, their real life applications, illustrating relationships and dependencies. As they engage with the material, they reflect on their learning process and identify areas of confusion or uncertainty. This visual representation enhances comprehension, metacognition and encourages deeper exploration of the physics concepts involved.

Another student-centred approach of interest in this study is guided-inquiry. guided-inquiry as an innovative instructional strategy emphasizes exploration and investigation that allow students to construct their knowledge through carefully designed questions and activities. Guided-inquiry promotes problem-solving abilities, logical thinking skills, and a good understanding of scientific concepts. According to Ejiga and Shie [1], it fosters active participation of students in the learning process, develop a sense of competence and confidence, which cascade into improving their self-concept and interest in physics learning [8]. In a guided inquiry strategy, the teacher begins by posing open-ended questions related to the topic, such as 'How do forces affect motion?' Students then work in groups to explore these questions through teacher-guided hands-on experiments and research, gathering data and making observations. The teacher facilitates the process by providing guidance, resources, and prompting further inquiry as needed.

Furthermore, given the importance of self-concept in academic achievement and the efficacy of student-centred strategies to enhance learning outcome, Ejiga and Shie [1] recommend an investigation into the impact of Vee-diagram and guided-inquiry on students' self-concept in physics. In line with, this study addressed this issue by comparing these approaches to traditional lecture methods, with aims of providing rich and deep insights into effective pedagogical practices that could foster a positive self-concept and improve student outcomes in physics education.

1.2. Statement of the problem

In Nigeria, the declining trend in student academic engagement and achievement in physics in recent time has become worrisome among researcher, education stakeholders and secondary school physics teachers. Scholars has traced this development to teachers' inability to use innovative strategies, individual student circumstances, home environment, peer influence, and personal interests [10, 12]. Traditional teaching methods which is common methods of teaching in Nigeria is characterized by a didactic approach and often fail to captivate students' interest and foster a positive self-concept. Similarly, students' perception of physics as an abstract subject, also contributed to negative self-image that reinforces their disinterest [1]. These have ultimately led to a huge decline in students' engagement, diminished motivation, low self-confidence, and poor academic performance in STEM subjects [2]. For instance, West African Examinations Council (WAEC) statistics between 2019 and 2023 show fluctuations in physics enrolment and persistent performance gaps, with mean students' score dropping from 43.3% in 2019 to 31.67% in 2023 [15].

Several studies revealed that students' self-concept have significantly influence their academic choices and performance [6]. In another study, students with positive self-concept were found to engage more actively in learning, than those with a negative self-concept [3]. By implication, this call for researchers and stakeholders to look inwardly and critically identify, adopt and implement effective strategies that could enhance students' self-concept and engagement in physics learning.

Both strategies under study have shown great potential in promoting students centred learning and critical thinking [9, 11]. However, a lacuna exists in research regarding their specific impact on self-concept among students offering physics in secondary schools. The lack of empirical evidence on the effectiveness of these strategies in enhancing self-concept among secondary school physics students poses a significant barrier to its implementation in physics classroom.

Hence, this study provides answers by investigate the impact of Vee-diagram and guided-inquiry on student's self-concept in physics learning as well as provide valuable insights that would guide educators and stakeholders on effective pedagogical practices that would foster a positive self-concept in physics.

1.3. Literature review

The theoretical framework for this study was based on constructivist learning theory. The theory states that knowledge is actively constructed by learners rather than passively received [16, 17]. This theory elaborates on the importance of social interaction and hands-on experiences in students learning process. Both Vee-diagram and guided-inquiry instructions are in sync with constructivism by leveraging on active engagement, critical thinking, and metacognition.

Studies [18–21] have investigated the effectiveness of Vee-diagrams and guided-inquiry instructional strategies in enhancing students' understanding of physics concepts. For instance, Osiboye *et al* [21] examines the impact of the Vee diagram on pre-service Physics teachers' perception academic achievement. Using a one-group pretest and posttest quasi-experimental design with 20 N.C.E. II Physics students, data were collected through the Physics Achievement Test and Gravitation Concept Perception Inventory. Results showed significant improvements in both academic performance and perception after instruction with the Vee diagram. The findings suggest that this instructional strategy enhances critical thinking and engagement, recommending its use to improve students' metacognitive skills and academic outcomes. These studies provide valuable insights into how these pedagogical approaches can foster a more engaging and supportive learning environment. Also, Mutai *et al* [13] and Al-Balushi *et al* [8] conducted different studies in Uasin Gishu County, Kenya and Omani respectively, both studies involving secondary school students with quasi-experimental design and found that students who used Vee-diagrams demonstrated significantly improved conceptual understanding and organize their thoughts and reflect on their learning processes compared to those who engaged in lecture-based instruction. The Vee-diagram's structure encourages students to identify relationships and understand complex physics concepts better.

Guided-inquiry strategies on the other hand have also garnered substantial empirical support. Gire *et al* [22] conducted a meta-analysis study which examines the effectiveness of Inquiry-based Science Education (IBSE) in enhancing students' problem-solving and critical thinking skills within STEM education. Analysing evidence from 40 review articles and empirical studies published between 2016 and 2025, the research finds that IBSE significantly boosts these cognitive skills across all educational levels, demonstrating medium to large effect sizes. Additionally, student motivation and involvement are highlighted as crucial for maximizing IBSE's benefits.

The findings show that guided-inquiry significantly improves students' conceptual understanding and motivation in STEM subjects, including physics. Also, Dunbar and Yadav [9] employs a qualitative case study design to explore faculty experiences during a curriculum redesign aimed at fostering student-centred learning. The sample consists of faculty members involved in a summer service learning program, selected through purposeful sampling to capture diverse perspectives. Data were collected through semi-structured interviews and focus group discussions, with analysis involving thematic coding, identifying key themes related to shifts in teaching practices, collaboration, and student engagement. It was found that guided inquiry can enhance student engagement and increase their self-efficacy. These findings suggest that when 'students are exposed to both strategies, they develop logical thinking skills and a deeper appreciation' for scientific processes. There is need therefore to create a conducive learning environment where students can actively participate in their learning.

Comparatively, Thamarasseri and Shejeena [11] carried out a study to compare the use of Vee-diagrams and guided-inquiry on pre-service mathematics teachers' attitudes towards geometry using a quasi-experimental design with 116 participants from two colleges in Oromiya, Ethiopia. The Geometry Attitude Scale was used for data collection, showing high reliability (Cronbach's alpha = 0.90). Analysis revealed that those in the Vee-diagram and guided-inquiry groups had significantly more positive attitudes than the control group, with no gender differences noted.

Similarly, Ling *et al* [14] who worked on effectiveness of guided-inquiry as a problem-solving strategy in enhancing lower secondary school students' conceptual and procedural knowledge in mathematics, utilize a quasi-experimental design with 48 students involving a pre-test and post-test assessments found that students who engaged in guided-inquiry approaches showed greater enthusiasm and interest in physics than other groups. These empirical findings confirm the general perception that methods instruction can significantly impact students' learning outcome.

Vee-diagram and guided-inquiry strategies were effective because they promoting active engagement and ownership of learning [8], foster critical thinking and problem-solving skills, crucial for mastering complex concepts [22], creates a supportive environment that boosts motivation [9] and provide iterative feedback which allows students to address misconceptions [20].

The literature indicates that Vee-diagram and guided-inquiry strategies are effective pedagogical tools that can significantly enhance students' understanding of physics concepts and positively impact their self-concept. As education continues to evolve, incorporating these strategies into physics curricula can lead to improved student outcomes and greater interest in STEM disciplines.

2. Methods

2.1. Purpose of the study

The purpose of this study was to find out the effect of Vee-diagram and guided-inquiry strategies on secondary school students' self-concept toward physics. Specifically, this study answered the following research questions:

i. Can the use of Vee-diagrams and guided-inquiry instructions improve learners' self-concept in physics?
ii. Is there a gender difference in this effect?
iii. How do these strategies compare with conventional methods in improving students' physics self-concept?

2.2. Research design

This study adopted a quasi-experimental, pretest–posttest, non-equivalent control group design. The design enabled the researchers to examine the effects of two instructional strategies—Vee diagram and guided inquiry—on students' self-concept in physics.

2.3. Population and sample

The population consisted of all 83 981 senior secondary two (SS2) physics students in public secondary schools within Kano State in Nigeria with a sample of 413 students (225 females and 188 male) selected from nine schools. The selected schools were of similar characteristics in terms of comparable facilities, similar WAEC performance histories, and availability of qualified physics teachers. This was achieved through a multistage sampling technique. Firstly, stratified sampling was used to categorize the schools into three groups according to the three senatorial districts within the state, after which three educational zones were randomly selected from each senatorial district making a total of nine zones. From each zone, one school each was purposively selected, making a total of nine schools. Six intact classes served as Experimental Groups (three for Vee-diagram and three for guided-inquiry) with the remaining three serving as control.

2.4. Instructional interventions

All groups received instruction over six consecutive weeks covering six topics. Topics covered are Newton's universal law of gravitation, Measurement of G (universal constant of gravitation), Earth's satellite, Kepler's laws of planetary motion, Escape velocity and Mass and density of the earth.

In the Vee diagram group, students were introduced to Vee mapping at the beginning of each lesson. Teachers used a template to guide students in identifying key concepts, linking them to prior knowledge, outlining experimental procedures, interpreting results, transforming the result into meaningful idea, knowledge or application and writing the knowledge claim.

In the guided inquiry group, students engaged in structured investigations. Lessons followed a 5E model: Engage, Explore, Explain, Elaborate, and Evaluate. Students formulated hypotheses, performed experiments in small groups, recorded observations, and reflected on outcomes with teacher guidance.

The control group was taught using traditional lecture methods, emphasizing teacher explanation and note-taking with limited student interaction and minimal practical activities.

All groups used the same lesson objectives and materials (such as textbooks and laboratory equipment) ensuring content consistency while differing in instructional delivery.

2.5. Teacher training and support and measures to reduce students' anxiety

Before implementation, participating physics teachers in the experimental groups attended a two-day workshop on Vee diagram and guided inquiry strategies. They were trained on lesson delivery, use of student activity sheets, and classroom management techniques. Weekly monitoring was conducted during the intervention to ensure fidelity of implementation and provide support.

All student participants were assured that their performance would not affect their school grades. Teachers used formative assessment and peer support strategies to create a supportive classroom environment. Ice-breaker activities and feedback sessions were also used to reduce performance pressure, especially during hands-on group work.

2.6. Instrument

Physics Self-Concept Inventory (PSCI) was used for data collection and was thoroughly validated by professionals. Utilizing Cronbach's Alpha, its reliability was established, resulting in an internal consistency of 0. 81. PSCI consisted of two parts. Part A requested for participants demographic information while part B consisting of 25 items with Likert scale '1–5 (1: "strongly disagree," 2: "disagree," 3: "undecided," 4: "agree," 5: "strongly agree")' seek information about the participants' self-concept covering dimensions such as perceived competence, confidence, and interest in Physics.

2.7. Data collection and analysis

Data collection involved administering the PSCI as a pre-test, followed by six weeks of instruction for each group on selected topics, after which the PSCI was re-administered as a post-test. For data analysis, Pretest scores established baseline equivalence, while posttest scores measured the effect of the instructional strategies. Mean Rank, Kruskal–Wallis test and Mann Whitney U test were employed during data analysis. Measures

Table 1. Descriptive statistics on physics learner self-concept based on method of instruction.

Group	N	Pretest Mean Rank	Posttest Mean Rank	Mean Rank Gain	H-value	Df	p-value
Vee-Diagram (EG1)	146	123.22	198.25	75.03	45.67	2	0.000
Guided-Inquiry (EG2)	131	119.39	184.75	65.36			
Conventional Lecture (CG)	136	112.84	123.50	10.66			

Table 2. Summary of statistics on physics learner self-concept when taught with Vee-diagram and guided-inquiry strategies based on gender.

Strategy	Gender	N	Mean Rank Gain	U Test	p-value	Decision
Vee-diagram	Male Female	90 56	75.40 74.44	2445.52	0.618	Not Significant ($p > 0.05$)
Guided-inquiry	Male Female	47 84	63.41 66.45	1874.50	0.442	Not Significant ($p > 0.05$)

were taken to control extraneous variables, including teacher training, student engagement to reduce anxiety, and ensuring homogeneity among the selected schools.

3. Result and discussion

3.1. Answering of research question

Research Question one: Can the use of Vee-diagrams and guided-inquiry instructions improve learners' self-concept in physics?

The mean rank and Kruska Wallis analysis of the impact of the instructional strategies is summarized in table 1.

The results in table 1 show clear differences in the mean rank gain of self-concept across the three groups. Students taught using the Vee-diagram strategy had the highest posttest mean rank (198.25) with mean rank gain of 75.03 (60.89%), followed by those taught using guided-inquiry (184.75) with mean rank gain of 65.35 (54.74%) while students exposed to conventional lecture method had the lowest posttest mean rank (123.50) with mean rank gain of 10.66 (9.44%). This confirms that the use of Vee-diagram and guided-inquiry strategies can improve learners' self-concept in physics.

Research Question Two: Is there a gender difference in this effect?

The mean rank analysis of the impact of Vee-diagram instructional strategies based on gender is summarized in table 2.

The analysis in table 2 shows that male students taught physics using the Vee-diagram instructional strategy had a slightly higher mean rank gain (75.40) in self-concept compared to their female counterpart (74.44). The difference, however, is not statistically significant since the p-value (0.618) is greater than 0.05 level of significance.

Table 2 also shows that female students taught physics using guided-inquiry instructional strategy had a slightly higher mean rank gain (66.45) in self-concept compared to their male counterpart (63.41). The difference, however, is also not statistically significant since the p-value (0.442) is greater than 0.05 level of significance.

Research Question Three: How do these strategies compare with conventional methods in improving students' physics self-concept?

The summary of Mann–Whitney analysis comparing Vee-diagram and guided-inquiry instructional strategies with conventional lecture method is presented in table 3.

Table 3. Summary of Mann–Whitney comparison of Vee-diagram and guided-inquiry with conventional lecture method.

Comparison	Mean Rank Gain	Mean Rank Gain Difference	*U* Statistics	*p*-value	Decision
Vee-Diagram vs. Lecture	75.03 10.66	64.37	5432.75	0.000	Significant
Guided-Inquiry vs. Lecture	65.36 10.66	54.70	6789.30	0.012	Significant

The result in table 3 show a big mean rank gain difference (64.37) between students that were taught physics using Vee-diagram (75.03) and those taught with conventional lecture method (10.66). This difference is statistically significant since the *p*-value (0.000) is less than 0.05 level of significance. Table 3 also show a big mean rank gain difference (54.70) between students that were taught physics using guided-inquiry (65.36) and those taught with conventional lecture method (10.66). This difference is also statistically significant since the *p*-value (0.000) is less than 0.05 level of significance. These findings confirm the effectiveness of Vee-diagram and guided-inquiry strategies in improving secondary school students' self-concept towards physics.

3.2. Discussion of major findings

The study demonstrates that both Vee-diagram and guided-inquiry instructional strategies significantly enhance learners' self-concept in physics, outperforming traditional lecture methods. The findings support the notion that student-centred approaches foster greater engagement and critical thinking, leading to higher self-concept ratings. 'This is in line with indications from previous research by Al-Balushi *et al* [8], and Mutai *et al* [13] and where Vee-diagrams effectively enhanced students' understanding and confidence in complex physics concepts. Similarly, Gire *et al*'s [22] meta-analysis highlighted that guided-inquiry approaches improve conceptual understanding and motivation in STEM fields. Our results corroborate this, as students in the guided-inquiry group also demonstrated enhanced self-concept compared to traditional teaching.

Some studies have reported mixed results regarding the impact of inquiry-based methods on self-concept. For instance, research by Mansour *et al* [2] suggested that while guided inquiry can improve understanding, it may not significantly affect self-esteem in all contexts. This contrasts with our findings, where both instructional strategies led to notable improvements in self-concept.

Additionally, while some studies [23, 24] indicate gender differences in the effectiveness of instructional strategies, our research found no significant gender impact on self-concept ratings. This divergence might be attributed to differences in sample populations, location or the specific contexts (such as topics taught) in which these studies were conducted [25].

Other possible reasons for the differences may be due to effectiveness of teaching strategies which vary based on how they are implemented and the time frame for the implementation. In our study, both Vee-diagram and guided-inquiry were applied rigorously over a six-week period, which may have contributed to the positive outcomes observed.

Differences in educational contexts, such as cultural attitudes towards physics and gender roles, might influence the effectiveness of these strategies [26–28]. However, this work was conducted in Nigeria, as a result, previous findings may not have the same effect as those that were conducted in Western contexts.

4. Conclusion

The study's findings affirm that Vee-diagram and guided-inquiry instructions significantly enhance learners' self-concept in physics, outperforming traditional lecture methods. By implication, Vee-diagram approach fosters higher logical thinking and engagement, while guided-inquiry encourage exploration and competence among students. Notably, gender does not significantly influence self-concept development. An indication that the strategies are gender friendly. These findings underscore the need to integrate interactive instructional strategies in physics education. However, for effective implementation, teachers need more than just policy directives, there is a critical need for structured professional development programs that introduce teachers to these strategies. Workshops, peer-teaching sessions, and in-service training should focus on helping teachers design lessons that incorporate Vee-diagramming and guided-inquiry cycles into everyday classroom practice. Furthermore, teacher education institutions and school authorities should provide support systems, including access to resources, mentoring, and collaborative planning, that enable teachers to confidently transition from traditional methods to more interactive and reflective pedagogies.

Data availability statement

The data that support this study are not publicly available due to privacy and ethical considerations. However, data can be made available upon reasonable request. Interested researchers should contact the corresponding author to discuss the conditions under which the data may be shared.

Ethical approval

Ethical approval for this study was obtained from the Research Ethics Committee of School of Science and Technology Education (SSTE), Federal University of Technology, Minna, Niger State, Nigeria. The study was conducted in accordance with the ethical standards of the institution and the principles of the Declaration of Helsinki.

Informed consent

All participants in this study were adequately informed about the purpose, procedures, potential risks, and benefits of the research. Written informed consent was obtained from each participant prior to their participation in accordance with ethical standards approved by the Research and Ethics Committee of SSTE, Federal University of Technology, Minna, Niger State, Nigeria.

Statement regarding research involving human participants

This study involved human participants and was conducted in accordance with the ethical standards of the Research and Ethics Committee of SSTE, Federal University of Technology, Minna, Niger State, Nigeria, and with the 1964 Helsinki Declaration and its later amendments. Written informed consent was obtained from all participants prior to their participation in the study.

Consent to participate

All participants were provided with detailed information about the study, including its objectives, procedures, potential risks, and benefits. Written informed consent was obtained from each participant prior to data collection. Participation was entirely voluntary, and participants were informed of their right to withdraw from the study at any time without penalty.

Consent to publish

This study does not contain any personal data or identifiable information of participants. Therefore, specific consent to publish was not required.

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Conflict of interest

The authors declare that they have no competing interests.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author [A O ANWO] on reasonable request.

Author contributions

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