

**EFFECTS OF CONCRETE-VIRTUAL BLENDED
INSTRUCTION ON STUDENTS' UNDERSTANDING OF
SIMPLE A.C. CIRCUIT**

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Abstract: *This study investigated the effects of Concrete and Virtual Manipulative Blended Instruction (CVM-BI) and cognitive ability on senior secondary students' conceptual understanding of the Simple A.C. Circuit. A quantitative, quasi-experimental pretest–posttest non-equivalent control group design was adopted. The sample consisted of 134 SS II Physics students selected from public secondary schools in Ilorin, Kwara State, using a multistage sampling technique. Intact classes were assigned to experimental and control groups. The experimental group received CVM-BI, which combined hands-on manipulation of physical circuit components with interactive virtual simulations, while the control group was taught using the conventional lecture method over a six-week period. Data were collected using the Simple A.C. Circuit Test (SACT) and the Cognitive Ability Questionnaire (CAQ), both of which had reliability coefficients of 0.86. Descriptive statistics, *t*-test, and ANCOVA were used to analyze the data at the 0.05 level of significance, with pretest scores as covariates and cognitive ability as a moderating variable. The results revealed that students taught with CVM-BI achieved significantly higher conceptual understanding than those taught with the traditional method, with a mean*

gain difference of 16.11 in favor of the experimental group. ANCOVA confirmed a significant effect of instructional method on students' understanding. Furthermore, students with high cognitive ability performed significantly better than those with low cognitive ability. The study concludes that CVM-BI is more effective than the traditional method in teaching Simple A.C. Circuits, and that cognitive ability significantly influences students' learning outcomes in Physics.

Keywords: *concrete manipulative; virtual manipulative; blended instruction; conceptual understanding; simple A. C. circuit.*

Introduction

Physics is widely recognized as a fundamental discipline underpinning science and technology, as its principles, laws, and theories form the basis of many modern technological developments (Ilo et al., 2022). Within the Nigerian education system, adequate proficiency in Physics is a key requirement for students intending to pursue careers in engineering, medicine, pharmacy, and other applied sciences (Ibrahim, 2023; Shehu et al., 2024). Physics is a science that utilizes experimental observation and quantitative measurement to comprehend natural events (Mamuda et al., 2023). This branch of science has contributed immensely to solving problems that are faced in the contemporary world. The study of physics has contributed to the economic growth of Nigeria in the areas of Agriculture, healthcare, security, and energy. These suggest that physics plays a crucial role as it is essential in various aspects of human life. Despite its central role, the attainment of instructional objectives in Physics remains a challenge, as reflected in persistently low levels of student achievement (Ilo et al., 2022). Also, Offordile et al., (2021), reported that despite the enormous benefits of physics to the nation, there has not been satisfactory academic performance of students in physics. Reports from the West African Examinations Council (WAEC) indicate that the proportion of candidates obtaining credit-level passes in Physics has consistently remained below 50% in many examination years, raising concerns about the effectiveness of current instructional practices and assessment approaches (Ibrahim, 2023; Ilo et al., 2022).

Researchers have identified the teacher's instructional method as a primary factor responsible for massive failure (Ibrahim, 2023; Makhdum et al., 2023). Traditional teaching is often teacher-centered, where information is dished out to students who remain passive recipients, a method that fails to stimulate inquiry or innovation (Bo et

al., 2022). This disconnection is particularly problematic in complex Physics subthemes like Simple A.C. Circuits, which require students to master abstract relationships between current, voltage, and frequency (Avwiri & Okey, 2025). In response to these challenges, a blended instruction has been identified as an instructional approach that integrates online digital media with face-to-face instruction to enhance student engagement and promote active participation (Ibrahim, 2023; Ilo et al., 2022).

A wide range of instructional tools is employed in Physics classrooms to improve students' academic performance and to cultivate positive attitudes toward the subject. These tools are often described using different terms across the literature, with some scholars referring to them as manipulative while others classify them as models or representational tools. In essence, a manipulative is any object that engages multiple senses and enables learners to physically interact with ideas by touching, moving, rearranging, and transforming materials. The term manipulate originates from the Old French word *manipüle*, meaning "to handle," and in English it denotes the act of operating, controlling, or managing something with the hands (Kontas, 2016). Smith (2009) further defines manipulative as tangible classroom materials designed to promote interactive and meaningful learning experiences in Physics. From these perspectives, manipulative can be understood as learner-centered tools drawn from students' environments that support the construction of mathematical concepts through direct experience.

Manipulative serve as bridges between abstract symbols and concrete understanding, making mathematical ideas more accessible and less intimidating, especially for students who struggle with formal representations. By allowing learners to explore relationships and patterns physically, these tools reduce cognitive overload and support conceptual clarity. Recognizing their value, the National Council of Teachers of Mathematics (NCTM, 2015) strongly recommended the integration of manipulative into classroom instruction as a means of promoting developmentally appropriate, hands-on learning. Their use aligns with contemporary constructivist views, which emphasize that knowledge is actively built by learners through interaction with their environment.

Within this broader pedagogical shift toward learner-centered and inquiry-based approaches, the use of manipulative has also gained prominence in science and physics education (Ahmad & Siller, 2024). In both mathematics and physics, manipulative are commonly classified into two major categories: Concrete Manipulative (CM) and Virtual Manipulative (VM). Concrete manipulative are physical

materials, such as circuit components, lenses, springs, geometric solids, and measuring instruments, that students can touch, assemble, and manipulate directly. These tools engage multiple sensory channels and provide tactile and kinesthetic experiences that support memory formation, conceptual grounding, and experiential learning.

In contrast, virtual manipulative are interactive digital representations accessed through computers, tablets, or mobile devices. They allow learners to explore ideas using simulations, animations, and dynamic models that respond in real time to user input (Ahmad & Siller, 2024). While CM offer physicality and haptic feedback that help students connect abstract concepts to real-world experiences, VM extend learning by enabling the visualization of invisible or inaccessible processes, such as electron flow, electric fields, wave propagation, and atomic interactions that lie beyond direct human perception. Virtual environments also permit rapid manipulation of variables, immediate feedback, and safe experimentation with scenarios that may be impractical, costly, or dangerous in physical laboratory settings.

When strategically combined, concrete and virtual manipulative create complementary learning experiences. Concrete tools ground understanding in physical reality, while virtual tools enhance conceptual insight, representational fluency, and cognitive flexibility. This blended use of manipulative supports deeper conceptual change, strengthens problem-solving skills, and fosters meaningful engagement across mathematics and physics learning. As such, manipulative, whether physical or digital, represent powerful pedagogical resources for transforming abstract ideas into accessible, student-centered learning experiences.

Blended instruction refers to an instructional approach that combines traditional face-to-face teaching with online and technology-mediated learning experiences (Li et al., 2025). The rapid integration of digital technologies into education, alongside their widespread accessibility in everyday life, has profoundly transformed how students access information, engage with content, and construct knowledge. Within this evolving context, blended learning has emerged as a promising pedagogical model for enhancing instructional effectiveness. By integrating the innovative affordances of online environments with the interpersonal interaction and immediacy of classroom teaching, blended instruction creates a more flexible, adaptive, and inclusive learning experience.

More importantly, blended learning supports the development of modern, student-centered learning environments that promote active participation, autonomy, and deeper engagement. Learners are empowered to take greater responsibility for their academic

development through opportunities for self-paced study, collaborative tasks, and continuous feedback (Justine & Geronimo, 2025). When blended instruction is extended to include both Concrete Manipulative (CM) and Virtual Manipulative (VM), its instructional potential is further enhanced. Research suggests that a blended use of CM and VM is more effective than relying on either medium alone because it harnesses the unique affordances of both physical and digital tools. This dual approach enables students to transition more efficiently from concrete representations to abstract symbols and conceptual understanding within a shorter period (Ahmad & Siller, 2024; Siller & Ahmad, 2024).

Empirical evidence strongly supports the effectiveness of blended learning across science subjects. For instance, Demirkol and Kazu (2014) investigated the impact of a blended learning model on high school students' academic performance in biology and found that students in the blended learning group significantly outperformed those taught using only traditional classroom methods. Similarly, Ceylan and Kesici (2017) reported that students exposed to a blended learning environment demonstrated higher academic achievement than their counterparts in conventional face-to-face instruction. These findings collectively suggest that blended instruction, particularly when enriched with both concrete and virtual learning tools, offers a robust framework for improving students' understanding, engagement, and academic outcomes.

Despite advances in instructional design and the increasing adoption of blended and technology-enhanced approaches, a critical gap persists in achieving instructional effectiveness in physics education. High failure rates in Physics continue to be reported, in part because instruction is often designed for students as a homogenous group, without sufficient consideration of how individual learner characteristics interact with both physical and digital instructional components (Ahmad & Siller, 2024). This "one-size-fits-all" approach overlooks important student-level variables that influence how learners process information, engage with learning tasks, and construct conceptual understanding.

In particular, there is limited empirical understanding of how cognitive ability and critical thinking skills moderate the effectiveness of a blended manipulative instructional approach (Ahmad & Siller, 2024; Siller & Ahmad, 2024). While virtual tools can simplify and visualize real-world models to accommodate learners with varying cognitive levels, some students may still require the grounded, sensory-rich input provided by concrete materials in order to form stable and transferable mental representations (Siller & Ahmad, 2024). The absence of research that explicitly examines these moderating variables makes it

difficult for educators to determine whether a given blend of digital and concrete tools is equally effective for students who excel in abstract reasoning and those who rely more heavily on visual or tactile representations.

Consequently, without systematic investigation into how cognitive ability and critical thinking interact with blended manipulative instruction, instructional decisions remain largely intuitive rather than evidence-based. This study therefore seeks to address this gap by determining the comparative effects of concrete and virtual manipulative blended instruction on students' performance in Simple A.C. Circuits, with specific emphasis on examining how cognitive ability moderate the learning outcomes. By doing so, the study aims to provide empirically grounded insights that can inform more differentiated, inclusive, and effective physics teaching practices.

Cognitive ability refers to the capacity of the human brain to acquire, store, process, and retrieve information. It encompasses key mental functions such as attention, memory, logical reasoning, information processing, and the ability to transform and apply knowledge across contexts. Cognitive ability is widely regarded as one of the most extensively studied and most reliable predictors of students' academic achievement (Matthias et al., 2016; Vilia et al., 2017). Shi and Qu (2022) classify cognitive ability into several core components, including memory ability, representational ability, information processing ability, logical reasoning ability, and thinking transformation. These components work together to determine how effectively learners understand, organize, and apply knowledge in academic settings.

Empirical studies consistently show that cognitive ability plays a decisive role in shaping students' educational trajectories and long-term outcomes. Chen (2016) argues that cognitive ability significantly influences students' future directions, noting that learners with stronger cognitive skills are more likely to attend general academic high schools, whereas those with weaker cognitive abilities are more likely to be directed toward vocational pathways. These findings align with the Knowledge Processing Theory proposed by Xu and Li (2015), which posits that students with higher cognitive ability can extract key information more quickly and accurately, encode it more efficiently in memory, and generate more effective outputs during learning and assessment, as a result, such students tend to achieve higher academic performance (Zhang & Zhang, 2011).

Conversely, when cognitive ability is low, important information may be lost at various stages of the learning process, during attention, encoding, storage, or retrieval, which reduces the quality and quantity

of effective knowledge output and leads to lower academic achievement (Miriam et al., 2011). Although researchers agree that cognitive ability is strongly linked to academic success, there is no complete consensus on the exact mechanisms through which it exerts its influence. This lack of agreement is partly due to differences in how cognitive ability is defined and measured across studies (Formazin et al., 2011).

Further evidence highlights specific cognitive components as critical predictors of achievement. Tikhomirova et al. (2020) reported that information processing speed is a key predictor of fluid intelligence, working memory, and number sense, all of which contribute to individual differences in academic success. Similarly, Raj and Komalavalli (2021) found a strong positive relationship between students' cognitive ability and their academic achievement. Xu and Li (2015) also concluded that attention is significantly correlated with academic performance, with correlation coefficients ranging from 0.40 to 0.50. However, findings are not always consistent. For example, Zhang (2008) reported that logical reasoning ability had a moderate correlation (around 0.30) with both Chinese and Mathematics scores, while attention showed no significant relationship with either subject.

Taken together, these studies suggest that cognitive ability influences academic achievement both directly and indirectly through multiple cognitive pathways. However, the variability in results indicates that the effects of individual cognitive factors are complex and context-dependent. Therefore, although cognitive ability is a powerful determinant of academic success, more precise and comprehensive models are still needed to explain how specific cognitive components interact with instructional environments and student characteristics to shape learning outcomes.

Aim and Objectives of the Study

This study investigated analysis of concrete and virtual manipulative blended instruction' effects on students' conceptual understanding in simple A. C. circuit. Specifically, the study investigated:

- (1) the effect of concrete and virtual manipulative blended instruction in students' conceptual understanding in Simple A. C. circuit.
- (2) the effect of cognitive ability on students' conceptual understanding in Simple A. C. circuit.

Research Questions

The following research questions were raised and answered.

- (1) Is there any difference in the conceptual understanding of senior secondary students taught Simple A. C. Circuit using

concrete and virtual manipulative blended instruction and those taught using traditional teaching method?

(2) What is the effect of senior secondary students' cognitive ability on their conceptual understanding of Simple A. C. Circuit?

Hypotheses

The following hypotheses were formulated and tested:

H01: There is no significant difference in the conceptual understanding of senior secondary students taught Simple A. C. Circuit using Concrete and Virtual Manipulative blended instruction and those taught using traditional teaching method; and

H02: There is no significant effect of senior secondary students' Cognitive Ability on their conceptual understanding of Simple A. C. Circuit.

Material and Methods

This study adopted a quantitative research approach and utilized a quasi-experimental pretest–posttest non-equivalent control group design to investigate the analysis of Concrete and Virtual Manipulative Blended Instruction (CVM-BI) on senior secondary students' performance in Simple A.C. Circuit. The design was appropriate because intact classes were used and randomization at the individual level was not feasible, thus reflecting real classroom condition. The target population comprised all Senior Secondary School Physics students in Ilorin, Kwara State. A multistage sampling technique was employed to select a sample of 134 Senior Secondary School II (SS II) students from public secondary schools that had qualified Physics teachers, adequate Simple A.C. Circuit physical components, and functional ICT facilities. The selected intact classes were randomly assigned to either the experimental group or the control group. Students in the experimental group were taught using the CVM-BI approach, which integrated hands-on manipulation of physical circuit components with interactive virtual simulations, while those in the control group received instruction through the conventional lecture-based method. The instructional intervention lasted for six weeks, with two Physics lessons per week, and both groups were exposed to the same content using standardized lesson plans to ensure uniformity.

Data were collected using two validated instruments: the Simple A.C. Circuit Test (SACT) and the Cognitive Ability Questionnaire (CAQ). The SACT was designed to assess students' performance in Simple A.C. Circuit, whereas the adopted CAQ which was developed by Boadbent et al. (1982) measured students' cognitive ability in terms of memory, logical reasoning, and information-processing skills. Both instruments underwent face and content validation by experts in

Physics Education and Measurement and Evaluation to ensure relevance, clarity, and adequate coverage of the content. The reliability of the SACT was established using the Kuder–Richardson Formula 20 (KR-20), while the reliability of the CAQ was determined using Cronbach’s alpha, with coefficients of 0 .86 and regarded as acceptable for the study. The SACT was administered to both groups as a pretest before the commencement of instruction and as a posttest after the completion of the treatment, while the CAQ was administered prior to the intervention to determine students’ cognitive ability (high and low cognitive ability). Data were analyzed using descriptive statistics (mean and standard deviation) to answer the research questions, while t-test and Analysis of Covariance (ANCOVA) to test the hypotheses at the 0.05 level of significance, with pretest scores as covariates and cognitive ability treated as a moderating variable.

Approval to conduct the study was obtained from the principals of the selected schools prior to data collection. Because the participants were minors, informed consent was obtained from the students and their parents or legal guardians. Participation was voluntary, and students were informed of their right to withdraw from the study at any time without penalty. Anonymity and confidentiality were ensured by assigning identification codes in place of names on all research instruments. All data were used exclusively for research purposes and were securely stored to prevent unauthorized access. To ensure equitable treatment, students in the control group were granted access to the CVM-BI instructional materials after the study concluded so that no group was academically disadvantaged.

Table 1: Research Design Outline

Group	Pre-test	Treatment	Post-test
Experimental	O1	X	O2
Control	O3		O4

O1 indicates the pre-test of the experimental group

O2 indicates the post-test of the experimental group

O3 indicates the pre-test of the control group

O4 indicates the post-test of the control group

X indicates the treatment administered to the experimental group.

Results

Research Question 1: Is there any difference in the conceptual understanding of senior secondary students taught Simple A. C. Circuit

using concrete and virtual manipulative blended instruction and those taught using traditional teaching method?

Table 2 indicates a clear difference in the conceptual understanding of senior secondary students who were taught Simple A.C. Circuit using the Concrete and Virtual Manipulative Blended Instruction (CVM-BI) and those taught with the traditional teaching method. The students in the experimental group, who received the blended instructional approach, recorded a mean gain score of 41.38, whereas their counterparts in the control group achieved a lower mean gain score of 25.27. This represents a substantial mean gain difference of 16.11 in favour of the experimental group.

This result suggests that the CVM-BI approach was more effective in enhancing students' conceptual understanding of Simple A.C. Circuits than the conventional method. The higher gain scores among students exposed to both concrete and virtual manipulative imply that engaging learners through multiple representations and interactive experiences promotes deeper understanding of physics concepts like the simple A. C. circuit.

Table 2: Pre-Test and Post-Test Mean Scores of Students taught using Concrete and Virtual Manipulative Blended Instruction and those taught using Traditional Teaching Method

Groups	N	Pre-Test		Post-Test		Mean Gain	Mean Difference
		Mean	SD	Mean	SD		
Experimental	78	31.45	6.28	72.83	8.14	41.38	16.11
Control	56	30.97	6.11	56.24	7.92	25.27	

Hypothesis 1: There is no significant difference in the conceptual understanding of senior secondary students taught Simple A. C. Circuit using Concrete and Virtual Manipulative blended instruction and those taught using traditional teaching method

Table 3 reveals that the main effect of instructional methods; the comparison between the Concrete and Virtual Manipulative Blended Instruction (CVM-BI) and the traditional teaching method in teaching Simple A.C. Circuit, is statistically significant, $F(1, 174) = 1982.28$, $p < 0.05$. This indicates that the both instructional methods used had a strong influence on students' conceptual understanding. This result shows that there is a meaningful difference between the conceptual understanding of students in the experimental group and those in the control group, with the advantage clearly in favour of the experimental group. Students who were taught using the blended approach that

combined concrete and virtual manipulative demonstrated significantly higher conceptual understanding of Simple A.C. Circuits than those taught through the traditional method, highlighting the effectiveness of CVM-BI in promoting deeper learning of simple A. C. circuit.

Table 3: ANCOVA Summary of Differences in Students' Understanding of Simple A.C. Circuits by Teaching Method

Source	SS	Df	MS	F	p-value
Corrected Model	4553.225 ^a	2	2276.613	1097.36	0.001
Intercept	8999.579	1	8999.579	4337.92	0.001
Covariate	1159.172	1	1159.172	558.74	0.001
Group	4112.487	1	4112.487	1982.28	0.001
Error	360.986	174	2.075		
Total	41434.162	177			
Corrected Total	4914.211	176			

^a $R^2 = .927$ (Adjusted $R^2 = .926$).

Research Question 2: What is the effect of senior secondary students' cognitive ability on their conceptual understanding of Simple A. C. Circuit?

Table 4 summarizes the mean scores of senior secondary students' conceptual understanding of the simple A.C. circuit based on their levels of cognitive ability. The results show that students classified as having high cognitive ability obtained a mean score of 74.62, whereas those with low cognitive ability recorded a lower mean score of 66.41. This yields a mean difference of 8.21 points, indicating that students with higher cognitive ability demonstrated markedly better conceptual understanding of the simple A.C. circuit than their counterparts with lower cognitive ability.

Hypothesis 2: There is no significant effect of senior secondary students' Cognitive Ability on their conceptual understanding of Simple A. C. Circuit

The results presented in Table 4 indicate that the computed *t*-value is 3.94 with 132 degrees of freedom, and the associated probability value is 0.001, which is less than the 0.05 level of significance. Since the obtained *p*-value is lower than the alpha level, the null hypothesis 2 is not accepted. This implies that the difference observed is statistically significant. Consequently, senior secondary students' cognitive ability has a significant effect on their conceptual understanding of the simple A.C. circuit. In other words, variations in students' levels of cognitive

ability meaningfully influence how well they understand concepts related to simple alternating current circuits.

Table 4: T-test Analysis of Results of senior secondary students' Cognitive Ability on their conceptual understanding of Simple A. C. Circuit

Cognitive Ability Level	N	Mean	SD	Df	t-value	Mean Difference	Sig. (2-tailed)
High Cognitive Ability	68	74.62	11.84	132	3.94	8.21	0.001
Low Cognitive Ability	66	66.41	13.02				

Discussion

This study examined the effects of Concrete and Virtual Manipulative Blended Instruction on senior secondary students' conceptual understanding of the Simple A.C. Circuit. The findings showed that there was a significant difference in the conceptual understanding of students who were taught using the Concrete and Virtual Manipulative blended approach and those who were taught with the traditional teaching method. Specifically, students in the blended instruction group performed better than their counterparts in the traditional group. This result is consistent with the studies of Demirkol and Kazu (2014) and Ceylan and Kesici (2017), which reported that students exposed to blended learning significantly outperformed those taught solely through conventional methods. These results collectively indicate that blended instruction, especially when enriched with both concrete and virtual learning tools, provides a strong framework for enhancing students' understanding, engagement, and academic achievement.

Furthermore, the study also revealed that senior secondary students' cognitive ability had a significant effect on their conceptual understanding of the Simple A.C. Circuit. This finding aligns with the work of Chen (2016) and Xu and Li (2015), who argued that students with higher cognitive ability are able to extract key information more quickly and accurately, encode it more efficiently in memory, and generate more effective responses during learning and assessment. As a result, such students tend to achieve higher levels of academic performance.

Conclusion

This study examined the effects of Concrete and Virtual Manipulative Blended Instruction (CVM-BI) and students' cognitive ability on senior secondary students' conceptual understanding of the Simple A.C. Circuit. Using a quasi-experimental design, the study compared students exposed to the CVM-BI approach with those taught using the traditional lecture-based method. The results revealed that students who were taught through CVM-BI demonstrated significantly higher conceptual understanding than their counterparts in the control group. This indicates that integrating concrete manipulatives (such as physical circuit components) with virtual simulations within a blended instructional framework creates a more interactive and learner-centered environment that promotes meaningful learning. The superiority of the CVM-BI approach may be attributed to its capacity to engage multiple senses, enhance visualization of abstract concepts, and provide opportunities for active exploration. Alternating current circuits are often perceived as abstract and mathematically demanding; however, the combination of hands-on experiences and computer-based simulations enables students to observe circuit behavior, manipulate variables, and receive immediate feedback. This process strengthens conceptual connections, reduces misconceptions, and supports deeper understanding beyond rote memorization. Furthermore, the findings showed that students' cognitive ability significantly influenced their conceptual understanding of the Simple A.C. Circuit. Students with higher cognitive ability achieved better mean scores than those with lower cognitive ability. This suggests that abilities such as logical reasoning, information processing, memory retention, and problem-solving skills play a crucial role in mastering complex physics concepts. Learners with stronger cognitive skills may find it easier to integrate new information with prior knowledge, interpret graphical representations, and apply theoretical principles to practical situations. Overall, the study underscores the importance of adopting innovative instructional strategies like CVM-BI while also recognizing individual differences in learners' cognitive abilities. For optimal learning outcomes in physics, educators should combine effective teaching methods with instructional supports that accommodate diverse cognitive levels, thereby promoting improved conceptual understanding and overall academic achievement.

Recommendation

Based on the findings of the research, it was recommended that physics teachers should incorporate Concrete and Virtual Manipulative Blended Instruction into the teaching of abstract topics such as Simple

A.C. Circuits to enhance students' conceptual understanding and active participation. Also, teachers should design instruction that accommodates different levels of cognitive ability by using Teachers should design instruction that accommodates different levels of cognitive ability by using differentiated teaching strategies, scaffolding, and varied learning activities to support both high and low cognitive ability learners. to support both high and low cognitive ability students.

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