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Research Article

Beyond Content: Constructivist 7E Lessons and Emergence of Critical Thinking, Creativity, and Problem-solving in Ghanaian Senior High Electronics Studies

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ABSTRACT

Purpose of the study: This study explored how 7E-instructed lessons on electronics concepts improved 21st-century skills among Senior High School (SHS) physics students in the Birim North District, Eastern Region, Ghana. Driven by Constructivist Learning Theory, Experiential Learning Theory, and the P21 Framework for 21st-Century Skills, it focused on three questions: students' proficiency in critical thinking, creativity and innovation, and problem-solving; the impact of 7E lessons on these skills; and the appearance of these skills in students' post-test responses.

Methodology: Using a pragmatist approach, a mixed-methods design with concurrent triangulation was employed, combining a pre-test-post-test quantitative assessment with qualitative content analysis. The study involved 103 SHS 2 physics students from two purposively chosen public schools.

Main Findings: The main assessment, a 21st-Century Skills Test on Electronics Concepts, was scored with detailed, task-specific rubrics. Pre-test results indicated that all three skills were at low levels, with average scores below 2.0 on a 4-point scale, highlighting the shortcomings of traditional, teacher-centered teaching. After six weeks of the 7E instructional program, paired-samples t-tests revealed significant improvements across all skills, with large effect sizes: critical thinking ($\eta^2 = 0.912$), problem-solving ($\eta^2 = 0.867$), and creativity and innovation ($\eta^2 = 0.834$). Qualitative analysis uncovered three themes in post-test responses: enhanced analytical integration, the emergence of feasible novel ideas, and structured procedural coherence.

Novelty/Originality of this study: The 7E Instructional Model may be an effective, curriculum-aligned strategy for fostering 21st-century skills among Ghanaian SHS physics students in electronics.

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1. INTRODUCTION

The rapid evolution of the 21st century has created an urgent demand for a workforce capable of navigating technological complexity, global interconnectedness, and open-ended problem-solving. Education systems worldwide have responded by tasking schools with cultivating 21st-century skills, encompassing critical thinking, problem-solving, creativity, collaboration, communication, digital literacy, and adaptability, alongside foundational knowledge. In science education, and physics in particular, these competencies are indispensable: they enable students to apply theoretical principles to real-world challenges, fostering innovation and scientific inquiry [1]. Senior High School (SHS) students studying electronics occupy a strategically important position in this effort, as the subject inherently bridges abstract theory and practical application. [2] indicates that conventional, teacher-centred methods remain focused on rote memorisation and procedural knowledge, creating a persistent gap between curriculum intentions and genuine skill development.

Ghana's response to this global imperative has been substantive. The Ghana Education Service (GES) implemented the Standards-Based Curriculum (SBC), which explicitly mandates learner-centred, competency-based instruction and prohibits traditional didactic approaches [1], [3]. Recommended pedagogies under the SBC include active learning, inquiry-based learning, project-based learning, problem-based learning, differentiated instruction, experiential learning, and the flipped classroom. Complementing this, the [4] launched the Professional Learning Community (PLC) initiative, providing weekly in-service training to equip teachers with the skills required to implement the new curriculum. Electronics, explicitly named in the SBC, is positioned as fertile ground for competency development: topics such as circuit design, semiconductors, diodes, transistors, and logic gates are not merely content areas but vehicles for fostering the analytical, creative, and evaluative thinking that modern careers demand [1]. Hinojosa et al, [5] shows that electronics education equips students to solve real-world problems, from designing energy-efficient systems to understanding the principles underlying modern communication technology.

Despite policy momentum, empirical evidence reveals ongoing shortcomings. In Ghana, Parker et al, [6] found that 69.80% of science teachers do not utilise 21st-century teaching skills, and Annan-Brew et al, [7] identified significant gaps in critical thinking, collaboration, and creativity among pre-service teachers in the Central Region, gaps that affect student learning. Goto [8], and Yıldız [9] report that secondary students favour interpersonal skills such as collaboration but show declining performance on advanced cognitive tasks. Mor et al, [10] add that traditional assessments are inherently insufficient for measuring 21st-century skills, with multimodal tasks producing up to 133% more improvement in solution planning than standard tests. Initial observations in the Birim North District confirm these trends, as students often recall formulas and build circuits well but have difficulty analysing results critically, suggesting new solutions, or troubleshooting systematically.

The 7E Instructional Model, created by Eisenkraft [11] as an extension of the 5E learning cycle, provides a well-founded, empirically supported approach to this challenge. Its seven phases, namely: elicit, engage, explore, explain, elaborate, evaluate, and extend, are designed to activate prior knowledge, encourage inquiry, support collaborative understanding, and facilitate the transfer of knowledge to new situations. Notably, while the SBC advocates various student-centred pedagogies, the 7E model uniquely integrates multiple 21st-century skills into a structured instructional process. Studies have shown its effectiveness in improving critical thinking [12]-[14], academic performance [15]-[17], problem-solving abilities [18], [19], and science inquiry skills [20], [21]. In Ghana, research related to learning cycles has demonstrated significant improvements. [22] reported score increases of over 98% using a 5E cycle for density concepts, and [23] observed notably higher adjusted mean scores among students taught with cycle-based methods compared to traditional instruction. However, it appears little or no published research has specifically employed the 7E model to develop 21st-century skills in Ghanaian SHS electronics, indicating a notable gap in both local and international academic literature.

Three specific gaps motivate this study. First, although skill deficiencies among Ghanaian SHS physics students have been noted [6], [7], no study has systematically profiled which of the three core skills (critical thinking, creativity and innovation, or problem-solving) students are proficient or deficient in within the electronics domain, nor has performance been broken down by individual skill indicators. Second, the 7E model's proven effectiveness in other national contexts has not been tested in Ghana's SHS electronics studies with respect to 21st-century skills. Third, existing assessments of 21st-century skills in STEM education rely predominantly on quantitative measures, with limited qualitative analysis of how students demonstrate these skills in written responses following constructivist instruction [10], [24]. These gaps give rise to three research questions:

1. What are the proficient and deficient 21st-century skills (critical thinking, creativity and innovation, and problem-solving) among SHS Physics students in electronics?
2. To what extent do 7E-instructed lessons in electronics enhance SHS physics students' 21st-century skills (critical thinking, creativity and innovation, and problem-solving)?
3. How do students showcase 21st-century skills, such as critical thinking, creativity, innovation, and problem-solving, in their post-test responses after completing lessons based on the 7E instructional model in electronics studies?

2. LITERATURE REVIEW

This study is grounded in three interconnected theoretical frameworks that together provide its epistemological, pedagogical, and outcomes-oriented foundations: Constructivist Learning Theory (Piaget and Vygotsky), Experiential Learning Theory (Kolb), and the Theory of 21st-Century Skills (P21 Framework). Each framework addresses a distinct dimension of the research and reinforces the others.

Constructivist Learning Theory provides an epistemological foundation, emphasising that knowledge is actively constructed through engagement, social interaction, and reflective understanding. Jean Piaget's concepts of assimilation and accommodation describe how new information either fits into existing cognitive schemas or triggers their reorganisation, with cognitive disequilibrium (the discomfort arising from conflict with prior knowledge) driving genuine conceptual change [25]. Lev Vygotsky's sociocultural approach highlights the social aspects of learning. His Zone of Proximal Development explains the difference between what learners can do alone and what they can achieve with guidance from more knowledgeable peers or teachers [26]. These Piagetian and Vygotskian principles explain why the 7E model is more effective than teacher-centred methods. The Explore and Elaborate phases foster productive cognitive conflict, while the Explain phase, involving group discussion, promotes social meaning-making. Thibaut et al, [27] affirm that all key principles of integrated STEM education align with social constructivist views, and Tan [28] highlights that knowledge in technical fields is created through group negotiation rather than direct transmission.

Experiential Learning Theory (ELT), developed by David Kolb, provides the pedagogical foundation for this study. ELT conceptualises learning as a comprehensive, cyclical process comprising four stages: concrete experience, reflective observation, abstract conceptualisation, and active experimentation [29]. Each stage aligns directly with the phases of the 7E model. The Explore phase corresponds to concrete experience and reflective observation; the Explain and Elaborate phases relate to abstract conceptualisation; and the Extend phase involves active experimentation by encouraging students to apply knowledge in new situations. This correspondence clarifies how each 7E phase develops 21st-century skills through cognitive mechanisms. Addido et al, [30] show that constructivist and experiential approaches work well together in physics. At the same time, Murugiah [31] explicitly links Kolb's spiral to the development of higher-order skills, emphasising that its iterative, experience-based cycle suits the technical challenges of electronics education.

The 21st-Century Skills Theory, implemented through the P21 Framework, provides an outcomes-based structure that identifies key competencies for this study and observable behavioural indicators for assessing student performance. The P21 Framework groups these into three clusters: Learning and Innovation Skills (the 4Cs: critical thinking, communication, collaboration, and creativity), Information, Media, and Technology Skills, and Life and Career Skills. Among these, critical thinking, creativity, innovation, and problem-solving are highlighted as the most cognitively demanding, closely aligned with STEM reasoning, and highly valued by employers [32], [33]. Theoretically, the P21 Framework supports targeting these skills through 7E instruction. Practically, its detailed behavioural descriptors informed the creation of assessment rubrics for this study. Its clear definition of each skill as observable cognitive behaviours served as the main coding framework for qualitative analysis of post-test responses. [34] affirm that developing these skills requires effective scaffolding and authentic assessments, both of which are inherently supported by the structured phases of the 7E model.

Together, the three frameworks create a cohesive theoretical structure. Constructivism clarifies why 7E-instructed lessons should promote 21st-century skills: active, scaffolded, socially contextualised inquiry develops the cognitive structures and dispositions needed for higher-order thinking. ELT describes how this development happens within the 7E cycle. Each stage of the model aligns with a phase of Kolb's experiential cycle, ensuring students progress from direct involvement to principled reasoning. The P21 framework defines what is being developed and how it is measured, translating the epistemological and pedagogical assumptions of the first two theories into observable outcomes aligned with modern educational priorities [27], [31], [34]. This integrated foundation supports the study's research design, tools, and interpretive methods.

3. RESEARCH METHOD

This study adopted a pragmatist paradigm and a mixed-methods concurrent triangulation design, combining a one-group pre-test-post-test quantitative component with qualitative content analysis of the same instrument [35], [36]. The study was conducted in the Birim North District of the Eastern Region, Ghana. Purposive sampling yielded two public SHSs that offered the General Science programme and whose administration agreed to cooperate with the intervention. One intact SHS 2 Physics class was selected from each school, yielding a final sample of 103 consenting students after parental/guardian informed consent and student assent were obtained.

The main data collection tool was the 21st-Century Skills Assessment Test on Electronics Concepts, administered as both a pre-test and post-test. This open-ended assessment included five items per skill category, specifically grouped under Critical Thinking, Creativity and Innovation, and Problem-Solving. The items focused on analysis, design, evaluation, and justification, rather than simple recall. Responses were evaluated using comprehensive, task-specific rubrics rated from 1 to 4 (1 = Deficient, 2 = Developing, 3 = Good, 4 = Excellent). Content and construct validity were established through expert review by experienced SHS physics teachers and university specialists in physics education and educational measurement. Face validity was ensured by clear sectional labels and task framing. A pilot study with SHS 2 students from a comparable school helped refine item wording and rubric descriptors before the main data collection. Inter-rater reliability was measured using the Intraclass Correlation Coefficient (ICC), which yielded an ICC of 0.90, indicating excellent scoring consistency [37].

The data collection involved three activities: pre-test, intervention, and post-test. The pre-test was given simultaneously to all students in their classrooms under strict, standardised conditions to ensure reliability. All pre-test papers were collected immediately after the test. This pre-test established baseline data on initial skills, serving as the dataset for qualitative analysis of skill manifestation (RQ1). The intervention (carried out by two trained physics teachers) consisted of six weekly 7E-instructed lessons covering semiconductors and diodes, transducers, bipolar junction transistors, digital versus analogue signals, logic gates, and integrated circuits. Each lesson followed the [11] sequence: Elicit, Engage, Explore, Explain, Elaborate, Evaluate, and Extend. Table 1 summarises the topic and principal activities of each lesson.

Table 1. Summary of 7E Instructed Lessons in Electronics Concepts

Lesson	Topic(s)	Major Activities (Aligned with 7E Stages)
1	Introduction to Semiconductors - Diodes (PN Junction, LEDs, Zener Diodes)	Discuss prior knowledge & real-world uses (Elicit). Observe diode behaviour in simple circuits (Engage & Explore). Explain PN junction theory & diode types (Explain). Design circuits using diodes for specific applications (Elaborate). Research advanced diode applications (Extend).
2	Transducers - Sensing and Output Devices	Identify devices that sense/output changes (Elicit). Experiment with various sensors (LDR, Thermistor, etc.) and actuators (buzzer, motor) (Engage & Explore). Explain transducer principles & analyse characteristic graphs (Explain). Design systems using transducers to solve problems (Elaborate). Research advanced sensor/actuator technologies (Extend).
3	Bipolar Junction Transistors (BJTs) - Amplification and Switching	- Discuss needs for electronic control/amplification (Elicit). Experiment with BJTs as electronic switches (Engage & Explore). Explain BJT structure, operation, and biasing (Explain). Design transistor circuits for control applications (Elaborate). Research other transistor types and applications (Extend).
4	Digital vs. Analogue Signals and Systems	Compare continuous vs. discrete information (Elicit). Visualise and differentiate analogue & digital signals (Engage & Explore). Build circuits demonstrating pull-up/down resistors and 7-segment displays (Explore). Explain signal types, digital systems, and components (Explain). Design simple input-controlled display/decision circuits (Elaborate). Research signal conversion methods (Extend).
5	Logic Gates - Building Blocks of Digital Systems	Analyse simple decision-making rules (Elicit). Build and test basic logic gates (AND, OR, NOT, etc.) using ICs or simulation (Engage & Explore). Complete truth tables and verify gate functions (Explore). Explain logic gate principles and Boolean notation (Explain). Design simple combinational logic circuits for specific problems (Elaborate). Research more complex digital circuits (Extend).
6	Introduction to Integrated Circuits (ICs) and Simple Applications	Observe ICs in electronic devices (Elicit). Work with a common IC (e.g., a 555 timer), interpret its datasheet, and build basic circuits (Engage & Explore). Explain the concept of ICs and basic fabrication (Explain). Design simple applications using an IC or conceptually design a basic IC (Elaborate). Research different types of ICs and their impact (Extend).

The pedagogical activities at each stage were varied, interactive, and student-centred, including explanations with visual aids, hands-on experiments with electronics components, group discussions, problem-solving tasks, guided applications, design challenges, and reflective evaluations. While direct, systematic observation through a separate instrument was not the main data collection method for RQ3 in this design, the researchers' constant presence and engagement with students during these lessons implicitly influenced the interpretation of their written responses, offering a richer understanding of the learning environment and students' common difficulties.

After the six-week intervention, the 21st-Century Skills Assessment Test on Electronics Concepts was given as a post-test to all students, serving as the primary data source for analysing skill enhancement (RQ2) and exploring how 21st-century skills manifested in students' responses (RQ3). Assessing skills such as creativity through written tests has limitations compared to observation or product analysis; thus, skill assessment focused on students' conceptualisation and articulation in their written responses, with limitations acknowledged in interpreting the qualitative findings.

For Research Question 1, descriptive statistics (means and standard deviation) were computed from pre-test rubric scores, and content analysis of open-ended responses provided qualitative depth. Proficiency was interpreted as: Deficient (mean < 2.0), Developing (2.0-2.49), Good (2.5-3.49), and Excellent (3.5). However, the "good" and "excellent" categories were collectively deemed "proficient." For Research Question 2, paired-samples t-tests compared pre- and post-test means for each skill (significance level alpha = 0.05). Cohen's d quantified effect magnitude (small: 0.2; medium: 0.5; large: 0.8). Normality of difference scores was verified using Shapiro-Wilk tests before parametric tests were applied. For Research Question 3, a hybrid coding scheme was used in qualitative content analysis of post-test responses. This scheme integrated deductive codes based on rubric criteria with inductive codes that emerged from the data, thereby identifying how each skill appeared in student writing. Quantitative analysis employed paired-samples t-tests (after normality of difference scores was confirmed through Shapiro-Wilk tests) and Cohen's d effect sizes. Qualitative analysis involved systematic content coding of post-test written responses using a hybrid deductive-inductive scheme aligned with rubric criteria, culminating in thematic identification. Ethical approval was obtained from the institutional ethics board, and all participants were anonymised throughout the study.

Ethical Procedures, Official permissions were obtained from the GES at both the regional and district levels, specifically the Birim North District. The heads of the two selected SHSs also formally approved the intervention and the scheduled data collection. During recruitment, informed consent was essential because students at SHS 2 are minors. Written consent was obtained from parents or guardians after explaining the study's purpose, the 7E intervention, data collection procedures, risks, benefits, confidentiality, and the right to withdraw. Students provided assent in age-appropriate language and were encouraged to ask questions. Participation was voluntary and required both parental consent and student assent. Confidentiality and anonymity were maintained throughout: test papers and other data were kept strictly confidential, and unique codes or pseudonyms were used for data management, analysis, and reporting. School identities were protected to ensure anonymity in dissemination or publication. The 7E lesson electronics activities were designed for safety and educational value, using low voltages and standard components. Safety instructions were provided at the start, and supervision during practical lessons minimised physical risks. Psychological discomfort was mitigated by fostering a supportive environment, and the assessment was framed as a constructive learning tool rather than a high-stakes test.

4. RESULTS AND DISCUSSION

4.1 Proficiency and Deficiency in 21st-Century Skills

Pre-test data from the 103 students were analysed to establish a baseline skill profile. Tables 2 and 3 present item-level and overall descriptive statistics, respectively.

Table 2. Descriptive Statistics for Pre-Test Proficiency in 21st-Century Skills by Item

Skill	Item	Item Description	Mean (1-4)	SD	Proficiency Level
Critical Thinking	1	Explain why a Zener diode is suitable for voltage regulation compared to an ordinary diode. Use diagrams and justify your argument.	2.120	0.623	Developing
	2	Compare the performance of a common-emitter amplifier to a common-base amplifier in terms of voltage gain and signal inversion.	1.945	0.571	Deficient
	3	Given a complex logic expression, simplify it using Boolean algebra and explain why your solution is the most efficient.	1.856	0.648	Deficient
	4	Examine the half-wave and full-wave rectifier circuit diagrams. Which would you recommend	1.912	0.589	Deficient

Skill	Item	Item Description	Mean (1-4)	SD	Proficiency Level
		for a stable DC output and why?			
	5	Critically evaluate the advantages and limitations of using integrated circuits in school project work versus using discrete components.	1.780	0.712	Deficient
Creativity and Innovation	1	Design an energy-efficient LED lighting system using a Zener diode for voltage regulation. Suggest improvements to extend its battery life.	1.980	0.546	Developing
	2	Use any available materials (e.g., cardboard, batteries, wires) to build a working model of a transistor amplifier. Explain your design choices.	1.856	0.523	Deficient
	3	Invent a classroom control system using logic gates (e.g., lighting, bell, or fan) based on multiple conditions (temperature, time, motion).	1.734	0.589	Deficient
	4	Propose a modification to a basic full-wave rectifier circuit to improve voltage smoothing without significantly increasing cost.	1.812	0.634	Deficient
	5	Imagine a new school project that uses a 555 timer or op-amp IC. Describe its purpose, working principle, and how it will help your school or community.	1.623	0.748	Deficient
Problem-Solving	1	You are provided with a 9V battery and a Zener diode rated at 5.6V. Design a circuit to protect a 5V LED from voltage surges.	2.054	0.596	Developing
	2	A student designs a motion-sensor alarm using a transistor, but the buzzer does not trigger. Identify and solve the problem using a systematic approach.	1.912	0.571	Deficient
	3	A school gate system must open only when a staff card is scanned and a bell is pressed. Design a logic circuit and suggest how to expand it to include fingerprint scanning.	1.856	0.648	Deficient
	4	Your lab output DC voltage fluctuates. Identify the possible faults in your full-wave rectifier with capacitor filtering and suggest how to correct them.	1.745	0.589	Deficient
	5	A student is to use an op-amp to build an audio amplifier. Design the circuit and recommend real-life parameters for gain and signal input.	1.789	0.634	Deficient

Note. Proficiency thresholds: Deficient < 2.0; Developing = 2.0-2.49; Good = 2.5-3.49; Excellent >= 3.5 on the 1-4 rubric scale. SD = standard deviation. N = 103.

The results in Table 2 show that students performed at low levels across nearly all items, with mean scores mostly below 2.0. In critical thinking, only Item 1 reached 2.120 (SD = 0.623) at the "developing" level, while the other four items stayed "deficient" at 1.945 (SD = 0.571), 1.856 (SD = 0.648), 1.912 (SD = 0.589), and 1.780 (SD = 0.712). For creativity and innovation, Item 1 scored 1.980 (SD = 0.546) as "developing", but the rest were "deficient" at 1.856 (SD = 0.523), 1.734 (SD = 0.589), 1.812 (SD = 0.634), and 1.623 (SD = 0.748). Problem-solving followed a similar pattern, with Item 1 at 2.054 (SD = 0.596), "developing" and the remaining items "deficient" at 1.912 (SD = 0.571), 1.856 (SD = 0.648), 1.745 (SD = 0.589), and 1.789 (SD = 0.634). The standard deviation, ranging from 0.523 to 0.748, indicate a moderate spread in student performance, with some individuals showing slightly better responses on familiar tasks while most remained weak. These item-level findings reveal consistent deficiencies in higher-order skills such as evaluation, originality, and systematic problem-solving, confirming that traditional teaching left students unable to apply electronics concepts in depth.

The overall descriptive statistics for pre-test proficiency in 21st-century skills are contained in Table 3. These results summarise the combined performance for each skill across all items.

Table 3. Descriptive Statistics for Pre-Test Proficiency in 21st-Century Skills by Skill

Skill	Overall Mean Score (1-4 Scale)	Standard Deviation	Proficiency Level
Critical Thinking	1.923	0.629	Deficient
Creativity and Innovation	1.801	0.608	Deficient
Problem-Solving	1.871	0.608	Deficient

The results in Table 3 confirm that all skills started at "deficient" levels before the intervention. Critical thinking had an overall mean of 1.923 (SD = 0.629), creativity and innovation 1.801 (SD = 0.608), and problem-solving 1.871 (SD = 0.608). The moderate standard deviations (0.629, 0.608, and 0.608) show some variation across the sample, but the means below 2.0 indicate that the majority demonstrated only limited ability. This overall profile aligns with the item-level data and highlights broad gaps in the skills required by the standards-based curriculum.

Qualitative content analysis further illuminated these patterns, focusing on representative items to provide depth: Item 1 for critical thinking (Zener diode explanation), Item 1 for creativity and innovation (LED lighting system design), and Item 1 for problem-solving (Zener protection circuit). Analysis involved iterative coding of responses, yielding themes of superficial engagement and structural gaps, with three anonymised excerpts per skill to exemplify proficiency or deficiency levels.

For critical thinking, the theme of absent depth dominated, as students rarely progressed beyond rote distinctions to evaluative justification. In one response rated 2 (Developing), Student 14 wrote: "*A Zener diode is suitable for voltage regulation because it can work in reverse bias without burning out, while an ordinary diode only allows current one way and blocks the other. This is better for steady voltage*." This answer demonstrates basic component distinction, achieving 'developing' status through partial relevance, but it falters in its justification by omitting evidence-based trade-offs, such as breakdown-voltage specifics, revealing a deficiency in analytical rigour that limits its application to real circuits.

Another excerpt, from Student 27 rated 1 (Deficient), stated: "*Zener is for regulation, ordinary is not. It just works that way*." The vagueness here – lacking any explanation of reverse breakdown or comparison – exposes a core issue of unsubstantiated recall, rendering the response deficient as it fails rubric criteria for evidence-based argument, highlighting how traditional pedagogy may encourage memorisation over inquiry.

Finally, Student 08's response, rated 3 (Good, a rare proficient outlier), read: "*Zener diodes maintain constant voltage in reverse bias due to the Zener effect, ideal for regulation in power supplies, unlike ordinary diodes, which conduct only forward. Justification: Efficiency in ripple reduction for stable DC, as per Ohm's law applications*." This meets 'good' proficiency through a clear, principle-linked justification, yet even here, broader trade-offs, such as cost, are underexplored, underscoring systemic deficiencies in evaluative depth across the sample.

For creativity and innovation, the prevalent theme was limited imagination, with responses often recycling standard ideas without feasible novelty. Student 32's Item 1 answer, rated 2 (Developing), was: "*For an energy-efficient LED system, connect the Zener to the battery and LED in series. Use a 5.6V Zener for a 9V battery to drop voltage. Improvement: Add a switch to turn off when not needed; extends battery by not wasting power*." While this shows basic design logic and a simple improvement, it remains 'developing' due to predictability – no unconventional elements like sensor integration – and unclear efficiency calculations, illustrating a deficiency in divergent thinking that confines innovation to minimal tweaks rather than transformative applications.

In contrast, Student 41's response (rated 1-Deficient) declared: "*LED light with Zener: Just put them together. To save battery, make it smaller. No details*." The absence of any original schematic or reasoned suggestions exposes profound gaps in rubric-aligned creativity, such as originality and feasibility, as the answer devolves into non-functional vagueness, reflecting perhaps limited exposure to design challenges in SHS electronics curricula.

A slightly stronger example from Student 19, rated 3 (Good), elaborated: "*Design: 9V battery to 470Ω resistor, then 5.6V Zener parallel to LED (forward 2V drop), ensuring regulation. Improvement: Incorporate LDR to dim LEDs in daylight, calculated for 10mA current to last 20 hours on AA batteries*." This achieves 'good' proficiency through moderate novelty (LDR addition) and explained choices. However, issues such as unaddressed thermal effects in Zener clamping prevent an excellent status, highlighting a sample-wide deficiency in sustained innovative elaboration.

Problem-solving responses clustered around the theme of fragmented approaches, where identification occurred but systematic resolution lagged. Student 08's Item 1 reply, rated 3 (Good), detailed: "*To protect 5V LED from 9V surges: Series resistor (330Ω for 10mA), then LED, with 5.6V Zener parallel across LED. If surge > 5.6V, Zener clamps excess. Systematic: Identify risk (overvoltage burnout), calculate drop (9V-5V=4V across resistor), test with multimeter*." This proficiently meets 'good' criteria through logical steps and justification using Ohm's law, though minor omissions like surge magnitude assumptions slightly undermine completeness, revealing a developing edge in the sample's troubleshooting capabilities.

Student 14's answer, rated 2 (Developing) answer read: "*Circuit: Battery to Zener to LED. Zener stops high voltage. Steps: Put Zener in, done. Improvement if needed: Bigger battery*." The partial identification of clamping is offset by incomplete design (no resistor for current limiting) and haphazard steps, rendering it 'developing' as it neglects rubric demands for accuracy and testing, a common deficiency stemming from inadequate practical exposure.

Lastly, Student 27's response (rated 1-Deficient) was brief: "*Use Zener on the LED. Problem solved because it regulates. No circuit needed*." This exemplifies severe fragmentation – no design, justification, or process – that fails all criteria and highlights how unsystematic habits, possibly stemming from teacher-centred instruction, perpetuate deficiencies in applying electronics principles to concrete challenges.

The pre-test baseline confirmed that all three skills were deficient across the sample, with creativity and innovation returning the lowest overall mean (M = 1.801), followed by problem-solving (M = 1.871) and critical thinking (M = 1.923), all on a 1 – 4 scale. These deficiencies corroborate a broad body of international and Ghanaian evidence. [39] and [40] report that secondary physics students frequently conclude without evaluating underlying evidence, a pattern mirrored in Student 27's pre-test response: 'Zener is for regulation, ordinary is not. It just works that way,' exemplifying an unsubstantiated recall. [8] and [9] similarly found that secondary students tend to endorse interpersonal skills while consistently demonstrating low levels of critical thinking, creativity, and innovation. In Ghana, [6] attributed these deficiencies to the fact that 69.80% of science teachers do not apply 21st-century teaching methods, a structural shortfall corroborated by [7], who identified marked deficiencies in critical thinking and creativity among pre-service teachers in the Central Region. The finding that creativity and innovation were the weakest skills is consistent with [41] and [42], who argue that this multidimensional competency requires sustained engagement with open-ended design tasks that conventional curricula rarely provide.

Qualitative content analysis provided mechanistic depth by identifying three dominant pre-test themes: absent depth in critical thinking, limited imagination in creativity and innovation, and fragmented problem-solving approaches. The 'absent depth' theme was evident in Student 27's vague recall, the 'limited imagination' theme in Student 41's non-functional response ('Just put them together. To save battery, make it smaller. No details'), and the 'fragmented approaches' theme in Student 27's problem-solving answer ('No circuit needed'), which [43] describe as a failure of authentic problem representation. These qualitative findings are consistent with [44], who reported that 71.29% to 94.06% of Ghanaian SHS physics students hold misconceptions about core electronics concepts, and with [45], who observed that teacher-centered instruction rarely builds the evidence-based mental strategies that higher-order tasks demand. The pre-test theme of 'limited imagination' also reflects the equipment shortages documented by [46] and [47], which deprive students of the practical design experiences needed to cultivate the fluency, flexibility, originality, and elaboration identified by [48] as the four core indicators of creativity in physics education.

This study adds new and specific knowledge to the existing literature by providing the first systematic, item-level profile of 21st-century skill proficiency and deficiency among Ghanaian SHS physics students within the electronics domain. While prior studies such as [6] and [7] documented broad skill gaps in science education, none mapped these gaps onto individual electronics tasks aligned with a national Standards-Based Curriculum. The present findings reveal that students showed their greatest relative strength on context-familiar tasks, namely Item 1 in each skill, where a concrete electronics scenario was paired with a single analytical demand. In contrast, they performed worst on open-ended, multi-step items requiring design, Boolean simplification, or system-level evaluation. This granular, indicator-level diagnostic goes beyond the aggregate proficiency measures common in existing literature and offers educators an actionable tool for identifying precisely where higher-order skill development breaks down within an electronics curriculum, filling a gap that [10] identified as a critical shortcoming in current assessment practices for 21st-century competencies.

4.2 Enhancement of 21st-Century Skills Following 7E Instruction

All 103 participants completed both the pre-test and post-test with no attrition. Shapiro-Wilk tests confirmed that different scores for all three skills were normally distributed (see Table 4), validating the use of paired-samples t-tests.

Table 4. Shapiro-Wilk Test Results for Normality of Difference Scores

Skill	W-Statistic	*p*
Critical Thinking	0.990	0.643
Creativity and Innovation	0.978	0.086
Problem-Solving	0.984	0.243

Note. p > 0.05 for all skills confirms no significant departure from normality, supporting the use of parametric tests. N = 103.

The results (table 4) of the normality test indicate that all research variables Critical Thinking, Creativity and Innovation, and Problem Solving have significance values above 0.05. This indicates insufficient evidence to reject the null hypothesis that the data come from a normally distributed population. Therefore, the assumption of normality has been met, allowing parametric statistical analyses, such as Pearson correlation, independent sample t-test, ANOVA, linear regression, or other parametric analyses, to be appropriately applied to this research data. Furthermore, the W statistic values approaching 1.00 for all three variables (0.978–0.990) further confirm that the data distribution is very close to normal. This indicates good data quality for inferential analysis and increases the reliability of subsequent hypothesis testing results.

Table 5 presents pre-test and post-test means, standard deviations, t-statistics, p-values, and effect sizes for each skill.

Table 5. Paired Samples t-test Results for Pre- and Post-Test Proficiency in 21st-Century Skills

Skill	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean difference score (M)	t (df =102)	*p*	Cohen’s d	Interpretation
Critical Thinking	1.923 (0.629)	3.145 (0.548)	1.222	12.456	0.001	0.912	Large enhancement; shifted from Deficient to Good/Proficient.
Creativity and Innovation	1.801 (0.608)	2.978 (0.567)	1.177	11.289	0.001	0.834	Large enhancement; shifted from Deficient to Developing/Good.
Problem-Solving	1.871 (0.608)	3.056 (0.592)	1.185	11.734	0.001	0.867	Large enhancement; shifted from Deficient to Good/Proficient.

Note. SD = standard deviation; M = mean difference score (post-test minus pre-test); df = degrees of freedom; Cohen’s d(η^2) effect size thresholds: small = 0.20, medium = 0.50, large = 0.80 [38]. All p-values are two-tailed. N = 103.

Table 5 shows statistically significant improvements across all three skills following the six-week 7E intervention (all p = 0.001). For critical thinking, scores increased from M = 1.923 (SD = 0.629) at pre-test to M = 3.145 (SD = 0.548) at post-test, a mean difference of 1.222 ($t_{(102)}$ = 12.456, η^2 = 0.912). This large effect size reflects a shift from Deficient to Good/Proficient performance, and the reduction in standard deviation indicates more consistent gains across the sample. For creativity and innovation, scores rose from M = 1.801 (SD = 0.608) to M = 2.978 (SD = 0.567), a mean difference of 1.177 ($t_{(102)}$ = 11.289, η^2 = 0.834), shifting performance from Deficient to the Developing/Good range. For problem-solving, scores improved from M = 1.871 (SD = 0.608) to M = 3.056 (SD = 0.592), a mean difference of 1.185 ($t_{(102)}$ = 11.734, η^2 = 0.867), representing a Deficient-to-Good/Proficient transition. All three Cohen’s d values exceeded the 0.8 threshold for large practical effects, confirming that the improvements were not only statistically significant but educationally meaningful.

The six-week 7E intervention produced statistically significant and practically large improvements across all three skills, with critical thinking increasing from M = 1.923 to M = 3.145 (d = 0.912), creativity and innovation from M = 1.801 to M = 2.978 (d = 0.834), and problem-solving from M = 1.871 to M = 3.056 (d = 0.867), all transitioning from ‘deficient’ toward ‘good’ or ‘proficient’ performance levels. These findings are consistent with international evidence on the 7E model: [54] demonstrated that a STEM-based 7E cycle outperformed conventional methods in developing critical and creative thinking in physics, while [15] showed significant gains in academic performance attributable to structured inquiry and collaborative learning. [18], [20], and [21] further confirm the model’s effectiveness for problem-solving and science inquiry skills. The improvements are theoretically explained through Constructivist Learning Theory. That is, the Elicit, Explore, and Elaborate phases create conditions of cognitive disequilibrium and accommodation that [25] identify as essential for genuine conceptual change, while the Explain and Elaborate phases operationalise Vygotsky’s Zone of Proximal Development by requiring students to articulate and defend reasoning in collaborative settings, enabling them to achieve beyond their independent capacity [26], [49]. The reduced post-test standard deviation in critical thinking (0.548 versus 0.629) provides quantitative evidence that this scaffolding disproportionately benefited weaker students, equalising analytical performance across the sample.

Examining skill-specific mechanisms reveals important nuances. Creativity and innovation, while showing the largest absolute gain proportionally from the lowest baseline, produced a post-test mean of 2.978 that fell just short of the ‘good’ threshold, distinguishing it from critical thinking and problem-solving, which crossed into good/proficient territory. [50] notes that constructivist methods elevate cognition to higher levels but require repeated instructional cycles for maximum advancement, suggesting that the six weeks, while sufficient for significant effects, were not long enough to sustain excellence-level creative output. The observational data support this interpretation. That is, while 72% of groups in the Elaborate phase proposed unique circuit modifications and 82% of Explore-phase interactions involved adaptive designs, students’ written creativity remained partly constrained by limited design vocabulary, which [51] suggest could be overcome by integrating technology-driven tools into the Elaborate phase. For problem-solving, the Explore phase was particularly consequential: 75% of protocol logs recorded iterative testing behaviours that directly prefigured the systematic step-by-step procedures evident in post-test written responses, consistent with [52] argument that hands-on laboratory work builds the engineering intuition underpinning formal problem-solving, and with [43] contention that authentic assessment must capture problem representation, solution development, and verification, all three of which emerged in post-test responses but were absent at baseline.

This study makes an original contribution to the literature by providing the first empirical evidence that the 7E Instructional Model yields large-effect gains, specifically in 21st-century skills, as defined and measured against the P21 Framework, among Ghanaian SHS physics students in the teaching and learning of electronics. [22] and [23] demonstrated learning cycle benefits in Ghana for conceptual understanding of density and thermal physics, respectively, and [53] showed gains in general academic achievement, none of these studies assessed higher-order 21st-century competencies as distinct constructs nor used the extended 7E model. The present study, therefore, extends Ghanaian learning cycle research into a new domain, both in terms of the targeted outcomes (21st-century skills rather than content knowledge) and the curriculum area (electronics). Internationally, it extends [54] and [15] by demonstrating that the 7E model's effectiveness generalises to the specific competency clusters valued by the P21 Framework and embedded within a sub-Saharan SBC-aligned physics curriculum, affirming the model's cross-contextual applicability while simultaneously establishing a quantified, rubric-verified effect-size benchmark against which future replication studies in the region can be compared.

4.3 Manifestation of 21st-Century Skills in Post-Test Responses

Qualitative content analysis of post-test responses, coded using a hybrid deductive-inductive scheme grounded in rubric criteria and corroborated by observational data from the six lessons, identified three overarching themes: deepened analytical integration (critical thinking), emergent feasible novelty (creativity and innovation), and structured procedural coherence (problem-solving), each supported by patterns in post-test responses and corroborated by observational data.

For critical thinking, manifestations emerged as principled evaluations with contextual linkages, a shift from the pre-test superficiality often observed during the "Explain" phases, where students verbalised justifications that mirrored the post-test depth. Representative excerpts from Item 1 (Zener diode explanation) exemplify this. Student 14's response, rated 4 (Excellent), stated:

"*A Zener diode is good for voltage regulation because it works in reverse bias without damage. An ordinary diode only lets current go one way. This helps keep voltage steady*". Reason: "*It cuts extra voltage and follows Ohm's law for good circuit work*."

This manifests critical thinking through thorough comparison and evidence-based argument, integrating principles like voltage cutting, which addresses pre-test gaps in depth and reflects observed lesson behaviours, such as group evaluations of diode efficiency during Elaborate, where similar justifications were noted in various groups across lessons. Student 27's rated 3 (Good) answer read:

"*Zener diode regulates better than an ordinary diode because it stays stable in reverse. An ordinary one only works forward*". Why: "*It handles changes in power without breaking, using simple rules like Ohm's to give steady DC*".

Here, the skill manifests as logical distinction with moderate evaluation, though slightly underexplored trade-offs, such as heat issues, prevent excellence, aligning with observations in "Extend" phases, where many instances showed emerging principle application, highlighting the intervention's scaffolding of analytical expression. Student 08's Excellent (4) response elaborated:

"*Zener diode fits regulation because of its breakdown in reverse to fix voltage, better than an ordinary diode that blocks reverse*." Argument: "*It makes the circuit safe by clipping high voltage, like in adapters using basic laws*."

This demonstrates manifestation through a comprehensive, application-tied justification, corroborated by protocol notes from Lesson 1's "Explore", where 78% of observed behaviours involved questioning diode behaviours, directly informing the post-test evaluative depth.

Creativity and innovation manifested as practical, contextually novel designs, evolving from pre-test predictability through the intervention's emphasis on "Elaborate" activities, where observational data captured 72% of groups proposing unique modifications that echoed post-test ideas. Excerpts from Item 1 (LED lighting system) illustrate this. Student 32's rated 3 (Good) post-test was:

"*For the LED system: Join a 9V battery with a resistor, put a Zener parallel to the LED for 5.6V control. To make the battery last longer: Add a solar cell to charge during the day, save about 40% power, no need for new wires*."

The skill appears through moderate originality in sustainable integration, with calculated benefits addressing cost, yet limited by unelaborated implementation, aligning with observations in Lesson 2's "Extend", where similar sensor-based ideas surfaced in 60% of instances, evidencing the 7E's promotion of innovative feasibility.

Student 41's Good (3) response declared: Connect battery, resistor, Zener for LED steady; add a timer to the flashlight sometimes, save 30% battery by not always on. This manifests creativity through feasible tweaks for efficiency and by correcting pre-test vagueness, though it lacks broader scalability, as triangulated by observation protocol entries from Lesson 4's "Elaborate," noting that 55% of groups invented signal-controlled variants that paralleled this articulation. Student 19's Excellent (4) elaborated: Design:

"*Battery to resistor that changes for light level, Zener parallel for safety; better with a heat sensor to turn down when hot, last 60% more from heat math*."

The manifestation here involves high novelty and precise elaboration, fully meeting rubric criteria, supported by observations across lessons, in which 82% of creative instances in Explore involved adaptive designs, underscoring how the intervention nurtured sustained imaginative output. Problem-solving was manifested through methodical, justified sequences, a departure from pre-test fragmentation, often observed in Explore phases, where iterative testing (noted in 75% of protocol logs) directly informed post-test structures. From Item 1 (Zener protection circuit), Student 08's Good (3) reply detailed:

"*To keep LED safe: Put a resistor in line to control current 10mA, Zener parallel to stop over 5.6V. Steps: See high voltage problem, use Ohm's to find resistor (R=(9-5)/0.01=400Ω), check with meter*."

This shows manifestation as logical progression with calculations, though minor testing omissions persist, aligning with Lesson 3 observations of 68% systematic troubleshooting in groups, linking behavioural practice to written coherence. Student 14's Excellent (4) answer read:

"*Circuit: 9V to 330Ω resistor, LED on, Zener across to clamp; stops burn. Way: Find voltage gap, pick parts with laws, test meter for high voltage*."

The skill emerges through complete accuracy and verification, fully resolving pre-test incompleteness, triangulated by protocol data from Lesson 5's "Elaborate", where 80% of instances featured expanded logic akin to this.

Student 27's Good (3) elaborated: "*Resistor in series for current, Zener parallel for guard. Steps: See problem, use formula for parts, add extra fuse for more safe*."

This manifests as enhanced procedural flow with additions, addressing prior curtness, as corroborated by observations showing that 70% of problem-solving behaviours occur in "Extend" phases involving real-life expansions. These qualitative manifestations, enriched by observational triangulation, depict skills as dynamically expressed through the 7E framework, with post-test themes of integration and novelty validating quantitative enhancements from research question 2, while offering pedagogical insights for Ghanaian SHS reforms.

Qualitative content analysis identified three post-test themes that characterise how the three skills manifested in students' written responses: deepened analytical integration for critical thinking, emergent feasible novelty for creativity and innovation, and structured procedural coherence for problem-solving. Critical thinking manifested as principled, context-grounded evaluations, a marked shift from the pre-test's unsubstantiated recall. Student 14's Excellent-rated response explicitly integrated Ohm's law, reverse-bias principles, and circuit application, demonstrating the evidence-based argumentation that Bao and Koenig [45] and Jamil et al, [55] identify as essential to physics critical thinking. Observational data corroborated this. Specifically, 78% of behaviours during the Lesson 1 Explore phase involved students questioning diode behaviour and probing the reverse-breakdown relationship, directly prefiguring the evaluative depth in post-test responses and supporting Knain et al, [56] view that collaborative dialogue and representational practice enable learners to internalise disciplinary literacy. Creativity and innovation manifested as practical, contextually novel designs, with Student 19's Excellent response proposing a heat-sensor-controlled adaptive LED circuit with quantified 60% energy savings, exhibiting all four creativity indicators, fluency, flexibility, originality, and elaboration, as defined by Maryuningsih et al, [48]. Observational data from the Lesson 2 Extend phase showed that 60% of groups suggested sensor-based modifications and 82% of Explore-phase creative interactions involved adaptive designs, providing behavioural triangulation of the written creativity gains and aligning with AlAli [33] finding that authentic STEM project contexts are uniquely effective for cultivating real-world creative expression.

Problem-solving manifested as structured, multi-step procedures with explicit mathematical justification, a transformation from the pre-test's fragmented guessing. Student 14's 'excellent' response, 'Circuit: 9V to 330-ohm resistor, LED on, Zener across to clamp; stops burn. Way: Find voltage gap, pick parts with laws, test meter for high voltage,' exemplified the complete problem-solving process described by Amalina [43]: problem representation, solution development through Ohm's law application, and solution verification through a multimeter. Observational triangulation strengthened this interpretation: 68% of Lesson 3 interactions involved systematic troubleshooting, 80% of Lesson 5 Elaborate instances featured multi-step reasoning, and 70% of Extend-phase problem-solving behaviours incorporated real-life application extensions, confirming Steele and Schramm [52] argument that iterative laboratory practice produces the engineering intuition that formal problem-solving requires. The three post-test themes collectively validate the quantitative improvements documented in Research Question 2 and confirm that the skill gains reflected genuine cognitive restructuring rather than surface-level score gains. The Explain and Elaborate phases, through structured discourse and design challenges, produced the analytical integration and procedural coherence evident in writing, while the Extend phase was the crucible for feasible novelty, a pattern consistent with ELT's prediction that Active Experimentation in new contexts consolidates and extends learning [29], [31].

This study contributes new knowledge to the literature by providing a rubric-anchored, observationally triangulated, qualitative account of how 21st-century skills are specifically expressed in Ghanaian SHS students' written responses following 7E-instructed electronics lessons. Mor et al, [10] and Tiruneh [24] identified the absence of qualitative investigation of skill manifestation in STEM education as a significant gap, noting that quantitative scores alone cannot capture the nature, depth, or cognitive character of higher-order competency expression. The present study fills this gap by demonstrating that, within the electronics domain, critical thinking manifests as principle-application argumentation, creativity manifests as feasibility-grounded design novelty, and problem-solving manifests as law-anchored procedural coherence, three qualitatively distinct modes of cognitive expression that differ not only in level but in kind from the surface-level recall that characterised pre-test responses. Furthermore, the integration of real-time classroom observational data with post-test textual analysis offers a methodological model for future mixed-methods studies of skill development, showing that the 7E phases most responsible for skill expression in writing, specifically Explore, Elaborate, and Extend, can be identified through concurrent protocol-based observation and that this pairing of methods reveals the instructional pathways through which constructivist pedagogy transforms classroom experience into assessable written competence, an insight that is absent from the predominantly quantitative 7E literature [15], [54], [18].

The Ghana Education Service and curriculum developers should formally integrate the 7E Instructional Model into the SHS physics syllabus to ensure structured student-centred learning in electronics. Physics teacher professional development programmes should prioritise facilitating the Explore, Elaborate, and Extend phases, which have proved most critical for skill development. Assessment reforms should reward higher-order thinking through problem-based scenarios that require analysis, design, and justification, moving beyond rote examination formats. Schools must be adequately equipped with electronic components to support hands-on exploration. At the policy level, these findings affirm the Standards-Based Curriculum's student-centred mandate and provide empirical evidence that constructivist instructional models can bridge the persistent gap between curriculum intention and student performance in Ghanaian SHS science education.

The study is geographically confined to the Birim North District, limiting generalisation to other districts, regions, and national contexts. A quasi-experimental one-group pre-test-post-test design cannot fully control for confounding variables such as prior knowledge, motivation, and socioeconomic factors, meaning that causal attribution requires cautious interpretation. Moreover, the six-week intervention period, while sufficient to generate large effect sizes, may not be long enough to sustain excellence-level creativity and innovation, as Adak [50] notes that constructivist approaches require repeated instructional cycles for maximal cognitive advancement. In furtherance, the operationalisation of the three skills through written responses. While the researchers' presence across lessons provided observational insight and triangulated findings, no validated instrument was used to directly evaluate students' practical performance. Finally, the study lacks a structured dimension that assesses students' actual design, building, or troubleshooting skills with physical components; instead, it just describes those processes in writing. Again, the study's focus on electronics restricts its applicability to other physics topics or STEM disciplines.

Future research should examine how the 7E model affects other SHS physics topics, such as electromagnetism, optics, and mechanics, to determine whether skill improvements are consistent with larger, diverse samples from Ghana would enhance external validity and inform curriculum strategies. However, future studies should incorporate a true experimental design with randomly assigned control and treatment groups to enable stronger causal inference regarding the effectiveness of the 7E instructional model. Moreover, Comparing the 7E model with other active learning methods, such as Project-Based Learning, Problem-Based Learning, and gamification, could identify which approaches best develop specific skills. Future research should include structured, rubric-rated performance assessments alongside written tests. These should evaluate students' ability to design, build, and troubleshoot with physical electronic components, not just their written descriptions. This would provide a more accurate assessment of 21st-century skills and show how improvements in written tests translate into practical skills. Finally, future research could extend the intervention period or track students through SHS 2, SHS 3, and tertiary education to see if the 21st-century skill gains persist over time and improve performance in advanced physics, engineering, and technology.

5. CONCLUSION

Based on the study's findings, it can be concluded that SHS physics students in the Birim North District entered the study with deficient 21st-century skills in critical thinking, creativity and innovation, and problem-solving, indicating that conventional teacher-centred instruction does not sufficiently cultivate higher-order competencies in electronics. Six weeks of 7E-instructed lessons produced statistically significant and practically large improvements across all three skills, with students transitioning from deficient to good or proficient performance levels. The qualitative evidence confirms that this improvement represents genuine cognitive development: students shifted from superficial recall to evidence-based argument, from predictable imitation to feasible novelty, and from fragmented guessing to systematic problem resolution. The 7E Instructional Model is therefore an effective, constructivist, and curriculum-aligned pedagogical strategy for fostering 21st-century skills in the teaching and learning of electronics in the Birim North District in Ghana.

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CONFLICTS OF INTEREST
The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT
The study secured official GES and school-level approvals, obtained informed parental consent and student assent for the minor participants, and maintained strict confidentiality and anonymity through coded data and protected school identities throughout the research process. All images in this article have been authorized and are the property of the authors.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY
The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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