



# Bridging AI-Assisted Learning and Conceptual Mastery in Genetic Engineering 11 with Active Science Through Responsible AI (ASTRA) Model

Roberto Jr. P. Tacobo, Regina S. Decayan, Angel Pitch R. Geronggay, Jan Erika Niña R. Lawas,

James Henry Vallezer, & Ruperto I C. Zabala

Davao Central College, Philippines

**Abstract:** This study examined the effectiveness of the Active Science Through Responsible AI (ASTRA) Model in enhancing Grade 11 students' conceptual mastery and responsible use of artificial intelligence in science learning. The model addresses the growing misuse of AI tools as shortcuts by promoting critical and ethical engagement through five cyclical phases: Assess, Search, Triangulate, Reflect, and Apply. Anchored on Piaget's Cognitive Constructivism and Vygotsky's Social Constructivism, ASTRA integrates Responsible AI Use (RAIU) as the core driver of cognitive and social learning. Using an action research design, the study involved 26 Grade 11 students from J.V. Ferriols National High School during the first semester of SY 2025–2026. Data were gathered through diagnostic tests, pre- and post-assessments, formative tasks, and an RAIU survey, analyzed using Repeated Measures ANOVA, T-Test, Correlation, and Regression. Results revealed significant improvements in Cognitive and Social Constructive Learning, with RAIU emerging as a strong predictor of learning outcomes. The study concludes that ASTRA effectively fosters critical thinking, collaboration, and ethical AI use in science education. It is recommended that the model be integrated into the curriculum and supported through teacher training and institutional initiatives for responsible AI-enhanced learning.

**Keywords:** Artificial Intelligence, ASTRA Model, Cognitive Constructivism, Responsible AI Use, Social Constructivism

**DOI:** <https://doi.org/10.31756/jrsmte.924>

## Introduction and Literature Review

### Context and Rationale

In today's classrooms, we have observed how many Grade 11 Senior High School learners misuse artificial intelligence tools by relying on them as shortcuts rather than as supports for deeper learning. Instead of fostering curiosity and critical thinking, these technologies are often used merely to generate ready-made answers, which students copy without reflection or comprehension. This practice leads to shallow understanding and prevents learners from truly mastering essential scientific concepts that are crucial for their academic and future success. If left unaddressed, this growing dependency threatens to weaken students' problem-solving skills and their ability to think independently. Therefore, it is urgent and necessary to conduct this study to ensure that AI integration in education truly empowers learners to engage actively and meaningfully with science.

### Action Research Questions

This study aims to determine the effectiveness of the Active Science Through Responsible AI (ASTRA) Model in enhancing Grade 11 students' science learning through responsible and meaningful integration of artificial intelligence tools. Specifically, it seeks to answer the following questions:

1. To what extent does the implementation of the ASTRA Model lead to a statistically significant improvement in students' science learning performance from pre-test to post-test in terms of:

- 1.1. Cognitive Constructive Learning?
- 1.2. Social Constructive Learning?
2. Is there a statistically significant difference in learning gains between students exposed to Cognitive Constructivist Learning (CCLG) and those exposed to Social Constructivist Learning (SCLG) under the ASTRA Model?
3. Does the implementation of the ASTRA Model result in a statistically significant improvement in students' Science Assessment (SA) scores from the diagnostic phase to the formative phase?
4. To what extent can Science Formative Assessment (SFA) be predicted by Cognitive Constructivist Learning Post-test (CCL Post) and Social Constructivist Learning Post-test (SCL Post) scores?
5. What is the level of Responsible AI Use (RAIU) among Grade 11 science students in utilizing the ASTRA Model during science learning activities?
6. Is there a statistically significant correlation among the core components of the ASTRA Model—Assess, Search, Triangulate, Reflect, and Apply?
7. To what extent can Responsible AI Use (RAIU) serve as a predictor of Cognitive Constructive Learning (CCL Post), Social Constructive Learning (SCL Post), and Science Formative Assessment (SFA)?

### **Proposed Innovation, Intervention, and Strategy**

The proposed innovation of this study is the Active Science Through Responsible AI (ASTRA) Model, a pedagogical framework designed to enhance scientific learning and responsible technology use among Grade 11 students. ASTRA is grounded on the principle that artificial intelligence (AI) tools should not replace learners' thinking but should instead augment it, guiding students to construct meaning actively and collaboratively (Muzakki et al., 2025). The model integrates Responsible AI Use as a catalyst for fostering both Cognitive Constructivist Learning (Guo et al., 2024) and Social Constructivist Learning (Richter et al., 2024), enabling students to become reflective, ethical, and independent learners in the digital age.

The ASTRA Model was developed to address the growing misuse of AI tools in classrooms, where learners often rely on automated outputs without reflection or comprehension. Through structured and purposeful engagement, ASTRA aims to transform AI use from a shortcut into a scaffold for deeper understanding and inquiry-based learning. It aligns with John Piaget's (1952) theory of Cognitive Constructivism, which emphasizes that learners build knowledge through active mental engagement, and Lev Vygotsky's (1978) Social Constructivism, which underscores learning through collaboration, dialogue, and shared meaning-making.

#### ***Process of the ASTRA Model:***

The ASTRA Model follows a structured five-phase process that guides students in using AI tools responsibly and productively during science instruction. Each phase develops both cognitive and social dimensions of learning, ensuring that AI integration promotes 4Cs of the 21<sup>st</sup> century: Critical Thinking, Collaboration, Creativity, and Communication.

**1. Assess (5 Minutes)**

In this phase, students perform a brief self-assessment or pre-test to activate prior knowledge and uncover misconceptions. This aligns with Piaget's Cognitive Constructivism (1952), emphasizing schema activation and readiness for new learning. By reflecting on what they know, learners build a foundation for deeper conceptual engagement.

**2. Search (5 Minutes)**

Students use AI tools and credible sources to gather information, guided by Responsible AI principles to ensure ethical and critical evaluation of data. This stage promotes Cognitive Constructivism, developing critical thinking and discernment. It also encourages Social Constructivism as learners discuss and compare AI outputs with peers.

**3. Triangulate (15 Minutes)**

Learners will create a concept map guided by a rubrics, and validate information by comparing AI outputs, textbooks, teacher guidance, and peer insights. This mirrors scientific inquiry and supports Vygotsky's Social Constructivism (1978) through collaborative reasoning within the Zone of Proximal Development. It strengthens understanding through evidence-based and socially mediated learning.

**4. Reflect (5 Minutes)**

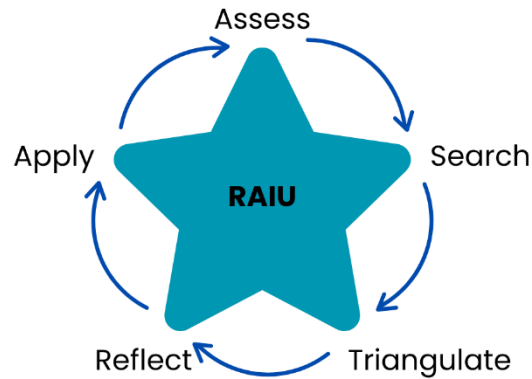
Students synthesize and evaluate their learning by journaling, mapping concepts, or group reflection. This embodies Cognitive Constructivism's metacognitive aspect, helping learners reorganize and internalize new knowledge. Shared reflection also aligns with Social Constructivism, fostering collective meaning-making.

**5. Apply (20 Minutes)**

Learners will have a group work where they apply their understanding through presentations using AI as a supportive tool. This phase reflects Social Constructivism, where learning is demonstrated and negotiated collaboratively. It bridges theory and practice, reinforcing comprehension and responsibility for learning outcomes.

***The Cyclical and Star-Shaped Nature of the ASTRA Model:***

Unlike traditional instructional models that follow a strictly linear sequence, the ASTRA Model is circular in nature and represented by a star-shaped framework which symbolizes the dynamic, interconnected, and recurring processes of scientific learning. Each of the five points of the star corresponds to one of the core phases: Assess, Search, Triangulate, Reflect, and Apply, which are not meant to occur only once or in a fixed order. Instead, learners may enter the cycle at any phase and continuously move between them as understanding deepens and new questions emerge.

**Figure 1***Active Science Through Responsible AI (ASTRA) Model*

The star shape signifies how each process radiates toward the others, illustrating that learning through responsible AI use is interactive, iterative, and integrative (3Is). For instance: the Reflect phase may lead back to a new Assess stage as students recognize new gaps in understanding. Also, during Apply, students may need to Search again for supporting information or Triangulate new evidence. Moreover, continuous reflection and collaboration keep the learning cycle active, ensuring that knowledge construction is never static.

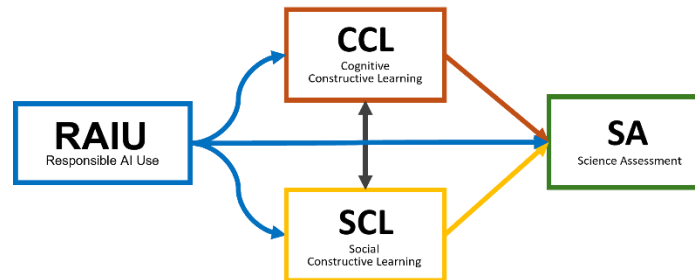
This circular structure aligns with the constructivist principle that learning is an ongoing process of building, testing, and reconstructing knowledge (Piaget, 1952). It also reflects Vygotsky's (1978) idea that social interaction and dialogue continuously reshape individual understanding within the Zone of Proximal Development (ZPD).

In this design, Responsible AI Use (RAIU) serves as the core center of the star, embodying the ethical and cognitive anchor that connects all learning processes. From the center, RAIU extends outward to each point of the star, energizing and guiding every phase. This placement reinforces that AI tools are not external add-ons but integral supports for active, reflective, and socially grounded learning.

### **Action Research Conceptual Framework**

The ASTRA (Active Science Through Responsible AI) framework rests on three foundational linkages, each supported by relevant literature. These linkages inform how we position Responsible AI Use (RAIU), Constructivist Learning (Cognitive & Social), and Science Achievement in our model.

As shown in Figure 2 (*ASTRA Conceptual Framework Simplified*), the model operates through a dynamic and recursive process anchored on Constructivist Learning Theories, specifically Piaget's (1952) Cognitive Constructivism and Vygotsky's (1978) Social Constructivism. These theories collectively emphasize that learners actively construct meaning through individual inquiry and social collaboration.

**Figure 2***ASTRA Conceptual Framework (Simplified)*

**Cognitive & Social Constructivist Learning.** The ASTRA model draws on Cognitive Constructivism (Piaget) and Social Constructivism (Vygotsky) as the philosophical and pedagogical bases of knowledge-building. Constructivist theory posits that learners actively construct knowledge by integrating new information into their existing mental structures (assimilation/accommodation) and through social interaction and scaffolding (Devries, 2004).

In particular, constructivist environments emphasize interaction, reflection, collaboration, and negotiation of meaning, features essential to ASTRA's triangulate, reflect, and apply phases. Research has shown that constructivist learning environments enhance motivation, strategy use, and deeper learning outcomes (Do et al., 2023). Additionally, Constructivist Approach of Evaluation Strategies in Science Education argues that evaluations aligned with constructivist learning should emphasize reasoning, explanation, and conceptual change rather than rote recall (Iofciu et al., 2012). Thus, in ASTRA, Cognitive Constructive Learning (CCL) represents the internal, individual meaning-making and reasoning processes, while Social Constructive Learning (SCL) represents the co-construction, negotiation, and interaction with peers (or AI as "scaffold") to refine ideas.

**Constructivist Learning towards Science Achievement.** A key assumption of ASTRA is that improvements in CCL and SCL will translate into better Science Achievement (or performance on assessments). This aligns with research showing that constructivist teaching and assessment approaches correlate with deeper understanding and improved science learning.

For example, *The Effect of Using the Constructivist Learning Model in Teaching Science on the Achievement and Scientific Thinking* found that constructivist-based instruction improved scientific thinking and content mastery in science classes (Qarareh, 2016). Constructivist theorists argue that assessment should be integrated with learning, offering feedback, opportunities for reflection, and tasks that require explanation and application rather than mere recalling of facts (Kumar, 2025). In ASTRA, the phases of reflect and apply intentionally bridge students' reasoning and collaboration to performance tasks and post-tests, thus linking learning processes to assessment outcomes.

**Responsible AI Use towards Constructivist Learning & Science Achievement.** The novelty of ASTRA lies in embedding a Responsible AI Use (RAIU) component as a driver of deeper learning. RAIU is conceptualized as ethically, critically, and thoughtfully interacting with AI tools rather than passively consuming AI outputs.

Recent work in AI and education supports this direction. The systematic review *Fostering Responsible AI Literacy* maps K-12 AI ethics education and emphasizes that learners should be guided to question, evaluate, and contextualize AI *outputs* rather than treat them as authoritative (Ma et al., 2025). Moreover, *Responsible AI in Education: Understanding Teachers' Priorities* explores educators' values (e.g. transparency, fairness) and how these inform responsible integration of AI in learning environments (Yin et al., 2025).

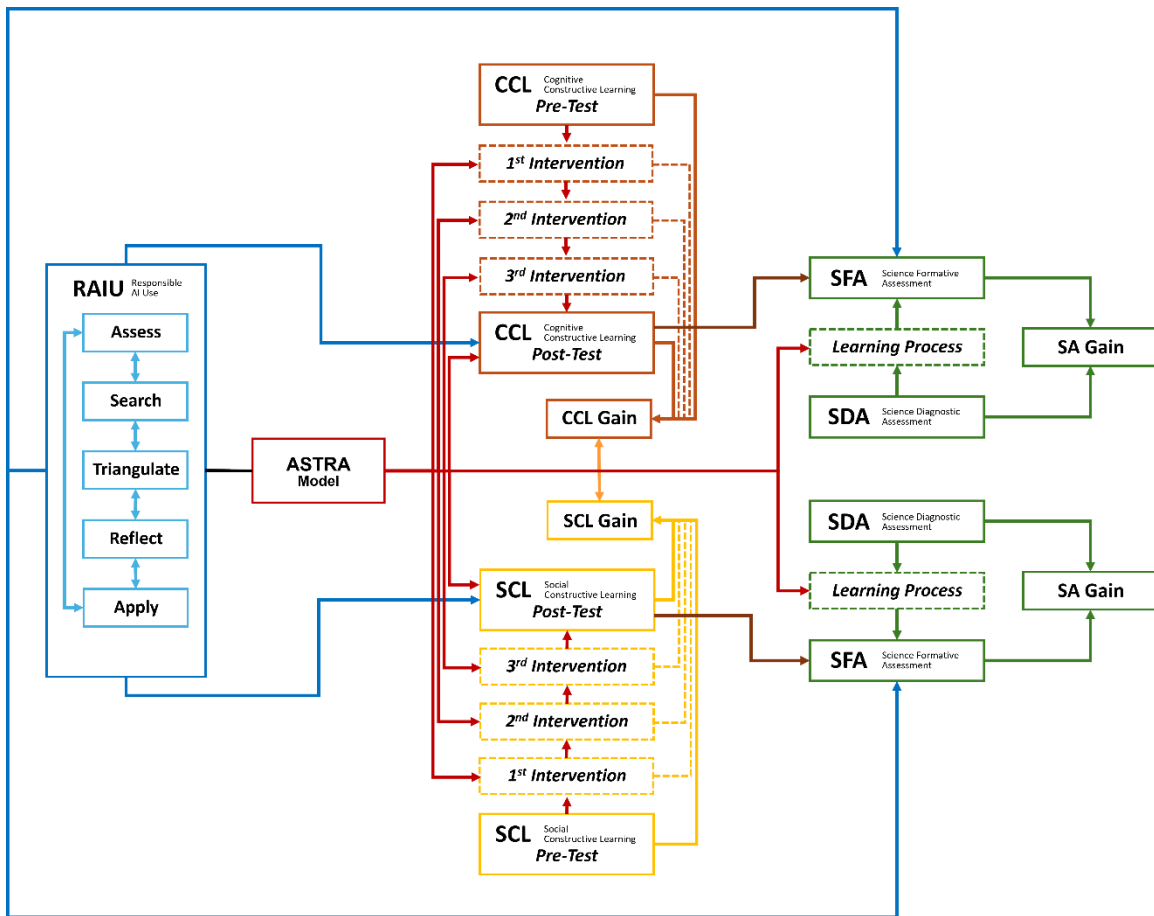
In higher education, studies like *Evaluating AI-Powered Learning Assistants* show that students' perceptions about AI ethics, trust, and usage patterns influence whether AI supports or undermines learning outcomes (Sajja et al., 2025). The landscape review *Navigating the Ethical Terrain of AI in Education* underscores the need for frameworks that guide responsible AI to support educational values (e.g., equity, agency, feedback) (Fu & Weng, 2024). Figure 3 presents the expanded version of the ASTRA (Active Science Through Responsible AI) Framework, which illustrates in greater detail how the variables interact throughout the implementation of the intervention. This version extends the simplified conceptual framework by highlighting where and how specific learning processes occur within the five core phases of the ASTRA Model: Assess, Search, Triangulate, Reflect, and Apply.

The framework further illustrates that both Cognitive and Social Constructive Learning Gains contribute to the improvement of Science Achievement, representing the dependent variable of the study. The double-headed arrows between CCLG and SCLG indicate their mutual reinforcement, cognition deepens through collaboration, and collaboration becomes meaningful through critical thinking. Thus, ASTRA posits that Responsible AI Use will enhance both Cognitive and Social Constructivist Learning (by promoting reflective inquiry, evaluation, and discourse) and thereby contribute to Science Achievement Gains. This expanded framework provides a clearer visualization of where each variable operates and interacts during the ASTRA intervention, demonstrating how Responsible AI Use drives both cognitive and social learning processes that lead to measurable gains in science achievement.

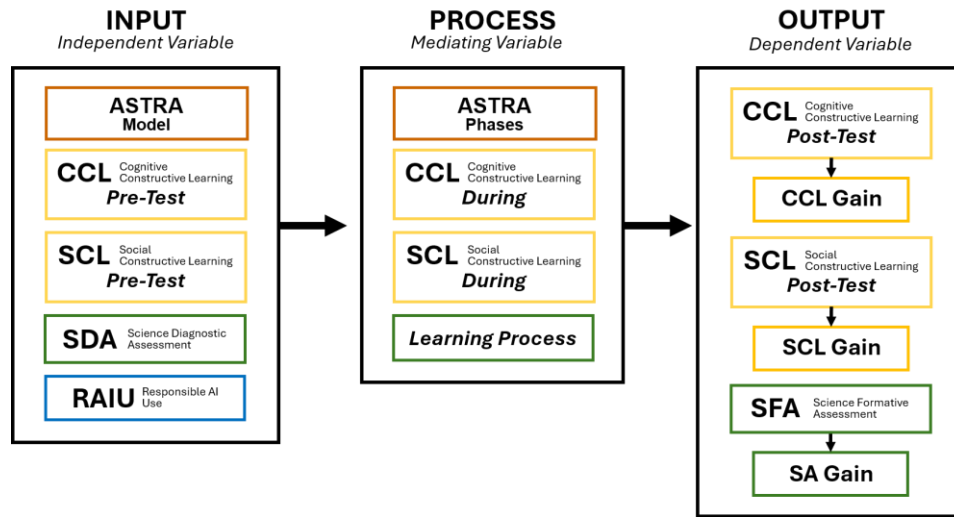
### **Action Research Paradigm**

The action research paradigm follows the Input–Process–Output (IPO) framework illustrating how the ASTRA Model (Active Science Through Responsible AI) enhances students' constructivist learning and science achievement. The Input phase includes the ASTRA Model as the main intervention, CCL and SCL Pre-Tests to assess baseline knowledge, Science Diagnostic Assessment, and Responsible AI Use (RAIU).

**Figure 3**  
*ASTRA Conceptual Framework (Expanded)*



The Process involves the five cyclical stages of the ASTRA Phases—Assess, Search, Triangulate, Reflect, and Apply—anchored on Piaget’s (1952) cognitive and Vygotsky’s (1978) social constructivism. These stages promote active knowledge construction, critical thinking, collaboration, and ethical AI use throughout the intervention. The Output presents the Cognitive Constructive Learning Gain (CCLG), Social Constructive Learning Gain (SCLG), and Science Achievement Gain (SAG) reflecting improved understanding, collaboration, and responsible engagement with AI tools. This paradigm highlights the dynamic and interconnected nature of the ASTRA Model as a cyclical framework promoting meaningful, responsible, and constructivist science learning.

**Figure 4***ASTRA IPO Paradigm*

### Action Research Methods

#### Participant and Source of Data

The participants of this study consisted of all Grade 11 Senior High School students from Section A at J.V. Ferriols National High School, who were enrolled during the first semester of the academic year 2025–2026. A census sampling technique was employed, involving all 26 students in the class to ensure a comprehensive evaluation of the Active Science Through Responsible AI (ASTRA) Model without sampling bias. The sample size was considered appropriate within the context of classroom-based action research, where the unit of analysis was naturally bounded to a single intact class. The study prioritized depth of intervention implementation and ecological validity over statistical generalizability. The primary sources of data were derived from multiple research instruments, including a Diagnostic Assessment, Cognitive Constructive Learning (CCL) Performance Tasks with rubrics, Social Constructive Learning (SCL) Performance Tasks with rubrics, Formative Assessments, and a Responsible AI Use (RAIU) Survey. These instruments were designed to measure students' conceptual mastery, constructivist learning competencies, and ethical engagement with AI tools. Full versions of these instruments were provided in Appendices C–G.

#### Research Instruments

This study utilized a set of researcher-developed and adapted instruments to capture both cognitive and behavioral dimensions of learning. The Diagnostic Assessment consisted of 15 multiple-choice items designed to measure students' prior knowledge of key scientific concepts in Genetic Engineering. The items were constructed based on the Most Essential Learning Competencies (MELCs) and were aligned with Bloom's Taxonomy, targeting both lower- and higher-order thinking skills.

The Cognitive Constructive Learning (CCL) Rubric-Based Assessment assessed students' conceptual understanding, knowledge construction, and ability to apply scientific concepts. The rubric consisted of five criteria rated on a four-point scale (1–Needs Improvement, 2–Fair, 3–Good, 4–Excellent). This instrument was grounded in constructivist learning theory, particularly the principles of active knowledge construction and cognitive engagement. The Social Constructive Learning (SCL) Rubric-Based Assessment evaluated students' collaborative learning, communication, and participation in group-based scientific tasks. The rubric included five criteria rated on a four-point scale (1–Needs Improvement, 2–Fair, 3–Good, 4–Excellent), measuring dimensions such as interaction, shared understanding, and co-construction of knowledge. This instrument was anchored in social constructivist theory, particularly Vygotsky's principles on social interaction and learning.

The Formative Assessments were administered periodically during the intervention and consisted of 15 multiple-choice items designed to monitor learning progress and provide immediate instructional feedback. The Responsible AI Use (RAIU) Survey consisted of four Likert-scale items using a four-point scale (1 = Strongly Disagree to 4 = Strongly Agree). The instrument measured students' awareness, attitudes, and behaviors related to ethical AI use, including transparency, accountability, and responsible engagement with AI tools. The survey was aligned with foundational AI ethics principles integrated within the ASTRA Model.

All instruments were either researcher-made or adapted based on established theoretical frameworks, including constructivist learning theory (Piaget), social constructivism (Vygotsky), and ethical AI use principles. The development process involved systematic item construction aligned with learning competencies and intended constructs. To establish content validity, the instruments were evaluated by three experts: one Science education specialist, one educational research expert, and one ICT/AI integration specialist. Each expert assessed the instruments based on clarity, relevance, alignment with objectives, and appropriateness for Grade 11 learners using a validation checklist. Feedback from the experts was consolidated, and necessary revisions were made to improve item clarity, alignment, and construct representation.

A pilot test was conducted with 30 Grade 11 students from J.V. Ferriols National High School who were not part of the actual participants. The pilot testing aimed to evaluate item clarity, difficulty level, and internal consistency. The results indicated that the instruments were clear, appropriate, and suitable for the target learners, leading to minor revisions prior to full implementation.

Reliability analysis using Cronbach's alpha yielded a coefficient of 0.87 for the RAIU Survey, indicating high internal consistency. For the rubric-based assessments (CCL and SCL), reliability was established through inter-rater agreement, where two independent raters evaluated a subset of student outputs, yielding an agreement rate of 91%, which indicated acceptable scoring consistency.

During pilot testing, item analysis was conducted to evaluate clarity, difficulty, and discrimination of test items. The results indicated that most items were of appropriate difficulty and were able to distinguish between varying levels of student performance. Items identified as unclear or potentially ambiguous were revised to improve wording and alignment with learning objectives. No items were removed after revision, as all were deemed suitable for final implementation.

Scoring procedures were established as follows: Diagnostic and Formative Assessments were scored based on the number of correct responses, with higher scores indicating greater conceptual mastery. CCL and SCL performance tasks were evaluated using rubric scores with a total possible score ranging from 5 to 20. The total scores were interpreted as follows: 5–8 (Needs Improvement), 9–12 (Fair), 13–16 (Good), and 17–20 (Excellent). RAIU Survey responses were averaged and interpreted as follows: 1.00–1.75 (Strongly Disagree), 1.76–2.50 (Disagree), 2.51–3.25 (Agree), and 3.26–4.00 (Strongly Agree).

### **Ethical Guidelines**

This study adhered to established ethical standards in educational research. Since the institution does not maintain a formal Institutional Review Board (IRB), approval to conduct the study was secured from the school principal and school administration prior to implementation. All procedures followed institutional research guidelines, including the acquisition of informed consent from both students and their parents or guardians, ensuring voluntary participation and the right to withdraw at any time without academic penalty. Confidentiality and anonymity of participants were strictly maintained throughout the study. All collected data—including assessments, surveys, and student outputs—were handled in compliance with the Data Privacy Act of 2012 (Republic Act No. 10173) and stored in password-protected digital files accessible only to the research team. Furthermore, ethical use of artificial intelligence was emphasized throughout the intervention, promoting transparency, accountability, and responsible engagement consistent with ethical AI principles.

### **Data Gathering Methods**

Prior to data collection, formal approval was obtained from the school principal. An orientation session was conducted to inform participants about the study's objectives, procedures, and ethical considerations. The data collection process began with the administration of the Diagnostic Assessment to establish baseline knowledge. This was followed by the administration of the CCL Pre-Test and SCL Pre-Test to determine initial levels of cognitive and social constructivist learning competencies. All instruments underwent verification and validation by experts prior to implementation.

During the implementation of the ASTRA Model, formative assessments were conducted periodically to monitor student progress and guide instructional adjustments. After the intervention, the CCL Post-Test and SCL Post-Test were administered to measure learning gains. Finally, the Responsible AI Use (RAIU) Survey was distributed to evaluate students' awareness and practices regarding ethical AI use.

### Data Analysis Plan

Data were analyzed using JASP statistical software with a significance level set at 0.05. Descriptive statistics, including mean and standard deviation, were used to determine students' levels of Responsible AI Use (RAIU). Paired sample t-tests were conducted to compare pre-test and post-test scores in science assessments, determining the effectiveness of the ASTRA Model in improving conceptual mastery. Repeated Measures ANOVA was employed to examine changes in Cognitive Constructive Learning (CCL) and Social Constructive Learning (SCL) over time and to compare the relative effects of the two learning dimensions. Pearson product-moment correlation analysis was used to explore relationships among CCL, SCL, and RAIU variables. Furthermore, multiple regression analysis was conducted to determine whether CCL Post-Test scores, SCL Post-Test scores, and RAIU levels significantly predicted students' science learning outcomes.

## Results and Discussions

This section presents the statistical analyses conducted to determine the effectiveness of the Active Science Through Responsible AI (ASTRA) Model in enhancing Grade 11 students' science learning. The results are organized according to the specific research questions, focusing on the students' performance in Cognitive Constructive Learning (CCL), Social Constructive Learning (SCL), Science Assessment (SFA), and Responsible AI Use (RAIU).

### Improvement in Students' Science Learning

#### *Cognitive Constructive Learning*

Table 1 explains the improvement of Cognitive Constructive Learning of students using ASTRA Intervention.

**Table 1**

*CCL Repeated Measures ANOVA Results*

Cases	Sum of Squares	df	Mean Square	F	p
Sessions	674.3 <sup>a</sup>	4 <sup>a</sup>	168.576 <sup>a</sup>	67.07 <sup>a</sup>	< .001 <sup>a</sup>
Residuals	251.3	100	2.513		

Table 1 depicts the repeated measures ANOVA of students' CCL scores across the ASTRA sessions. The associated effect was significant,  $F(4, 100) = 67.07$ ,  $p < .001$ , indicating that over time, there was a significant increase in students' cognitive engagement and knowledge construction. Furthermore, the large effect size confirms that 56% of the variance in CCL scores is contributed by the ASTRA intervention.

The finding also agrees with Piaget's Cognitive Constructivism of 1952, which puts forward the view that actively, learners construct knowledge through assimilation and accommodation. It furthers Do et al. (2023), who showed that constructivist learning environments enhance reasoning and strategy use, and Qarareh (2016), who found that constructivist-based science instruction enhances scientific thinking and achievement. The strength of this finding underlines ASTRA's capacity to operationalize principles of constructivism effectively, thereby yielding higher cognitive learning gains than is usually reported in conventional instruction.

**Table 2**

*CCL Post Hoc Comparisons - Sessions*

		Mean Difference	SE	df	t	P <sub>bonf</sub>
Pre Test	Plants	-0.436	0.570	25	-0.765	1.000
	Animals	-2.795	0.372	25	-7.517	< .001
	AnD	-3.782	0.297	25	-12.719	< .001
	Post Test	-6.215	0.294	25	-21.120	< .001
Plants	Animals	-2.359	0.463	25	-5.096	< .001
	AnD	-3.347	0.557	25	-6.006	< .001
	Post Test	-5.779	0.579	25	-9.983	< .001
Animals	AnD	-0.988	0.344	25	-2.874	.081
	Post Test	-3.420	0.414	25	-8.268	< .001
AnD	Post Test	-2.432	0.383	25	-6.354	< .001

*Note.* P-value adjusted for comparing a family of 10 estimates.

Bonferroni-adjusted post hoc comparisons of students' scores on Cognitive Constructive Learning across ASTRA sessions are shown in Table 2. Significant gains were present between almost all pairs of sessions, especially from pre-test to Animals, AnD, to post-test sessions (all  $p$ s < .001), most strongly between pre-test and post-test sessions with the largest mean difference ( $M_{diff} = -6.215$ ,  $p < .001$ ). These results imply consistent and progressive improvement in students' performance at the cognitive level during the treatment.

This is in line with Piaget's (1952) principle that cognitive development takes place through continuous restructuring of knowledge and corroborates Devries (2004) and Qarareh (2016), who reported that constructivist learning environments facilitate iterative conceptual development and scientific reasoning. Furthermore, Do et al. (2023) established that reflective, constructivist activities enhance deep learning, supporting the sustained development

which took place throughout ASTRA's successive stages. The sustained significance of CCL gains underscores strengths of the model for fostering enduring cognitive engagement rather than short-term recall.

These findings imply that the integration of Responsible AI Use within a constructivist pedagogy significantly enhances the conceptual understanding and reflective reasoning of students in science. Embedding iterative reflection and AI-supported inquiry within the ASTRA Model enables cumulative cognitive gains to be achieved, which highlights the importance of maintaining structured progression across sessions to reinforce assimilation and accommodation cycles. Further studies can investigate how the intensity and type of AI-mediated scaffolds influence various dimensions and rates of cognitive development over longer learning phases.

**Figure 5**

*Cognitive Constructive Learning Post Hoc*

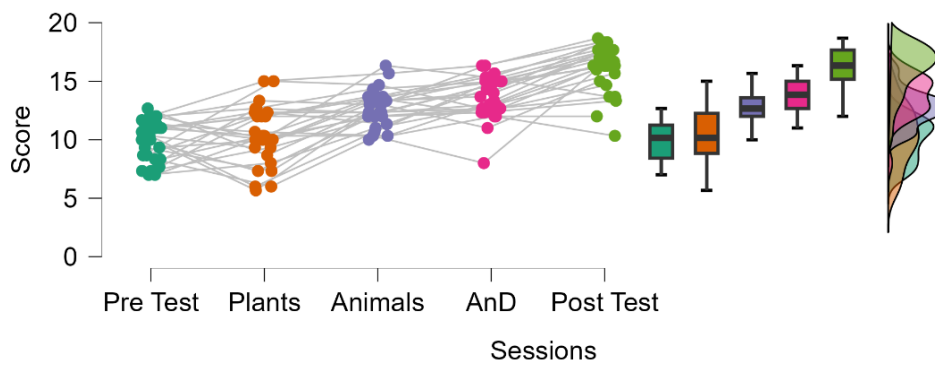


Figure 5 presents the steady increase in the CCL scores of the students from the pre-test to the post-test for the ASTRA Model. Most of the students consistently improve through each session, with scores getting higher and closer together at the post-test. This visual trend supports the fact that, over time, the ASTRA Model effectively enhanced the cognitive understanding and learning progression of the students.

***Social Constructive Learning***

Table 3 explains the improvement of Social Constructive Learning of students using ASTRA Intervention.

**Table 3**

*SCL Repeated Measures ANOVA Results*

Cases	Sum of Squares	df	Mean Square	F	p
Sessions	939.1	4	234.772	218.6	< .001
Residuals	107.4	100	1.074		

*Note. Type III Sum of Squares*

This result is in line with Lev Vygotsky's Social Constructivism, which states that knowledge is built by interaction, scaffolding, and dialogue in collaborative settings. Recent meta-analyses support this interpretation; for instance, cooperative and collaborative learning in science education has been shown to produce large positive effects ( $g \approx 1.07$ ) on student achievement and engagement (Yaşar et al., 2024). Furthermore, a 2023 study on the co-construction of knowledge and socio-emotional interaction in pre-service teacher education showed that a social constructivist design engenders deeper engagement in collaborative tasks (Lehtinen et al., 2023). The size of the effect from this intervention thus suggests that it not only aligns with prior evidence but may indeed be larger than that typically reported in collaborative-learning research.

**Table 4**

*SCL Post Hoc Comparisons – Sessions*

		Mean Difference	SE	df	t	p <sub>bonf</sub>
Pre Test	Plants	-3.002	0.400	25	-7.512	< .001
	Animals	-3.248	0.331	25	-9.824	< .001
	AnD	-4.068	0.296	25	-13.745	< .001
	Post Test	-8.348	0.119	25	-70.237	< .001
Plants	Animals	-0.246	0.391	25	-0.630	1.000
	AnD	-1.066	0.334	25	-3.188	.038
	Post Test	-5.346	0.323	25	-16.543	< .001
Animals	AnD	-0.820	0.059	25	-13.790	< .001
	Post Test	-5.100	0.224	25	-22.806	< .001
AnD	Post Test	-4.280	0.181	25	-23.597	< .001

*Note.* P-value adjusted for comparing a family of 10 estimates.

The Bonferroni-adjusted pairwise comparisons of the SCL scores of the students across the ASTRA Model sessions, as presented in Table 4, indicate an increase from pre-test to Plants, Animals, Advantages & Disadvantages, and post-test sessions (all  $p < .001$ ) and the largest mean difference between pre-test and post-test sessions ( $M_{diff} = -8.348$ ,  $p < .001$ ). Continuous observed gains between the intermediate sessions, such as from Plants → Post-Test or Advantages & Disadvantages → Post-Test, point to the sustained improvement in the students' collaborative and interactive learning behaviours throughout the intervention.

These results confirm that ASTRA substantially strengthened the social constructive learning dimension of the cohort over time. This pattern of enhanced social constructivist interaction coheres with the theory of Lev Vygotsky that posits knowledge is co-constructed through peer and scaffolded dialogue, negotiation, and meaning-making rather than passively acquired. Recent meta-analytic evidence concerning collaborative and cooperative learning in science and STEM contexts provides robust positive effects, such as  $g \approx 1.07$  concerning cooperative learning in science education, on student engagement and achievement (Yaşar et al., 2024). The magnitude and consistency of the SCL gains in this study therefore not only replicate but arguably exceed typical outcomes from standard peer-interaction frameworks.

In practical terms, these results suggest that embedding structured, socially interactive phases—such as joint inquiry, peer negotiation, and collaborative reflection—within the ASTRA Model can substantially enhance students’ social constructive learning behaviors in science. Educators are encouraged to design sessions that emphasize the “triangulate” and “reflect” phases as opportunities for scaffolded peer discourse, negotiation, and co-construction of ideas through AI-mediated tools. Future research may investigate how variations in AI-mediated peer scaffolding, group composition, or timing of social prompts influence the trajectory and sustainability of social constructive learning gains.

**Figure 6**

*Social Constructive Learning Post Hoc*

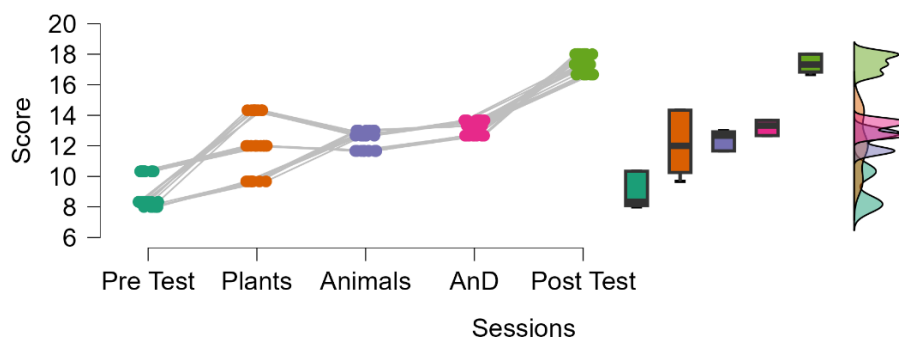


Figure 6 depicts a consistent upward trend in the students' SCL scores from pre-test to post-test through the implementation of the ASTRA Model. The upward pattern in all sessions indicates that students showed progressive development in collaboration, discussion, and shared problem-solving. This visual evidence supports that the ASTRA Model indeed strengthened the students' social engagement in cooperative learning over time.

### Significant Differences between CCL and SCL

Table 5 discusses the results of significant differences between CCLG and SCLG under ASTRA Intervention.

**Table 5**

*Repeated Measures ANOVA between CCL Gain and SCL Gain*

		Mean Difference	SE	df	t	p <sub>holm</sub>
CCLG	SCLG	-2.134	0.323	25	-6.604	< .001

Comparisons of learning gains between students exposed to the CCL and SCL under the ASTRA Model are shown in Table 5. The results revealed a significant difference,  $t(25) = -6.60$ ,  $p < .001$ , that SCL produced higher learning gains than CCL. From this result, it is inferred that collaborative and interactive learning processes effectively contributed much more to conceptual understanding and performance in science learning.

This outcome corroborates Vygotsky's Social Constructivism from 1978, articulating that knowledge is cosocially constructed through social interaction and scaffolding. Similarly, the works of Do et al. (2023) and Iofciu et al. (2012) showed that constructivist environments that embed collaboration and reflection lead to deeper learning and achievement. The stronger effect of SCL seen herein emphasizes the potential for the ASTRA Model to improve learning outcomes due to socially mediated engagement with the support of AI facilitation in a responsible way.

In other words, these results highlight the importance of embedding ASTRA into a scaffold of peer interaction and reflective discourse. By facilitating equal participation and critical assessment, RAIU enhances the social learning processes and cognitive reasoning within the ASTRA framework. Further research could be done to investigate how responsible AI-mediated collaboration may best optimize both social and cognitive constructivist benefits in various science learning contexts.

### Improvement in Students' Science Assessment

The following discusses the results of improvement of Science Diagnostic Assessment (SDA) and Science Formative Assessment (SFA) using ASTRA Intervention.

**Table 6**

*Paired Samples T-Test between SDA and SFA*

Measure 1		Measure 2	t	df	p
SDA	-	SFA	-9.228	25	< .001

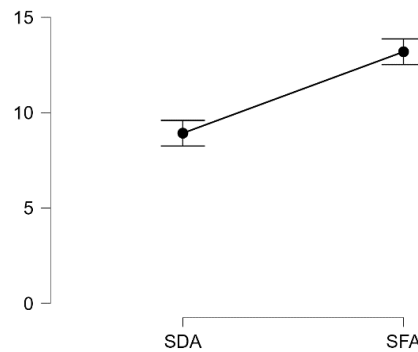
Table 6 presents the comparison of students' SA scores before and after the implementation of the ASTRA Model. The paired-samples t-test revealed a significant increase,  $t(25) = -9.23$ ,  $p < .001$ , meaning that students performed significantly better in the formative assessment than during the diagnostic phase. It gives evidence that the ASTRA Model significantly enhanced the science learning outcomes throughout time.

This result supports Piaget's theory of Cognitive Constructivism (1952) that states learning advances by means of active assimilation and accommodation of new experiences. Also, Qarareh (2016) found that the constructivist-based instruction significantly enhances scientific thinking and conceptual mastery, while Kumar (2025) pointed out that reflective and application-driven assessments lead to deeper understanding. Thus, this improvement confirms that recursive ASTRA learning phases in particular (Reflect and Apply) succeed in effective consolidations of knowledge and translation of learning processes into measurable achievement.

These findings confirm that the ASTRA Model is a valid pedagogical intervention to reinforce science comprehension through iterative learning cycles. The embedding of RAIU in those cycles likely enabled reflective inquiry and feedback, further solidifying knowledge retention and performance. Indeed, future studies could expand this investigation to include long-term retention and transfer of learning in various science domains under responsible AI-supported constructivist conditions.

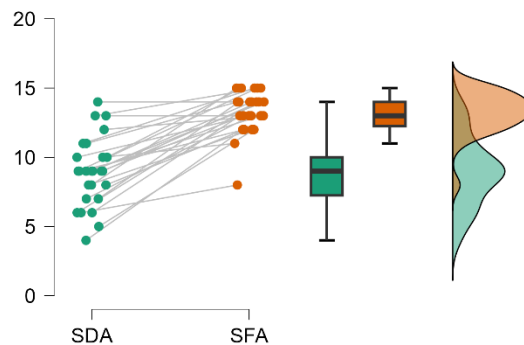
**Figure 7**

*SDA-SFA Descriptive Plots*



**Figure 8**

*SDA-SFA Rainclouds Plots*



The above descriptive and raincloud plot illustrates a clear increase in students' Science Assessment (SA) scores from the diagnostic to the formative phase. Most of the data points show upward movement, reflecting consistent improvement across participants. The distribution also shifted higher and became less variable, suggesting the ASTRA Model effectively enhanced students' performance and consistency of learning.

### Prediction of CCL Post and SCL Post towards SFA

Table 7 discusses the predictive analysis of CCL Post and SCL Post towards SFA.

**Table 7**

*Combined Regression Analysis on the Significant Influence of RAIU on CCL Post, SCL Post, and SFA*

Predictor	Standard Coefficient Beta	R	R <sup>2</sup>	p	Decision on Ho	Interpretation
CCL Post	0.459	.995	.990	<0.001	Reject Ho	Significant
SCL Post	0.158			<0.001	Reject Ho	Significant

The results of the regression analysis that evaluate the predictive relationship between Cognitive Constructivist Learning Post-test (CCL Post), Social Constructivist Learning Post-test (SCL Post), and Science Formative Assessment are shown in Table 7. The overall model was statistically significant,  $F(2, 1151) = 1151$ ,  $p < .001$ , with a strong coefficient of determination,  $R^2 = .990$ , which means that 99.0% of the variance in SFA was explained by the two predictors. These results indicate both the aspects of CCL and SCL are significant contributors towards science performance; however, CCL shows a stronger influence.

This is therefore in line with Piaget's and Vygotsky's constructivist perspectives of 1952 and 1978, respectively, which assert that cognitive restructuring and social interaction together enhance conceptual understanding and problem-solving. On their part, Devries' study of 2004 and Qarareh's study of 2016 further reiterate that constructivist-based approaches allow for better reasoning and scientific performance. The stronger predictive effect of CCL may suggest that when individual internalization and reflective reasoning are further supported through social learning processes, they are associated with higher performance outcomes within the ASTRA model.

Practically, these findings support the view that cognitive and social constructivist gains are essential in bringing about improvement in science achievement within the ASTRA framework. The embedding of RAIU probably enhanced these effects by promoting reflective thinking and enhancing cooperation in inquiry and assessment phases. Further studies can be done by examining how different levels of AI-mediated scaffolding affect the contribution of both cognitive and social learning to science performance.

### Level of Responsible AI Use of Grade 11 Students

Table 8 discusses the level of Responsible AI Use of Grade 11 student on utilizing ASTRA intervention.

**Table 8**

*RAIU Descriptive Statistics*

	Mean	Std. Deviation	Interpretation
Assess	3.183	0.391	High
Search	3.308	0.396	Very High
Triangulate	3.192	0.449	High
Reflect	3.173	0.484	High
Apply	2.990	0.545	High
	<b>3.169</b>	<b>0.453</b>	<b>High</b>

Table 8 presents the descriptive analysis for Grade 11 students' level of RAIU when engaging in the ASTRA Model. The overall mean score was high, with  $M = 3.169$  and  $SD = 0.453$ , indicating that the students generally conducted ethical and reflective engagement with AI tools during the science learning activities. Of the dimensions, the highest rating was given to the dimension "Search" with a mean of 3.308, while the lowest rated dimension was "Apply" with a mean of 2.990, which implies that while the information retrieval was responsibly conducted, further enhancement is needed in integrating the outputs of AI into application tasks.

These results are in line with the arguments of Ma et al. (2025), who claimed that responsible AI literacy deals with students' ability to critically assess and contextualize AI-generated information, rather than merely passively receive it. Similarly, Yin et al. (2025) and Fu & Weng (2024) found responsible AI engagement to enhance ethical awareness, autonomy, and cognitive discernment of learners in digital spaces. The current findings support the reflective use of AI, as provided by the ASTRA Model, and demonstrate that systematic scaffolding during the "Search" and "Reflect" stages effectively promotes appropriate and intentional use of AI tools.

These findings, in application, provide important emphasis on incorporating explicit guides on responsible AI use as part of science learning frameworks. Strengthening the "Apply" phase through scaffolded feedback and collaborative problem-solving may enhance the transfer ability of AI-assisted insights into practical, inquiry-based tasks by students. Future studies could investigate how deeper engagement with Responsible AI Use influences students' critical thinking, self-regulation, and long-term learning outcomes in a constructivist science environment.

### Relationship between ASTRA Components

Table 9 discusses the correlation between Assess, Search, Triangulate, Reflect, and Apply as a manner of a Responsible AI Use.

**Table 9**

*ASTRA Components Pearson Correlation*

			r	p	Decision on Ho @ 0.05 level of significance	Interpretation
Assess	-	Search	0.463	.017	Reject Ho	There is a significant moderate correlation
Search	-	Triangulate	0.512	.007	Reject Ho	There is a significant moderate correlation
Triangulate	-	Reflect	0.405	.040	Reject Ho	There is a significant moderate correlation
Reflect	-	Apply	0.462	.018	Reject Ho	There is a significant moderate correlation
Apply	-	Assess	0.443	.024	Reject Ho	There is a significant moderate correlation

The correlation matrix in Table 9 shows the relationships between the five components—Assess, Search, Triangulate, Reflect, and Apply—of the ASTRA Model as indicators of Responsible AI Use. The Pearson's  $r$  results showed moderate, positive, and statistically significant correlations between all component pairs ( $r = .405-.512$ ,  $p < .05$ ), reflecting that each phase is interconnected and inter-supportive. These findings suggest that effective RAIU is achieved through continuous and integrated functioning of all ASTRA components during science learning.

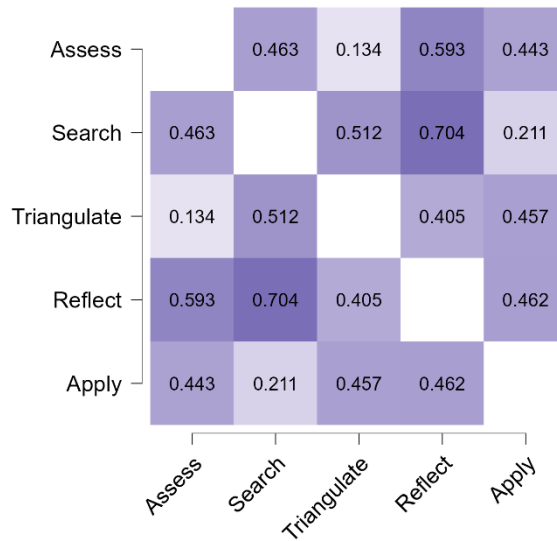
This supports the conceptualization of Responsible AI Use as a recursive and reflective process in which critical evaluation, triangulation of information, and ethical application are conducted in a cyclical manner (Ma et al., 2025; Fu & Weng, 2024). Likewise, Yin et al. (2025) stressed that the development of responsible AI engagement can be supported by scaffolding students' interactions through different stages of an inquiry process from information assessment to application. Therefore, the interrelatedness of the ASTRA components serves its theoretical underpinnings rooted in constructivist learning, where iterations of reflection and social negotiations enhance cognitive understanding (Piaget, 1952; Vygotsky, 1978).

These results also indicate, practically, that RAIU cannot be developed in isolation; it must be systematically integrated throughout all learning phases. Deepening the connections among "Triangulate," "Reflect," and "Apply" can further enhance critical evaluation and ethical reasoning involving the use of AI tools. Future studies might

address how fine-tuning these transitions between phases using AI-mediated scaffolding impacts students' long-term responsible use and science attainment.

**Figure 9**

*ASTRA Component Correlation Heat Map*



The heat map in Figure 9 shows the correlations between the different components of ASTRA: Assess, Search, Triangulate, Reflect, and Apply. Darker shades are indicative of stronger relations, with the strongest between Search and Reflect, at  $r = 0.704$ , which is strong and positive. Overall, most components show moderate correlations, suggesting that responsible AI behaviors across the ASTRA dimensions are related to each other and have a tendency to develop together.

**Prediction of RAIU towards CCL Post, SCL Post, and SFA**

Table 10 discusses the predictive analysis of RAIU towards CCL Post, SCL Post, and SFA.

**Table 10**

*Combined Regression Analysis on the Significant Influence of RAIU on CCL Post, SCL Post, and SFA*

Predictor	Standard Coefficient Beta	R	R <sup>2</sup>	p	Decision on Ho	Interpretation
CCL Post	0.825	.992	.984	<0.001	Reject Ho	Significant
SCL Post	3.301	.994	.989	<0.001	Reject Ho	Significant
SFA	0.898	.993	.986	<0.001	Reject Ho	Significant

Table 10 presents the results of the regression analysis using RAIU as a predictor of CCL Post, SCL Post, and SFA. It showed that RAIU significantly predicted all three learning outcomes, namely: CCL Post, with  $\beta = 0.825$  and  $R^2 = .984$ ; SCL Post, with  $\beta = 3.301$  and  $R^2 = .989$ ; and SFA, with  $\beta = 0.898$  and  $R^2 = .986$ , all at  $p < .001$ . The findings suggest that responsible engagement in using AI tools has a strong positive impact on both cognitive and social constructivist learning and on science achievement.

This result supports the ASTRA Model's central assumption that Responsible AI Use engenders deeper learning through reflective inquiry and ethical interaction with AI systems. Consistent with Ma et al. (2025) and Yin et al. (2025), the results showed that when learners critically assess and contextualize AI outputs, cognitive engagement and collaborative learning outcomes are increased. The stronger predictive power of RAIU on SCL indicates that ethical and dialogic use of AI fosters meaningful social construction of knowledge, congruent with Vygotsky's view of learning as socially mediated.

This implies that Responsible AI Use serves the dual transformative function of enhancing the growth in individual reasoning and collective building of knowledge. Embedding structured AI literacy and reflective evaluation activities within the ASTRA model could provide positive results for students' scientific understanding and performance. Future studies may also explore the ways in which differentiated levels of AI autonomy and feedback mechanisms further mediate the relationship between RAIU and constructivist learning gains.

## Conclusion

These findings constitute strong empirical evidence that the ASTRA Model effectively enhances Grade 11 students' science learning across cognitive, social, and assessment dimensions. The repeated measures ANOVA and post hoc analyses revealed significant and progressive improvements in both CCL and SCL, with SCL demonstrating higher gains. These findings establish that the integration of RAIU within constructivist pedagogy fosters individual knowledge construction and collaborative meaning-making. The significant difference between CCL and SCL gains points to the fact that socially mediated, AI-supported interactions are important in deepening students' conceptual understanding and engagement in the processes of science learning.

Moreover, the paired samples t-test and regression analyses confirmed that the ASTRA Model significantly enhanced students' SFA scores and that RAIU was a strong predictor of learning outcomes in CCL Post, SCL Post, and SFA. Exceptionally high coefficients of determination ( $R^2 = .984-.989$ ) show that responsible, reflective engagement with AI tools is a major contributor to learning success. These underpin the ASTRA Model's theoretical anchors in both Piaget's Cognitive Constructivism and Vygotsky's Social Constructivism by confirming that such a model can operationalize the processes of assimilation, accommodation, scaffolding, and co-construction through structured AI-mediated inquiry. All these results together validate that ethical and purposeful integration of AI amplifies cognitive reasoning and collaborative interaction while significantly enhancing students' science comprehension and performance.

In sum, the study concludes that the ASTRA Model works as a robust, theory-driven framework to foster Responsible AI Use as a catalyst for meaningful learning. The positive intercorrelations among its components (Assess, Search, Triangulate, Reflect, and Apply) illustrate that effective AI integration in education requires recursive reflection and interlinked learning phases. This would, quite practically, suggest that science educators should consider the use of AI-powered constructivist models designed on ethical engagement, reflective evaluation, and collaborative problem-solving. Further research can explore how different AI levels of scaffolding, feedback mechanisms, and contextual applications of RAIU might optimize long-term learning outcomes and foster responsible digital citizenship in science education.

### **Limitations of the Study**

This study has several limitations that should be considered when interpreting the findings and their applicability. First, the study utilized a relatively small sample size of 26 Grade 11 students from a single section at J.V. Ferriols National High School. While the census sampling approach ensured complete inclusion of the target group, the limited sample size may constrain the statistical power of the analyses and limit the robustness of generalizations beyond the study context. Second, the findings are context-specific, as the intervention was implemented only within a Grade 11 Science class focusing on Genetic Engineering. Therefore, the results may not be fully generalizable to other grade levels, subject areas, or educational institutions with different curricular structures or learner demographics.

Furthermore, there are potential limitations in the measurement instruments used. Although the tools underwent validation, pilot testing, and reliability analysis, self-reported data from the Responsible AI Use (RAIU) survey may still be subject to response bias. In addition, performance-based assessments using rubrics may involve a degree of subjectivity despite established inter-rater agreement. Fourth, the study did not control for certain external or learner-specific variables that may have influenced outcomes, such as students' prior familiarity with artificial intelligence tools, digital literacy levels, motivation, or access to technology outside the classroom. These factors may have contributed to variations in learning gains but were not directly measured within the scope of the study.

While the ASTRA Model demonstrated significant effects on Cognitive Constructive Learning, Social Constructive Learning, and Science Assessment outcomes, the study did not examine long-term retention or delayed effects of the intervention. Future research may consider longitudinal designs to determine the sustainability of these learning gains over time. These limitations suggest several directions for future research, including the need for larger and more diverse samples across multiple institutions to improve generalizability, stronger validation and refinement of measurement instruments, and the inclusion of additional variables such as prior AI familiarity, digital literacy, and learner motivation. Future studies may also employ longitudinal and mixed-method designs to further examine the sustained impact of the ASTRA Model.

## Recommendations

Based on the study's findings, the Department of Education could consider the study's recommendation that the integration of the ASTRA model across science curricula be institutionalized to further ensure that students practice Responsible AI Use and engage in constructivist learning. The J.V. Ferriols National School should consider embedding the ASTRA Model into classroom instruction, ensuring resources for teacher training in the new pedagogical approaches, and providing the appropriate technological infrastructure to support AI-enhanced learning. Teachers can be encouraged to adopt the phases of ASTRA (Assess, Search, Triangulate, Reflect, Apply) during lessons to afford students both cognitive and social constructivist engagement opportunities and ensure responsible AI use in an ethical and reflective manner. Students should be guided to use AI responsibly: critically evaluating, collaborating, and applying everything to enhance their understanding and performance of science. This study was limited to one Grade 11 class with 26 students, which may constrain the generalizability of its findings. Future research should involve larger and more diverse samples across multiple schools and disciplines, using mixed-method designs to capture both quantitative outcomes and qualitative experiences of Responsible AI Use. Moreover, subsequent studies are encouraged to examine the ASTRA Model's scalability, sustainability, and long-term impact on learners' cognitive, social, and affective domains—including retention, engagement, and digital citizenship.

## References



- Bednarski, M. H. (1997). University of Connecticut ProQuest Dissertations & Theses, 1997. 9806163.  
<https://www.proquest.com/docview/304342102>
- Devries, R. (2004). What Does Research on Constructivist Education Tell Us about Effective Schooling?  
<https://www.semanticscholar.org/paper/What-Does-Research-on-Constructivist-Education-Tell-Devries/7ea30332e417692be665f10c1218eae7f53ec07d>
- Do, H., Ngoc, B., DO, & Nguyen, M. H. (2023). How do constructivism learning environments generate better motivation and learning strategies? The Design Science Approach. *Heliyon*, 9(12), e22862.  
<https://doi.org/10.1016/j.heliyon.2023.e22862>
- Fu, Y., & Weng, Z. (2024). Navigating the Ethical Terrain of AI in Education: A Systematic Review on Framing responsible Human-Centered AI Practices. *Computers and Education Artificial Intelligence*, 100306.  
<https://doi.org/10.1016/j.caeai.2024.100306>
- Guo, H., Yi, W., & Liu, K. (2024). Enhancing constructivist learning: the role of generative AI in personalised learning experiences. <https://centaur.reading.ac.uk/id/eprint/116711>
- Iofciu, F., Miron, C., & Antohe, S. (2012). Constructivist approach of evaluation strategies in science education. *Procedia - Social and Behavioral Sciences*, 31, 292–296. <https://doi.org/10.1016/j.sbspro.2011.12.057>

- Lehtinen, A., Kostiaainen, E., & Näykki, P. (2023). Co-construction of knowledge and socioemotional interaction in pre-service teachers' video-based online collaborative learning. *Teaching and Teacher Education*, 133, 104299. <https://doi.org/10.1016/j.tate.2023.104299>
- Ma, M., Ng, D. T. K., Liu, Z., & Wong, G. K. (2025). Fostering Responsible AI literacy: A Systematic Review of K-12 AI Ethics education. *Computers and Education Artificial Intelligence*, 100422. <https://doi.org/10.1016/j.caeai.2025.100422>
- Muzakki, A., Wuryaningrum, R., & Yuliati, N. (2025). The Effect of Integrated Learning Management System with Augmented Reality and Artificial Intelligence on Critical Thinking Ability and Digital Literacy in Elementary Schools. *European Journal of Education and Pedagogy*, 6(3), 22–28. <https://doi.org/10.24018/ejedu.2025.6.3.930>
- Piaget, J. (1952). *The origins of intelligence in children*. New York, NY: International Universities Press. <https://archive.org/details/originsofintelli00piag>
- Qarareh, A. O. (2016). The effect of using the constructivist learning model in teaching science on the achievement and scientific thinking of 8th grade students. *International Education Studies*, 9(7), 178. <https://doi.org/10.5539/ies.v9n7p178>
- Richter, S., Giroux, M., Piven, I., Sima, H., & Dodd, P. (2024). A Constructivist Approach to Integrating AI in Marketing Education: bridging theory and practice. *Journal of Marketing Education*. <https://doi.org/10.1177/02734753241288876>
- Sajja, R., Sermet, Y., Fodale, B., & Demir, I. (2025, June 6). Evaluating AI-Powered Learning Assistants in Engineering Higher Education: student engagement, ethical challenges, and policy implications. *arXiv.org*. [https://arxiv.org/abs/2506.05699?utm\\_source=chatgpt.com](https://arxiv.org/abs/2506.05699?utm_source=chatgpt.com)
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press. <https://www.hup.harvard.edu/books/9780674576292>
- Yaşar, M. D., Erdoğan, M., Batdı, V., & Cinkara, Ü. (2024). Evaluation of cooperative learning in science education: A mixed-meta method study. *European Journal of Science and Mathematics Education*, 12(3), 411–427. <https://doi.org/10.30935/scimath/14872>
- Yin, Y., Karumbaiah, S., & Acquaye, S. (2025). Responsible AI in Education: Understanding Teachers' Priorities and Contextual Challenges. *ACM Digital Library*, 2705–2727. <https://doi.org/10.1145/3715275.3732176>

## Appendix

### Appendix A

#### *Letter of Approval*

**DAVAO CENTRAL COLLEGE**  
 College of Education and Liberal Arts  
 Toril, Davao City, Philippines  
 Tel. No. (082) 291-1002 / Fax No. (082) 291-2052

---

Email Address: [davaocentralcollege2011@gmail.com](mailto:davaocentralcollege2011@gmail.com)

Website: [www.davaocentralcollege.com](http://www.davaocentralcollege.com)

October 1, 2025

**DANILO P. MONDOYO**, Principal II  
 School Principal  
 J.V. Ferriols National High School

Dear Mr. Mondoyo,

*Mabuhay ug Madayaw!*

We, the undersigned, are student researchers from the Davao Central College – College of Education and Liberal Arts, currently enrolled in the Bachelor of Secondary Education Major in Science program. We are presently working on our course requirement for Field Study 2: Classroom-Based Action Research, with the research title,

**"BRIDGING AI-ASSISTED LEARNING AND CONCEPTUAL MASTERY OF GRADE 11 WITH ACTIVE SCIENCE THROUGH RESPONSIBLE AI (ASTRA) MODEL"**

This study seeks to explore the effect of the ASTRA Model on enhancing students' conceptual mastery in Science 11 by promoting responsible use of AI tools. It also aims to identify strategies that help learners shift from passive copy-paste reliance to active engagement, reflection, and application of AI-assisted learning in the classroom.

In line with this, we respectfully seek your approval to conduct the following data-gathering activities within the premises of J.V. Ferriols National High School to administer pre-tests and post-tests (written and performance-based), classroom observations, and student surveys with Grade 11 Senior High School Science students.

Participants will be carefully selected based on their eligibility and relevance to the study. They will be informed of the research purpose and asked to sign an informed consent form prior to any data collection. All selected student will be scheduled at their respective class hours.

Please rest assured that the confidentiality of all responses will be strictly maintained. No personal or identifying information will be disclosed in the final manuscript. Furthermore, participants may withdraw from the study at any time without any consequences.

We firmly believe that the findings of this research will provide valuable insights that can contribute to the development of effective leadership programs and strategies within our institution.

We are looking forward to your favorable response and support for this academic endeavor.



**DAVAO CENTRAL COLLEGE**  
College of Education and Liberal Arts


Torii, Davao City, Philippines  
Tel. No. (082) 291-1802 / Fax No. (082) 291-2053




Email Address: [davaocentralcollege2011@gmail.com](mailto:davaocentralcollege2011@gmail.com)


Website: [www.davaocentralcollege.com](http://www.davaocentralcollege.com)





Thank you very much, and more power!



Sincerely,   
**ROBER ACBOBO**  
Research Leader



Noted by:   
**ALKIMBER Y. SORIANO, LPT, PhD (CAR)**  
FS2 Supervisor

Recommending Approval:  
  
**JUDY**  
CELA Program Head **LPT, MAEd**

Approved by:  
  
**DANILLO M. MONDOYO, Principal II**  
School Principal

 RADO  ROMERO 10/14/25  
 JERRY  JERRY 10/14/25

Noted by:  
  
**GELZ**  
Asst. to the Principal - **CE**  
  
**LILLA**

 MARIE  AILLO  
10/14/2025



## Appendix C

### Survey Questionnaire



**DAVAO CENTRAL COLLEGE**  
College of Education and Liberal Arts

Toril, Davao City, Philippines  
Tel. No. (082) 291-1882 / Fax No. (082) 291-2053



Email Address: [davaocentralcollege2011@gmail.com](mailto:davaocentralcollege2011@gmail.com)

Website: [www.davaocentralcollege.com](http://www.davaocentralcollege.com)

#### SURVEY QUESTIONNAIRE

Dear Respondent,

We are conducting a classroom-based action research entitled "**BRIDGING AI-ASSISTED LEARNING AND CONCEPTUAL MASTERY IN SCIENCE 11 WITH ACTIVE SCIENCE THROUGH RESPONSIBLE AI (ASTRA) MODEL.**" This study aims to determine the effectiveness of the ASTRA Model in enhancing Science 11 students' conceptual understanding through responsible and meaningful integration of artificial intelligence (AI) tools in classroom learning.

Specifically, this research seeks to evaluate students' Cognitive Constructive Learning, Social Constructive Learning, and **Responsible AI Use**, and how these contribute to improved science achievement and responsible digital engagement. Your responses to this questionnaire will provide essential insights into how AI tools can be used effectively and ethically to support active science learning.

In compliance with the **Data Privacy Act of 2012 (RA 10173)**, all information you provide will be treated with the highest confidentiality. Your identity will remain anonymous, and all data gathered will be used solely for academic and research purposes. Participation in this study is entirely voluntary, and you may choose to withdraw at any time without penalty.

By answering this questionnaire, you indicate your informed consent and willingness to participate in this study. Your honesty and cooperation are greatly appreciated and will significantly contribute to promoting responsible AI integration in education.

Thank you very much for your time and participation.

Respectfully,  
*The Researchers*

---

#### Part 1. Demographics

**Direction:** Please provide the following information by checking or writing the appropriate response.

**Name:** \_\_\_\_\_ **Grade & Section:** \_\_\_\_\_



## DAVAO CENTRAL COLLEGE

### College of Education and Liberal Arts

Toril, Davao City, Philippines  
Tel. No. (082) 291-1882 / Fax No. (082) 291-2053



Email Address: [davaocentralcollege2011@gmail.com](mailto:davaocentralcollege2011@gmail.com)

Website: [www.davaocentralcollege.com](http://www.davaocentralcollege.com)

### Part 2: Responsible AI Use (RAIU)

**Direction:** The statements below describe your experiences and perceptions in using Artificial Intelligence (AI) tools during Science 11 learning through the Active Science Through Responsible AI (ASTRA) Model. Please read each statement carefully and honestly evaluate how much you agree with each one.

Put a checkmark (✓) in the box that corresponds to your response, based on the scale below:

Scale	Description
4	Strongly Agree
3	Agree
2	Disagree
1	Strongly Disagree

#### I. Assess

In using ASTRA, I...	4	3	2	1
1. evaluate what I already know about the topic before using AI tools.				
2. identify gaps or questions in my knowledge before consulting AI.				
3. plan which questions to ask AI based on what I do not understand.				
4. check whether I have misconceptions before relying on AI-generated outputs.				

*Adapted from Ma et al. (2025)*

#### II. Search

In using ASTRA, I...	4	3	2	1
1. frame my questions carefully when interacting with AI tools.				
2. try different searches when the initial AI response seems unclear or incomplete.				
3. check the reliability and accuracy of the sources suggested by AI.				
4. avoid copying AI outputs without verifying or modifying them.				

*Adapted from Yin et al. (2025)*



**DAVAO CENTRAL COLLEGE**  
 College of Education and Liberal Arts

Toril, Davao City, Philippines  
 Tel. No. (082) 291-1882 / Fax No. (082) 291-2053



Email Address: [davaocentralcollege2011@gmail.com](mailto:davaocentralcollege2011@gmail.com)

Website: [www.davaocentralcollege.com](http://www.davaocentralcollege.com)

**III. Triangulate**

<i>In using ASTRA, I...</i>	4	3	2	1
1. compare AI-generated information with textbooks, online articles, and teacher inputs.				
2. verify which AI information is more credible when answers conflict.				
3. cross-check AI information by asking follow-up questions or consulting other resources.				
4. discuss AI-generated information with my classmates to decide its accuracy.				

*Adapted from Kazu & Kuvvetli (2023)*

**IV. Reflect**

<i>In using ASTRA, I...</i>	4	3	2	1
1. reflect on how helpful the AI output was to my learning.				
2. evaluate whether I truly learned new ideas from AI or merely received answers.				
3. adjust how I use AI based on past mistakes or successes.				
4. think about how AI influenced my understanding of science concepts.				

*Adapted from Aonlamai & Kwangmuang (2025)*

**V. Apply**

<i>In using ASTRA, I...</i>	4	3	2	1
1. use AI outputs as guides to construct my own answers.				
2. contribute to group tasks using AI as a support tool, not as a substitute for thinking.				
3. synthesize AI-generated information into my own explanations or creative outputs.				
4. apply AI-supported insights in assignments by reinterpreting and personalizing content.				

*Adapted from Sajja et al. (2025)*

Appendix D  
CCL Rubrics

**COGNITIVE CONSTRUCTIVE LEARNING  
SCORING SHEET**

Name: \_\_\_\_\_ Grade & Section: Grade 11-A Subject: Earth and Life Science

CRITERIA	WEIGHTS				Needs Improvement (1)	SCORE			AVE.
	Excellent (4)	Good (3)	Fair (2)	Needs Improvement (1)		T1	T2	T3	
<b>Breadth of Scientific Concepts</b>	Concept map includes all key scientific ideas from the lesson (e.g., Genetic Engineering) with clear hierarchy and relationships.	Most major concepts included; hierarchy is mostly clear.	Some key concepts missing or loosely connected.	Few concepts shown; lacks structure or depth.	4	4	4		
<b>Interconnectedness of Ideas</b>	Concepts are meaningfully interlinked showing deep understanding of relationships among ideas.	Most concepts linked appropriately; some connections may be weak.	Limited linking between ideas; relationships are partly unclear.	Minimal connections; map appears fragmented.	3	3	3		
<b>Clarity and Accuracy of Links</b>	Linking words clearly and accurately describe relationships between concepts.	Linking words are mostly clear and valid for most relationships.	Some linking words unclear or inaccurate.	Links are vague, inconsistent, or missing.	3	3	3		
<b>Integration of AI Insights (Responsible Use)</b>	AI-generated information is appropriately integrated, verified, and synthesized into the map; reflects responsible AI use.	AI insights used meaningfully but with minor verification gaps.	AI information included but weakly verified or copied.	Overreliance on AI without verification or synthesis.	3	3	4		
<b>Organization and Layout</b>	Map is visually clear, logically structured, and easy to follow; reflects hierarchical organization.	Generally organized and clear, with minor layout inconsistencies.	Some disorganization; layout affects readability.	Disorganized and confusing; lacks structure.	3	3	3		
<b>TOTAL</b>					16	16	17	14.33	

Teacher-made rubrics, based on Waterloo (2024)

Appendix E  
SCL Rubrics

**SOCIAL CONSTRUCTIVE LEARNING  
SCORING SHEET**



Group: 1 Grade & Section: Grade 11-A Subject: Earth and Life Science Teacher: Rebekah

CRITERIA	WEIGHTS				Score
	Exemplary (4)	Accomplished (3)	Developing (2)	Beginning (1)	
<b>Content Understanding</b>	Presentation demonstrates deep conceptual understanding of the topic, integrating AI-assisted insights with scientific reasoning. All information is accurate and well-explained.	Presentation shows clear understanding with minor inaccuracies. AI resources are used meaningfully but not fully analyzed.	Content shows partial understanding; some ideas unclear or lack logical flow. AI-generated info used with minimal evaluation.	Presentation demonstrates limited understanding; heavy reliance on AI-generated content without comprehension or analysis.	4
<b>Collaboration and Group Dynamics</b>	All members actively collaborate, contribute ideas, and support each other. Tasks are equitably shared and group synergy is evident.	Most members contribute actively with minor imbalance in participation. Collaboration is generally effective.	Some members dominate or disengage. Limited coordination in planning or decision-making.	Minimal collaboration. Group lacks teamwork, showing individual rather than shared effort.	3
<b>Use of Responsible AI (RAIU Integration)</b>	AI tools are used ethically and responsibly — sources verified, outputs critically evaluated, and used to enhance understanding.	AI tools are used responsibly with occasional lapses in evaluation or verification.	Limited responsible use; AI used mostly as a shortcut or for direct copying.	No evidence of responsible AI use; outputs copied directly without verification or reflection.	3
<b>Presentation Design and Delivery</b>	Presentation is clear, engaging, and well-organized. Visuals are used effectively, and delivery shows confidence and mastery of content.	Presentation is organized and clear, with some inconsistencies in visuals or delivery.	Presentation lacks coherence; visuals are cluttered or unclear. Some presenters lack confidence.	Presentation is disorganized or confusing; poor visuals and delivery.	4
<b>Critical Discussion and Reflection</b>	Demonstrates strong reasoning, reflection, and synthesis of group ideas. Effectively connects scientific and AI-supported insights.	Demonstrates moderate reasoning and reflection; ideas are somewhat synthesized.	Reflection or discussion is surface-level with limited synthesis of ideas.	Lacks reflection; ideas presented mechanically with no integration.	4
<b>TOTAL</b>					<b>18</b>

Teacher-made rubrics, based on Pepperdine Community (2025)

## Appendix F

## Diagnostic Assessment

REPUBLIC OF THE PHILIPPINES  
 DEPARTMENT OF EDUCATION  
 REGION XI  
 DIVISION OF DAWAO CITY  
**J.V. FERRIONS NATIONAL HIGH SCHOOL**  
 Jose Vicente Ferrion St., Ujada, Toril, Davao City

7

---

**EARTH AND LIFE SCIENCE 11**

**DIAGNOSTIC ASSESSMENT**

Name: KALLO S. FERRELL Grade & Section: Grade 11-A Date: 7/21/25

Directions: Encircle the letter of the correct answer.

<ol style="list-style-type: none"> <li>1. What is <i>genetic engineering</i>?  <input type="radio"/> A. The study of heredity and traits  <input checked="" type="radio"/> B. The process of changing an organism's DNA to produce desired traits  <input type="radio"/> C. The natural selection of genes in offspring  <input type="radio"/> D. The use of breeding to improve plant species</li> <li>2. What is the main goal of genetic engineering?  <input type="radio"/> A. To observe genetic mutations  <input checked="" type="radio"/> B. To improve species for human benefit  <input type="radio"/> C. To reduce the number of genes in an organism  <input type="radio"/> D. To destroy unwanted genetic material</li> <li>3. Which molecule is directly modified in genetic engineering?  <input type="radio"/> A. RNA  <input type="radio"/> B. Protein  <input checked="" type="radio"/> C. DNA  <input type="radio"/> D. Lipid</li> <li>4. A scientist inserts a drought-resistance gene into a rice plant. What process is this an example of?  <input type="radio"/> A. Hybridization  <input type="radio"/> B. Natural selection  <input checked="" type="radio"/> C. Genetic engineering  <input type="radio"/> D. Artificial pollination</li> <li>5. How does genetic engineering differ from selective breeding?  <input type="radio"/> A. It depends on natural variation only.  <input checked="" type="radio"/> B. It involves direct manipulation of DNA.  <input type="radio"/> C. It requires longer generations to show results.  <input type="radio"/> D. It does not produce new traits.</li> <li>6. Which statement best explains why scientists genetically modify plants?  <input type="radio"/> A. To make plants taller  <input type="radio"/> B. To increase yield and resistance to pests  <input checked="" type="radio"/> C. To reduce plant population  <input type="radio"/> D. To remove all genes in plants</li> <li>7. Which of the following is an example of a genetically engineered plant?  <input type="radio"/> A. A rose that blooms naturally  <input checked="" type="radio"/> B. Bt corn that resists insect pests  <input type="radio"/> C. A hybrid rice from cross-pollination  <input type="radio"/> D. A wild banana growing in nature</li> <li>8. A farmer uses AI tools to analyze soil conditions before planting genetically modified corn. What responsible action does this show?  <input checked="" type="radio"/> A. Applying AI to make evidence-based farming decisions  <input type="radio"/> B. Replacing human knowledge with AI results</li> </ol>	<ol style="list-style-type: none"> <li> <input type="radio"/> C. Ignoring the data given by AI tools  <input type="radio"/> D. Depending on chance for crop growth         </li> <li>9. Which animal has been genetically modified to produce human insulin?  <input checked="" type="radio"/> A. Cow  <input type="radio"/> B. Goat  <input type="radio"/> C. Pig  <input type="radio"/> D. Sheep</li> <li>10. Compare one benefit and one risk of genetic engineering in animals. Which is correct?  <input checked="" type="radio"/> A. Benefit: faster reproduction; Risk: disease control  <input type="radio"/> B. Benefit: medical advancement; Risk: ethical concerns  <input type="radio"/> C. Benefit: higher cost; Risk: lower success rate  <input type="radio"/> D. Benefit: more meat; Risk: none</li> <li>11. Which of the following best shows an ethical risk of genetic engineering in animals?  <input checked="" type="radio"/> A. Better animal health  <input type="radio"/> B. Overuse of antibiotics  <input type="radio"/> C. Changing animal DNA for human benefit  <input type="radio"/> D. Faster breeding cycles</li> <li>12. Which of the following is a <i>social advantage</i> of genetic engineering?  <input checked="" type="radio"/> A. Increases food production and quality  <input type="radio"/> B. Causes unpredictable mutations  <input type="radio"/> C. Increases environmental risks  <input type="radio"/> D. Reduces biodiversity</li> <li>13. Which of the following is an <i>ethical concern</i> in genetic engineering?  <input checked="" type="radio"/> A. Developing drought-resistant plants  <input type="radio"/> B. Creating genetically modified humans  <input type="radio"/> C. Producing pest-resistant crops  <input type="radio"/> D. Treating diabetes with insulin</li> <li>14. A student uses AI tools to summarize sources on genetic engineering, then checks facts using textbooks. What does this behavior demonstrate?  <input checked="" type="radio"/> A. Responsible use of AI in learning  <input type="radio"/> B. Complete reliance on AI  <input type="radio"/> C. Copying without reflection  <input type="radio"/> D. Avoiding scientific inquiry</li> <li>15. Evaluate this statement: "Genetic engineering only benefits humans."  <input type="radio"/> A. True, because humans control the process  <input checked="" type="radio"/> B. False, because it can also help the environment and animals  <input type="radio"/> C. True, since it's man-made  <input type="radio"/> D. False, because it has no impact at all</li> </ol>
--	--



**Corresponding Author Contact Information:**

**Author name:** Roberto, Jr. P. Tacbobo

**Department:** College of Education and Liberal Arts

**University, Country:** Davao Central College, Philippines

**Email:** robertojrpelaeztacbobo.dcc@gmail.com

**Please Cite:** Tacbobo, R. Jr., Decayan, R., Geronggay, A. P., Lawas, J. E. N., Vallezer, J. H., & Zabala, R. (2026). Bridging AI-Assisted Learning and Conceptual Mastery in Genetic Engineering 11 with Active Science Through Responsible AI (ASTRA) Model. *Journal of Research in Science, Mathematics and Technology Education*, 9(2), 69-104. DOI: <https://doi.org/10.31756/jrsmte.924>

**Copyright:** This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Conflict of Interest:** The authors declare that there is no conflict of interest regarding the publication of this article.

**Publisher's Note:** All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

**Data Availability Statement:** All relevant data are within the paper and its supporting information files.

**Ethics Statement:** The study was conducted in accordance with ethical standards. Informed consent was obtained from all participants (or their guardians) involved in the study.

**Author Contributions:** R.P.T. and R.S.D. conceived and designed the study; A.P.G. and J.E.N.L. performed the experiments; J.H.V. and R.I.Z. analyzed the data; R.P.T. wrote the paper.

*Received: November 10, 2025 ▪ Accepted: April 30, 2026*