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Efficacy of ADDIE Instructional Design in Promoting Conceptual Change in Electronic Concepts at Tano-North Municipality, Ghana

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ABSTRACT

Purpose of the study: This study sought to determine the efficacy of the ADDIE instructional design in facilitating the conceptual change of senior high school physics students in Tano-North Municipality in Electronics.

Methodology: A design-based research (DBR) methodology was adopted using a sample of 101 participants. Data were collected using a 10-item Electronic Concepts Test (ECT). Data were analyzed quantitatively (frequencies, percentages, and Wilcoxon Signed Rank Test) and qualitatively (content analysis).

Main Findings: The results revealed that significantly high percentages of students (71.29% to 94.06%) demonstrated misconceptions about electronics concepts. The content analysis of the students' responses revealed various misconceptions, including 'temperature increases conductivity of the conductors' and 'heat increases conductor temperature,' among others. However, there was a significant increase in the percentage of students exhibiting scientific understanding after the intervention ($Z = -2.83$, $p = 0.002$, with a large effect size of $r = 0.89$).

Novelty/Originality of this study: While much attention has not been turned to the use of ADDIE instructional design as an instructional approach in physics teaching or, for that matter, the study of electronics, this study has revealed the efficacy of the ADDIE instructional design in promoting students' conceptual change in electronics concepts in the Tano-North Municipality. Based on the results, the researchers recommended the ADDIE instructional design to high school physics teachers in the Tano-North Municipality for teaching and learning electronics concepts.

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1. INTRODUCTION

The study of electronics has evolved, and today, engine management and in-car entertainment systems are two areas of heavy use for electronics in the automotive industry [1]. In the aerospace sector, electronics are significant. Also, the healthcare industry is an important sector that incorporates electronics in all aspects of its operations. For example, electronics are used in various treatments, including electrocardiogram, ultrasound, X-ray, nuclear magnetic resonance, and many more [2]. Air conditioners, elevators, lighting, laptops, printers, fax machines, and desktop computers are just a few of the electrical devices that apply electronics knowledge in offices. Agriculture, which supports our nation, also depends on electronics to water crops with motors and remotely monitor crop growth and soil moisture. Furthermore, the application of electronic devices aids in sending data from servers to computers and from computers to servers [3], [4].

Despite the importance of electronics, the research community has widely acknowledged that many students need more clarification about the basics of electronics [5]. This assertion is evident in the work of Nelson et al., who found that students had misconceptions about semiconductor phenomena, diffusion, drift, and excitation [6]. According to a study by Chen et al., on common misconceptions about learning about diodes, it was found that seven students had misconceptions about the semiconductor concepts of a diode, four about bias features of a diode, seven about simplified models of a diode, and ten about fundamental circuits of a diode [7].

According to Assem et al., misconceptions are false beliefs that students hold, often with great conviction, that are contrary to the generally acknowledged body of scientific knowledge [8]. Misconceptions can be detrimental to learning because they resist change [9]-[11]. In other words, they serve as obstacles to learning and "cognitive bottlenecks" that must be surmounted for further learning. Students may be unaware that they have formed a misconception when they think they grasp a phenomenon or concept because their limited prior knowledge of the physical world strengthens their sensory perceptions. Students must, therefore, engage in conceptual change to overcome their misconceptions.

In Ghana, the difficulty of physics students in electronics concepts is emphasized, particularly in external examinations [12]-[15]. According to the West African Examination Council (WAEC) chief physics examiners, “candidates could not list the advantages of the p-n junction diode over diode valves” [12]. The chief examiners speculated that “it appeared most candidates did not treat semiconductors." Few candidates gave the correct answer to questions related to intrinsic semiconductors and the difference between p-type and n-type semiconductors [13]. Again, few candidates could use band theory to explain why the electrical resistance of a semiconductor decreases with an increase in temperature [14]. Furthermore, in 2021, according to a report from WAEC, the candidates could not state the function of (i) low voltage battery and (ii) high tension source as a component of an X-ray tube [15]. Furthermore, “candidates could not state the reasons for the design characteristics of an X-ray tube."

Similarly, the researchers' observations at the study site in the Tano North Municipality revealed that some SHS physics students needed more understanding or clarification about electronics concepts. For example, when students were asked the question, “What happens to the holes when a p-n junction is reversed biased?” A student's response revealed the misconception that “*reverse bias makes holes move back through the P-N junction towards the negative side*." Another student's response revealed the misconception that “the *holes would absorb N-type material.”* Similarly, another student's response revealed the misconception that “*reverse bias causes the holes in the P-type material to flow toward the N-type material.”* These observations indicate the students' lack of understanding or misconception, which prompted the need for conceptual change.

When successfully implemented in the classroom, ADDIE (Analyse, Design, Develop, Implement, and Evaluate) instructional design can improve conceptual change, leading to improved student academic performance. The reason is that ADDIE focuses more on the learner, thus being an active learning technique or a learner-centered instructional approach [16]-[18]. This makes ADDIE align with the principles of constructivism propounded by Jean Piaget and Lev Vygotsky [19]-[21]. The ADDIE model is primarily a framework for instructional design, focusing on creating and organizing instructional materials and courses [22], [23]. However, it can also be adapted and used as an instructional teaching method, especially when planning and teaching lessons [17], [24], [25].

Studies, though limited, have thus found that the ADDIE instructional design model enhanced students’ academic performance in various learning disciplines. For example, Moral et al. found that the ADDIE model improved performance in natural science in the Philippines [17]. Additionally, Asuncion, revealed that using the ADDIE model improved the performance of students with bachelor's degrees in elementary education in educational technology [26]. Also, Ghana found that the use of the ADDIE model aided in improving the academic performances of final-year hospitality students in a Technical University [24]. Notwithstanding the perceived benefits of the ADDIE instructional design model, there appear to be few studies in the field of physics education, especially in Ghana, that account for how the ADDIE instructional design model could produce conceptual change in Senior High School physics students (SHS), and this presents a gap in research that needs to be filled. It was against this background of wanting to expel misconceptions in electronics studies of SHS physics students of Tano North Municipality in the Ahafo Region, Ghana, and the desire to fill this identified study gap that this study was initiated. Specifically, this study sought to determine the extent to which SHS physics students in the Tano North Municipality demonstrate misconceptions about electronics concepts and how the ADDIE instructional design model can promote conceptual change in electronics concepts among physics students at Tano North Municipality.

2. RESEARCH METHOD

Connecting pragmatism ideas, this study employed design-based research (DBR) methodology. The goal of the DBR methodology, which was created by and for educators [27], is to improve practice by maximizing the impact, transfer, and translation of education research while helping to create prototype solutions to address complex real-world problems that are context-specific [28]. DBR also highlights the need to develop and test design ideas and theories that direct, enlighten, and improve research and practice in educational settings [29]. Therefore, in the context of this study, SHS Physics students' misconceptions of electronics were identified through a pre-intervention test, and an intervention using the ADDIE model, based on the constructivism theory of learning, was designed to address the challenge. Following the intervention was the conduction of a post-intervention test to evaluate the effectiveness of the intervention in enhancing students' conceptual change in electronics. Within this DBR, the data collected were analyzed quantitatively and qualitatively, allowing for deeper exploration and a holistic understanding of the research problem [28].

2.1 Population and Sample

A total of 101 SHS physics students, constituted through a multi-stage sampling method, were used as the research subjects for the study. That is, simple random sampling was used to select two (2) SHSs, and of the two (2) selected SHSs, simple random sampling was used to select an intact class from each school. Both intact classes selected were exposed to the ADDIE instructional design model. Therefore, there was no control group in this study. The sampled students were selected from a population of SHS final-year physics students in the Tano North Municipality in the Ahafo Region, Ghana.

2.2 Data collection instrument

The Electronics Concepts Test (ECT) was the data collection instrument. The ECT consisted of ten open-ended questions. The ten questions were constructed in areas of electronics such as capacitors, transistors, conductors, insulation, and semiconductors. Other areas included the P-N junction diode and rectification. The same test items were used as the pre-intervention test and post-intervention test. The selection of the questions for the ECT was premised on these areas of electronics because the researchers identified through a preliminary observation that physics students in the study area (Tano North Municipality) demonstrated misconceptions about the selected electronics concepts. Also, it appears that most physics students have misconceptions [5], [6] and diverse difficulties [12]-[15] in these areas. Table 1 presents the detailed structure of the ECT.

Table 1. Structure of Electronics Concepts Test

Concept	Item	Questions
Capacitors and Transistors	6	Explain why a transistor has a thin base.
Conductors, Insulators, and semiconductors	1	Explain the effect of temperature on the conductivity of conductors.
	2	What is the effect of temperature on the resistivity of conductors?
	3	Why does conductivity increase with temperature in semiconductors?
	4	Explain why there is a wider forbidden band in insulators.
	5	Explain what happens when a semiconductor is doped with impurities.
	8	Why is the conduction band described as the highest energy band in a solid?
	9	Explain why the valence band can be described as the lowest energy band in a solid.
	10	How can normal temperature affect the conductivity of an insulator such as polythene?
P-N Junction Diode and Rectification	7	What is the effect of forward biasing a light-light-emitting diode?

The ECT was given to physics and science education experts to determine the appropriateness of each item on the instruments. Experts reviewed the items, after which modifications were made for subsequent piloting. Two independent raters scored the students' responses to determine the reliability of the ECT pilot test items. The internal consistency of the scores, specifically the reliability between the rats, was determined using Kappa's measure of agreement. A Kappa value of 0.720 was obtained, which indicates a substantial agreement, according to [30].

2.3 Ethical Procedures

Ethics permission was obtained from the school authorities, who conducted the study according to ethical standards. In addition, participants voluntarily participated in the study. Also, confidentiality was given priority; therefore, alphabets were used as names of participants to avoid easy identification.

2.4 Teaching intervention

This is the second stage of the data collection process, and at this stage, the implementation of the ADDIE model occurred. The intervention stage lasted four (4) weeks. Within these four weeks, students were exposed to the ADDIE instructional model while teaching and learning electronic concepts.

Table 2. Weekly Schedule of Electronic Content

Period	Content Taught
Week 1	Electronic Components and Circuit Diagrams
Week 2	Capacitors and Transistors
Week 3	Conductors, Insulators, and Semiconductors
Week 4	P-N junction diode and rectification

The following subheadings present how the relevant activities outlined in the ADDIE instructional design model were applied at each stage of the teaching intervention for every week.

Analyse

The analysis stage was characterized by examining the students' previous knowledge students before each lesson based on the lesson objectives to determine their lesson's objectives to determine student's strengths and weaknesses. This was done using an open 5-item test, which served as a diagnostic test, and students were required to answer on sheets of paper.

Design

Based on the students' responses to the diagnostic test, the researcher designed and planned instructional tasks, activities, and materials to be given to the students. The lesson objectives were also identified, including specific skills and knowledge the researchers wanted students to obtain. The specific objectives of the lesson were clearly stated. For example, by the end of the lesson, the student will be able to;

1. identify essential electronic components in a circuit. E.g., resistors, capacitors, and inductors.
2. explain the behavior of electronic components in a circuit.

Develop

At this stage, the researchers developed the materials students would use during classroom activities. Examples are transistors, capacitors, resistors, LEDs, and videos of how to construct some basic electronic components and how these components work.

Implementation

At this stage, the researchers presented the lesson to students. Students were sometimes allowed to watch videos on constructing a simple electronic circuit. After watching the videos, they were allowed to practice hands-on using the available components. During the activities, worksheets were given to students, which contained instructions on which activities students were to undertake based on the lesson objectives. The researchers were available in person to offer needed assistance and guidance.

Evaluate

To assess whether the lesson objectives were achieved, the researchers used formative and summative assessments to evaluate the students based on the objectives stated at the design stage. Formatively, students were given similar essay-type tests as formative assessments after every lesson. The essay-type test helped determine whether there had been an enhancement of conceptual understanding of the lesson objectives. However, the researchers conducted a summative evaluation test after completing the intervention stage. The results were used to determine any conceptual electronics concepts after using ADDIE instructional design.

2.5 Data Analysis Procedure

The results were presented in both quantitative and qualitative. Quantitative results involved the frequencies and percentages of students who demonstrated misconceptions and scientific understanding of each item. The independence chi-square test was then used to determine any significant association between each item and the response category (misconception and scientific understanding). Also, to determine whether the ADDIE instructional design model significantly promoted student conceptual change in electronics concepts, the Wilcoxon Signed Rank Test was used to test for any significant difference in the percentage of students who exhibited scientific understanding before and after the intervention. However, qualitative results involved content analysis of students' responses to each item.

3. RESULTS AND DISCUSSION

This section of the study represents the results of misconceptions about electronic concepts and subsequent findings of conceptual change.

3.1. Misconceptions among SHS Physics Students in Electronics Concepts

The results of the students' misconceptions and scientific understanding of the students from the ECT, which answers research question 1, are presented in this section. A student was deemed to possess misconceptions if their answer contained incorrect information, misused terminology, or demonstrated flawed reasoning inconsistent with scientific principles on the electronics concept. In contrast, a student was adjudged to possess scientific understanding if their answer was accurate, demonstrated clear understanding, and used correct terminology and logical reasoning. Furthermore, students who did not attempt to respond to an item that provided irrelevant or off-topic responses or lacked coherence or any indication of concept knowledge were considered to demonstrate "no understanding" of the concept. However, this study found that no student demonstrated "no understanding" of an item. All students attempted each item, and their responses were scientifically accurate or inaccurate. The quantitative results were expressed in frequencies and percentages, while the qualitative results were done through content analysis of students' responses. The quantitative results of the misconceptions of the students and the scientific understanding of each item before the intervention are presented in Table 3.

Table 3. Quantitative Results of Students' Misconceptions and Scientific Understanding of Electronics Concepts Before Intervention

Item*	NSEM (N=101)	%	rank	NSHSU (N=101)	%	rank	$\chi 2$	df	p
1	95	94.06	1	6	5.94	9	78.43	1	0.001
2	73	72.28	9	28	27.72	2	20.05	1	0.001
3	80	79.21	5	21	20.79	5	34.47	1	0.001
4	81	80.20	4	20	19.80	7	36.84	1	0.001
5	79	78.22	6	22	21.78	6	32.17	1	0.001
6	75	74.26	8	26	25.74	3	23.77	1	0.001
7	83	82.18	3	18	17.82	8	41.83	1	0.001
8	72	71.29	10	29	28.71	1	18.31	1	0.001
19	76	75.25	7	25	24.75	4	25.75	1	0.001
10	95	94.06	1	6	5.94	9	78.43	1	0.001

NSEM - Number of Students Exhibiting Misconception

NSESU – Number of Students Exhibiting Scientific Understanding

*Refer to Table 1 for the questions.

As presented in Table 3, a Chi-square test for independence indicated a significant association between each item and category of students' response (misconception and scientific understanding). Table 3 further reveals that high percentages of students generally had misconceptions about all the items in the ECT before the intervention. This is because the percentage of students who exhibited misconceptions on all the items in the ECT ranged from 71.29% to 94.06%. It can be seen from Table 3 that the most significant percentage of students (94.06%) exhibited misconceptions on items 1 and 10, while the lowest percentage of students (71.29%) exhibited misconceptions on item 8.

On the contrary, Table 3 reveals that very low percentages of students generally demonstrated a scientific understanding of electronics concepts, with the percentage of students having a scientific understanding of electronics concepts ranging from 5.94% to 28.71%. The highest percentage of students (28.71%) demonstrated a scientific understanding of item 8, while the lowest percentage (5.94%) demonstrated a scientific understanding of items 1 and 10.

Content analysis was conducted on students' responses to understand the context and deeper meaning behind students' answers to the items in the ECT, offering rich qualitative insights. This helped to understand students' misconceptions of electronics concepts comprehensively. The items selected for the content analysis were items 1, 3, 6, and 10, representing the items where the highest, moderate, and most minor percentage of students demonstrated misconceptions. Representative explanations of students from the ECT are presented as follows.

Question 1: Explain the effect of temperature on the conductivity of conductors.

Common student responses: Students demonstrated misconceptions about this particular item. For example, student **A** stated, **"***Increasing the temperature of a conductor will always increase its conductivity. This is because heat activates the electrons in the conductor, making them move more freely"* (student **A** answer).

Identified Misconception 1: Temperature increases the conductivity of conductors.

From the quote above, Student **A** could not explain that when the temperature of a conductor is increased, atoms within the conductor vibrate faster at greater amplitude. As a result, the number of collisions between the vibrating and free electrons increases, reducing the number of free electrons. Accordingly, Student **A** failed to acknowledge that the current flow also reduces, which increases the material's resistivity and conductivity.

Also, student **B** said, **"***The conductivity of a conductor remains constant regardless of temperature changes. This is because conductors always conduct electrons, so, no matter the amount of heat, their conductivity will not change*" (student **B's** answer).

Identified Misconception 2: conductivity remains constant

Student **B** also should have acknowledged that when the temperature of a conductor is increased, atoms within the conductor vibrate faster at greater amplitude. As a result, the number of collisions between the vibrating electrons and free electrons increases, reducing the number of free electrons. Accordingly, student **B** also did not understand that the current flow also reduces, increasing the resistivity of the material.

Similarly, student **C** articulated**,** "*When heat flows through a conductor, the conductor always gets hotter. "Heat always increases the temperature of objects, and this temperature will cause the conductor to get hotter. This will increase the conductivity of the conductor*" (student **C** answer).

Identified Misconception 3: Heat increases the temperature of conductors.

From student **C**, there was a lack of scientific understanding or explanation regarding the item. Student **C** specifically failed to acknowledge the difference between heat and temperature and how temperature would affect the conductivity of conductors.

Furthermore, student **D** said: "Temperature *always causes objects to change shape or state. So, when a conductor, which is a type of solid, is exposed to temperature, the material will change its shape. And when the shape is changed, conductivity will not take place*" (student **D's** answer).

Identified Misconception 4: The temperature causes a change in the shape of a conductor.

Student D's answer reflected a need for a more scientific understanding of electronics. Student **D** did not consider that internal changes in atomic particles increase or decrease the conductivity of the conductors.

Question 3: Why does conductivity increase with temperature in semiconductors?

Common students' response: students demonstrated common misconceptions concerning this particular item. For example, student **E** stated: "*It is the electron that causes an object to be conductive. So, when you increase the temperature of a semiconductor, it adds more electrons to the material, making it more conductive*" (Student **E's** answer).

Identified Misunderstood 5: The addition of electrons with an increase in temperature.

For this item, student **E** did not realize that the number of electrons in a semiconductor remains constant, and the temperature does not add or remove electrons. Thus, Student **E** failed to explain that when the temperature of a semiconductor is increased, some covalent bonds break, and more free electrons and holes are produced. With the increase in electrons, the conductivity of the semiconductor increases.

Furthermore, the student answered this particular item: "*I think higher temperatures cause electrons to move faster within the semiconductor, leading to increased conductivity*" (Student **F's** answer).

Identified Misconception 6: Faster movement of electrons

Student F's response suggests that an accurate explanation for why conductivity increases with increasing temperature is needed. Student **F** did not recognize that, while temperature affects the thermal motion of electrons, the change in the balance between electrons in the valence and conduction bands primarily influences conductivity in semiconductors.

Furthermore, student **G** provided an answer which stated that:

"As the temperature increases, semiconductors eventually become conductors. This is because higher temperatures increase the number of charge carriers in the conduction band, thus increasing the object's conductivity" (Student **G** answer).

Identified Misconception 7: Semiconductors become metals at high temperatures.

Student **G**'s answer did not reveal that while higher temperatures increase the number of charge carriers in the conduction band, semiconductors do not transform into metals solely because of temperature changes. The distinction between semiconductors and metals is based on their intrinsic properties and band gaps, not just on temperature.

Student **H**, in providing an answer to this item, also stated: "Temperature *increases the number of electrons in the conduction band, therefore increasing the conductivity of the conductor"* (Student **H's** answer).

Identified Misconception 8: Addition of electrons

The quote from student H also failed to reveal that while the temperature can promote some electrons to the conduction band through thermal excitation, it does not create new electrons. The total number of electrons remains constant.

Question 6: Explain why a transistor has a thin base.

Common students' response: Again, in the interview session, students revealed common misconceptions concerning this item. For instance, student **I** stated**, "***The base of a transistor is thin to increase the amplification of the device. So, a thicker base would result in lower amplification*" (Student **I's** answer).

Identified Misconception 9: Base Thickness Affects Amplification

From Student I's response, it can be deduced that the student did not know the function of a transistor's base. Student, **I** did not understand that the primary function of the thin base is to control the flow of current between the emitter and collector regions, not to enhance amplification.

Likewise, student **J's** response to this item was that: "A *thin base allows more electrons to pass through it. Therefore, reducing the thickness of the base leads to higher current flow*" (Student **J's** answer).

Identified Misconception 10: A thin base allows for the flow of electrons.

From student **J's** response, it could be seen that the student wrongly attributed the nature of the base to the current flow instead of acknowledging that the base's thinness is related to the control of minority carriers (holes or electrons), not the overall current flow.

Furthermore, student **K's** response to this item revealed a misconception. Student **K's** response was as follows: "The *type of transistor (NPN or PNP) is determined solely by the thickness of the base. That is, a thin base corresponds to an NPN transistor and a thick base to a PNP transistor*" (Student **K's** answer).

Identified Misconception 11: The base's thickness determines the transistor type.

Student **K** also, from the above quote, should have given the correct scientific explanation for item 6. In reality, the transistor type is determined by the arrangement of the layers and the types of semiconductor materials used, not by the thickness of the base.

Question 10: How can normal temperature affect the conductivity of an insulator such as polythene?

Typical student response: In the interview session, the students revealed common misconceptions about this item. For example, student **L** stated: "*Ordinary temperature can transform an insulator into a conductor of electricity. This is because, at ordinary temperatures, insulators become hot and start conducting electricity just like metals*" (Student **L's** answer).

Identified Misconception 12: Heat changes an insulator to a conductor.

From the quote of Student **L**, one could decipher that the student thinks it is heat that changes an insulator into a conductor. Therefore, any amount of heat can change an insulator into a conductor. Student **L** needed to understand what atomic changes occur within the heated substance and, therefore, could not acknowledge that ordinary temperatures have no significant effect in changing insulators into conductors. This is because, at ordinary temperatures, an insulator has no free-moving electrons and, therefore, has negligible electrical conductivity. However, at high temperatures, some electrons gain energy and break away from the influence of the nucleus, becoming free electrons that can conduct electricity.

Student **M** also responded, "*At normal temperatures, the conductivity of an insulator increases. This happens because an insulator has some conductivity property, but the extent to which it conducts heat or electricity increases under normal temperatures. This is because electrons within the material become free after heating, which will cause the material's conductivity to increase*" (Student **M's** answer).

Identified Misconception 13: Normal temperature increases the conductivity of the insulators.

Student **M** also did not acknowledge that

The answer from student **M** also revealed the inability to acknowledge that ordinary temperatures do not affect the conductivity of insulators, instead, the conductivity of an insulator increases with increasing temperature.

Student **N** also answered item 10, which stated: "Normal *temperatures will cause an insulator to melt, which will turn into a liquid, of which we all know that a liquid can conduct heat and electricity. So, at normal temperature, the conductivity of an insulator increases*" (Student **N's** answer).

Identified Misconception 14: Normal temperature changes the state of an insulator.

The answer from student **N** also needs more accurate scientific reasoning behind the effect of temperature on insulators. Student **N** did not refer to the internal atomic changes of the material under temperature. Instead, student **N** referred to the change of state of an insulator under temperature, after which the student linked it to a property of the new state of the insulator after it was heated. What student **N** needed to recognize was the fact that insulators have a small number of electrons, which, when exposed to high temperatures, could be free to conduct heat or electricity.

This aspect of the study's findings supports previous research on student misconceptions about electronic concepts. For example, Nelson et al. and Erceg et al., reported that students believed that the conductivity of semiconductors increases with temperature, mainly due to an increase in the number of one type of free charge carrier [6], [5]. Again, Erceg et al., reported that students thought that increasing the temperature increased the number of free electrons in a conductor, hence increasing the conductivity of a conductor [5]. The misconceptions students portray indicate that some arise because they have not grasped the concepts well enough, partly due to the teaching methods instructors employ in teaching some concepts [31]. For example, in a study by Widiyatmoko and Shimizu, students claimed that they memorized physics concepts because their teachers' teaching methods did not help them understand the material [32]. Karaarslan and Çetin revealed similar findings, where physics students claimed their teachers only lectured in class with little or no participation in the teaching and learning activities [33]. This leads to incomplete or no understanding of the concepts learned, triggering the development of misconceptions or alternative understandings of the subject matter.

3.2. Conceptual Change in Electronics Concepts after the Application of the ADDIE Instructional Design Model

The second part of the analysis aimed to determine how using the ADDIE model had helped students clear their misconceptions identified before the intervention. Consequently, using the students' responses from the ECT, the answers to each item were classified as misconceptions and scientific understanding, as explained in

Section 3.1. Table 4 shows the quantitative results of the students' misconceptions and their scientific understanding of each item after the intervention.

Table 4. Quantitative Results of Students' Misconceptions and Scientific Understanding of Electronics Concepts After Intervention

Item*	NSEM (N=101)	%	rank	NSHSU (N=101)	%	rank	χ^2	df	p
1	40	39.60	5	61	60.40	6	54.529	2	0.001
2	39	38.61	6	62	61.39	5	55.824	2	0.001
3	29	28.71	10	72	71.29	1	75.235	2	0.001
4	41	40.59	4	60	59.41	7	53.353	2	0.001
5	49	48.51	1	52	51.49	10	48.176	2	0.001
6	46	45.54	2	55	54.46	9	49.235	2	0.001
7	38	37.62	7	63	62.38	4	57.235	2	0.001
8	42	41.58	3	59	58.42	8	52.294	2	0.001
9	37	36.63	8	64	63.37	3	58.765	2	0.001
10	35	34.65	9	66	65.35	2	62.176	2	0.001

NSEM - Number of Students Exhibiting Misconception
NSESU – Number of Students Exhibiting Scientific Understanding
*Refer to Table 1 for the questions.

In Table 4, a chi-square test for independence indicated a significant association between each item and the category of students' responses (misconception and scientific understanding). As observed in Table 4, significantly low percentages of students generally had misconceptions about electronics after introducing the ADDIE model. This is because the percentage of students who exhibited misconceptions about all the items in the ECT after the intervention ranged from 28.71% to 48.51%. Table 4 also reveals that the most significant percentage of students (48.51%) exhibited misconceptions on item 5, while the lowest percentage (28.71%) was on item 3.

On the contrary, Table 4 shows that students generally demonstrated high percentages of scientific understanding of electronics concepts after the intervention, with the percentage of students having a scientific understanding of electronics concepts ranging from 51.49% to 71.29%. The highest percentage of students (71.29%) demonstrated a scientific understanding of item 3, while the lowest percentage demonstrated a scientific understanding of item 5.

The results in Tables 3 and 4 were compared to determine the ADDIE model's effect on students' conceptual change in electronics concepts, as shown in Table 5.

Table 5. Comparison of the percentage of students who demonstrated misconceptions and scientific understanding before and after intervention

*Item	Mis. before intervention	Mis. after intervention	% change	SU before intervention	SU after intervention	% change
1	95	40	-57.89	6	61	916.67
2	73	39	-46.58	28	62	121.43
3	80	29	-63.75	21	72	242.86
4	81	41	-49.38	20	60	200.00
5	79	49	-37.97	22	52	136.36
6	75	46	-38.67	26	55	111.54
7	83	38	-54.22	18	63	250.00
8	72	42	-41.67	29	59	103.45
9	76	37	-51.32	25	64	156.00
10	95	35	-63.16	6	66	1000.00

Mis. – Number of students exhibiting misconception
SU – Number of students demonstrating scientific understanding
% change – percentage change
*Refer to Table 1 for the questions.

As seen in Table 5, in the ten items, there was a decrease in the percentage of students who exhibited misconceptions after the intervention, hence the negative percentage changes in the ten items. However, there was an increase in the percentage of students who exhibited scientific understanding in each item after the intervention, hence the positive percentage changes observed across the ten items. The highest percentage change (decrease) in the misconception category was observed in item 3 (-63.75%), while the most minor decrease was observed in item 5 (-37.97%). Also, the highest percentage change (increase) in the scientific understanding category was observed in item 10 (1000.00%), while the lowest percentage increase was observed in item 8 (103.45%).

The effect of the ADDIE instructional design model in enhancing students' conceptual change across the ten items after the intervention was tested using the Wilcoxon Signed Rank Test on the difference in the percentage of students who exhibited scientific understanding before and after the intervention. The results are presented in Table 6.

Table 6. Results for Wilcoxon Signed Rank Test

	Scientific understanding after – scientific understanding before
Z	-2.805
Asymp. Sig. (2-tailed)	0.002

From Table 6, the Wilcoxon Signed Rank Test revealed a statistically significant increase in the percentage of students who exhibited scientific understanding after the intervention (z = –2.805, p =0.002). The negative z-value means that, on average, the ranks (absolute values) of positive differences (indicating improvement) are higher than the ranks of negative differences (indicating worsening). This means there were more significant decreases in the percentage of students with misconceptions after the intervention than increases. To determine the magnitude of the effect of the intervention, which was considered in this study to constitute the conceptual change, an effect size statistic was calculated using the formula shown in (1) by substituting the respective values into (1) gives r = 0.89. The effect size of 0.89 obtained for scientific understanding, according to Cohen, Manion, and Morrison, indicates a significant effect and, for extrapolation, a sizeable conceptual change [32].

$$r = \frac{Z}{\sqrt{N}} \quad \ldots(1)$$

where r = effect size statistic;
Z = absolute z-value from the Wilcoxon Signed Rank Test = 2.805
N = number of pairs of observations (items) = 10.

Graphical representation was also provided to visualize the change in the percentage of students who demonstrated misconceptions across the ten items in the ECT before and after the use of the ADDIE instructional design model, as shown in Figure 1.

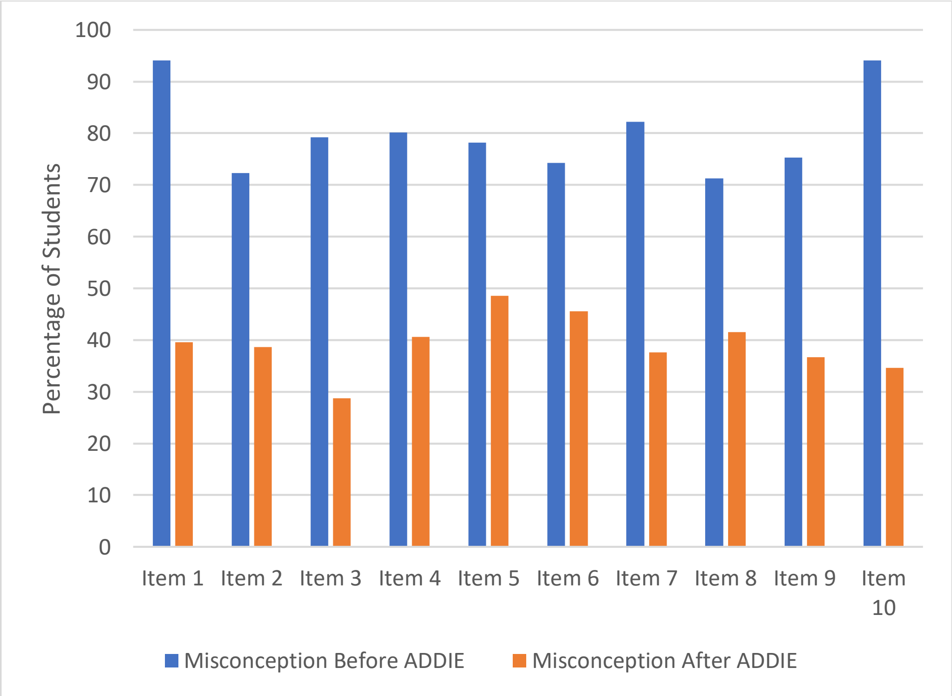

Figure 1. Percentage of students who demonstrate misconceptions about ECT items before and after exposure to the ADDIE model

Figure 4.1 shows that a higher percentage of students demonstrated misconceptions about all the items before the intervention than after the intervention. However, after introducing the ADDIE instructional design model, the percentage of students who demonstrated misconceptions about all items was significantly reduced, indicating that the students exhibited a conceptual change in electronic concepts, as shown in Figure 2.

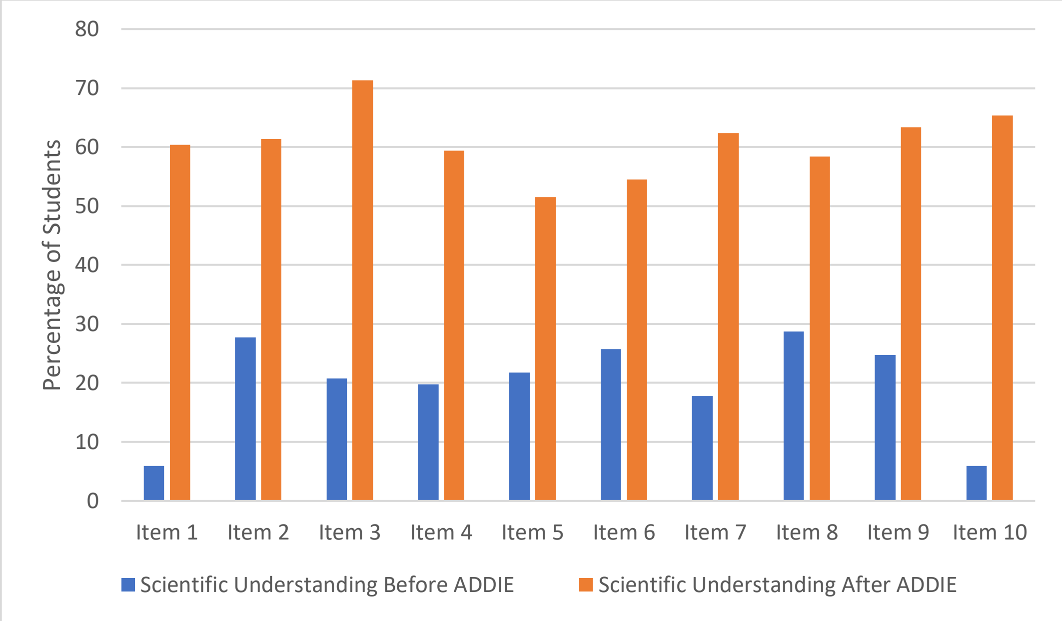

Figure 2. Percentage of students who demonstrate scientific understanding of ECT items before and after exposure to the ADDIE model

As shown in Figure 2, the percentages of students who had a scientific understanding of all elements of the Electronic Concepts Test were lower before using the ADDIE model, but after introducing the ADDIE model, the percentages of students who demonstrated a scientific understanding of electronic concepts increased for all elements.

Concerning this second aspect of the study, the significantly reduced percentage observed in students' misunderstanding and the significantly increased percentage of students who exhibited scientific understanding after the intervention could be interpreted as a conceptual change after using the ADDIE instructional design to teach electronics. Specifically, the significant effect size reported in this study means that the ADDIE instructional design model significantly contributed to promoting the conceptual change of SHS physics students in the electronics concepts considered in this study. This finding agrees with Alnajdi, Moral et al., Li and Abidin, Sarkodie, Sial, et al., and Asuncion, who found similar results and concluded that the use of ADDIE as a teaching method has positive effects on student performance [16]-[18], [24]-[26]. The reason for this positive effect observed from the use of the ADDIE model on the conceptual change of the students was that the ADDIE instructional design ensures that the students felt about the material through concrete experiences, as well as supplementing teaching and learning with audio and visual resources, such as videos and tutorials [21]. While previous studies focused on overall academic performance, with an apparent scarcity of studies focusing on physics students using the ADDIE instructional design model, this study focused on enhancing conceptual change, thereby revealing the misconceptions students demonstrate in electronics. This study adds to the body of knowledge in literature by providing evidence to support the ADDIE instructional design model, particularly in enhancing the conceptual change of SHS physics students in the Tano North Municipality.

One of the limitations of this study stems from the fact that it was restricted to only final-year SHS physics students in the Tano North Municipality. As a result, the study's findings cannot be extrapolated to other physics students in the municipality and other districts or municipalities in Ghana. Furthermore, the effectiveness of the intervention would have been fully understood if in-depth opinions from participants had been collected on using the ADDIE instructional design model to enhance their conceptual change in electronics concepts. Therefore, it is recommended that further studies should be conducted in different geographical areas and at different educational levels by soliciting students' opinions on the use of the ADDIE instructional design model in teaching and learning.

4. CONCLUSION

Based on the findings of this study, it can therefore be concluded, though cautiously, that the utilization of the ADDIE instructional design model could be effective in enhancing conceptual change of final year SHS physics students in the teaching and learning of electronics concepts in the Tano North Municipality. Subsequently, the researchers recommended the ADDIE instructional design model to SHS physics teachers in the Tano North Municipality who wish to reduce their students' misconceptions about electronics concepts.

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