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The use of engineering design process-oriented activities with GRASPS model integration in grade 11 Genetics

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ABSTRACT

This study aimed to develop engineering design process (EDP)-oriented activities integrated with the GRASPS model and to evaluate their effects on students' conceptual understanding and cognitive process skills. Likewise, this investigation documented the students' meaningful learning experiences during the implementation of the EDP. Moreover, this study employed a mixed-methods approach and a one-group pretest-posttest design, with 36 Grade 11 STEM students as participants. The engineering design process-oriented activities were implemented over a six-week period, and data were gathered through pretests and posttests, journals, observations, and focus group discussions. Results showed that six (6) engineering design process-oriented activities in genetics were developed. Additionally, the thematic analysis of students' meaningful learning experiences revealed four (4) emergent themes: *understanding of concepts, collaborative engagement, interests and attitudes,* and *development of engineering design process skills*. Notably, the developed EDP-oriented activities improved students' conceptual understanding, $t(35) = 8.51$, $p < .001$, $d = 1.42$, and cognitive process skills, $t(35) = 16.62$, $p < .001$, $d = 2.77$. This research recommends that the developed activities be used with proper guidelines and that the same inquiry be explored in other fields, including technology and livelihood education (TLE), engineering, and mathematics, using academic variables such as redesign ability, retention, and creativity. Lastly, this scholarly work offers essential insights that will guide teachers, administrators, and policymakers in the effective implementation of the engineering design process within the STEM framework.

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INTRODUCTION

Education is crucial for personal development, empowering everyone to acquire knowledge, cultivate skills, and develop values. In addition, it fosters critical thinking and decision-making abilities, enabling individuals to transform their perceived weaknesses into strengths and navigate life's challenges with greater resilience and adaptability. Likewise, education is also essential in advancing scientific research and technological innovation. Meanwhile, developing innovative solutions to complex problems and addressing global challenges is necessary, where education contributes to creating a better life for everyone (Abragan et al., 2022). Notably, research indicates that learners who receive high-quality science education are more likely to achieve academic success and pursue careers in science, technology, engineering, and mathematics (STEM) fields (National Science Board, 2018). Hafni et al. (2020) explain that science education is essential for individuals to thrive in the context of Industry 4.0, and it helps prepare learners to contribute to the advancement of the constantly changing society through innovation. This can be attained by providing them with the required knowledge and skills in data analytics, materials science, and engineering. On the other hand, Tavares et al. (2021) highlight that several scholars and educational organizations have stressed the importance of gaining a deeper understanding of the potential effectiveness of various science approaches in teaching and learning. Additionally, Kaleci and Korkmaz (2018) argue that teachers should ensure that students become productive, innovative, and capable of using higher-order thinking skills. Moreover, the educational system should be transformed into an environment where students are not afraid of making mistakes but are instead encouraged to build self-confidence. Lastly, an active learning space must foster inclusivity and enhance teacher and student academic performance (Munna & Kalam, 2021).

Background of the Study

According to the Program for International Student Assessment (PISA), the Philippines received a low score in science (356 mean scores compared to the OECD average of 485) and mathematics (355 mean scores compared to the OECD average of 472). These data indicate that in PISA 2022, results were comparable to those in 2018 in science and mathematics (OECD, 2023a; OECD, 2023b). Likewise, Mullis et al. (2020) reported low scores for the country in the 2019 Trends in International Mathematics and Science Study (TIMSS). Furthermore, students were evaluated in terms of critical thinking skills, problem-solving abilities, and higher-order thinking skills. These data provide essential insights into the learning gaps and possible research opportunities to explore various teaching and learning approaches, such as the implementation of the engineering design process. Similarly, as the World Bank (2019) reported, despite increased spending on primary education and some improvements in outputs in the Philippines, learning outcomes, as reflected in the National Achievement Test (NAT) scores, have remained stagnant at a level below proficiency over time. From SY 2009-2010 to SY 2014-2015, the National Achievement Test (NAT) Mean Percentage Scores (MPS) at the elementary and secondary levels showed fluctuations across all subject areas, with minimal to no improvement. Likewise, achievement scores on both elementary and secondary levels have consistently fallen short of the 75% proficiency mark set by the Department of Education. Lastly, science and mathematics showed the lowest MPS, highlighting a persistent challenge that reflects a trend observed in international assessments.

The Department of Education (DepEd) emphasizes the importance of active and inquiry-based learning in its curriculum to overcome these educational challenges. Notably, the Memorandum No. 054, s. 2023 on the Pilot Implementation of the MATATAG Curriculum was launched to address the gaps and issues within the curriculum guides by improving the learning competencies, including the curriculum standards (DepEd, 2023). In addition, the new features included in the curriculum are the introduction of big ideas, focus on foundational skills, clearer articulation of 21st-century skills, balanced cognitive demands, and intensified values education and peace education. Interestingly, the department also emphasizes the use of the engineering design process (EDP). However, few published studies have attempted to implement EDP in public schools in the Philippines. This study aims to address these gaps, providing valuable insights for teachers and school administrators on implementing the engineering design process in science classrooms. Likewise, the Department of Education's STEM framework emphasizes that the K to 12 Curriculum is designed to develop problem solvers, innovative thinkers, and entrepreneurs who can actively contribute to inclusive economic development.

Moreover, according to the MATATAG curriculum, the engineering design process is achieved through three (3) key learning areas: science, mathematics, technology and livelihood education (TLE). Further, these subjects collectively utilize the EDP to achieve the intended goals of the curriculum. Meanwhile, although the subjects are taught separately, the three learning areas are interrelated and utilize knowledge and skills to solve real-world problems. Additionally, incorporating the EDP into instruction enables learners to create solutions by understanding the needs and contexts, constructing and testing solutions, repeating the EDP stages necessary for improvements, learning from failures, and exploring new design possibilities to reach optimal solutions (Dankenbring et al., 2014). Furthermore, the MATATAG curriculum demonstrates that through the use of the EDP and problem-solving approaches, learners are able to utilize their mathematical, scientific, and technological knowledge to formulate ideas, make conjectures, reason logically, create solutions, and evaluate outcomes (DepEd, 2023). In this context, implementing approaches such as using EDP requires in-depth preparation in the classroom. Therefore, this present study aims to provide empirical data on the use of EDP in science subjects in the country prior to the full implementation of the new curriculum and teaching approaches across all grade levels.

Engineering Design Process and GRASPS Model

The implementation of the engineering design process (EDP) is a beneficial approach for teachers to introduce engineering design principles to students while encouraging higher-order thinking, problem-solving, and critical thinking skills (Nisa et al., 2021; Precharattana et al., 2023; Syukri et al., 2018). Additionally, TeachEngineering (2023) from the University of Colorado describes EDP as a series of steps that guide learners in solving problems. Moreover, EDP has distinct stages, including *defining the problem, identifying criteria and constraints, brainstorming possible solutions, selecting the best design or solution, creating and testing prototypes, refining the final design,* and *communicating results to others* (NASA eClips, n.d.; Hafiz & Ayop, 2019). Likewise, Tipmontiane and Williams (2021) explain that the various steps in the EDP are considered iterative and creative learning processes by applying interdisciplinary concepts from science, mathematics, and technology. On the other hand, Wiggins and McTighe (2005, as cited in Iter, 2017) introduced the GRASPS model, which encompasses the elements of *goal, role, audience, situation, product/performance/purpose,* and *standards* in designing authentic, engaging, and challenging student tasks. Additionally, the key to a well-designed activity is to have a clear goal and provide learners with defined roles and a target audience in a real-world situation or context. Thus, students will produce meaningful products or processes consistent with academic standards and offer authentic and relevant learning experiences (Figure 1).

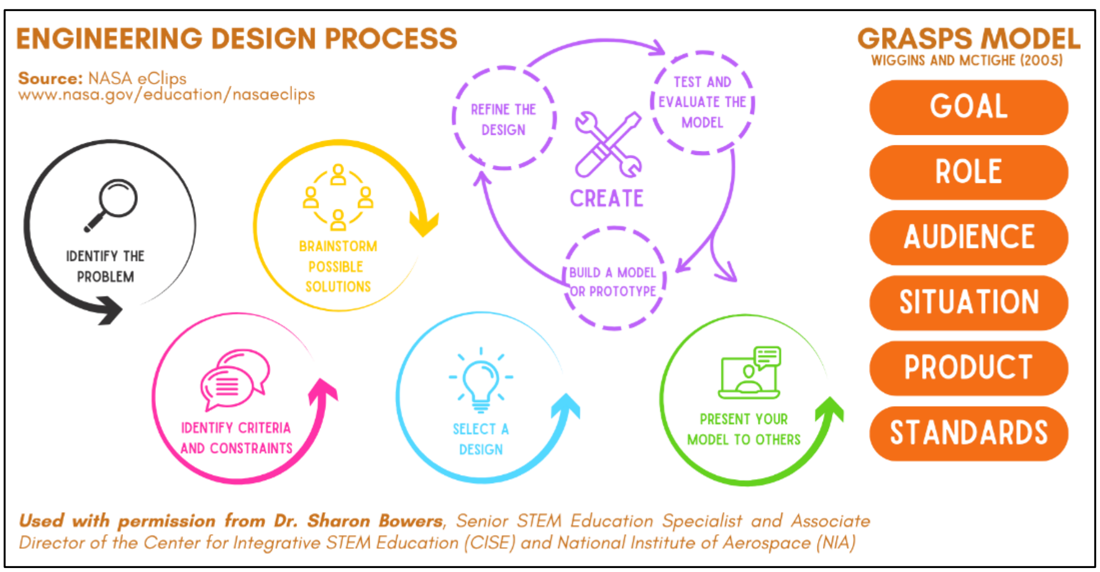

Figure 1. The engineering design process (NASA eClips, n.d.) and GRASPS model (Wiggins & McTighe, 2005)

Notably, there is a research gap in developing and applying engineering design process-oriented activities that integrate the GRASPS model. Several studies have shown that the development of EDP activities is conducted independently, distinct from the GRASPS model (Bunprom et al., 2019; Carvajal et al., 2021; Lin et al., 2021; Nurtjahyo et al., 2019; Thornburgh et al., 2020; Uzel & Bilici, 2022; Xue et al., 2023). Building on this context, the researchers utilized the GRASPS model as the framework for the problem scenario, and the EDP was used as an approach to develop products or processes that address the task. Likewise, the significance of this current investigation highlights the potential benefits to individuals and entities entrusted with implementing the new curriculum of the Department of Education. Significantly, this inquiry contributes to the delivery of quality basic education aimed at developing the desired competencies and skills of the learners. Moreover, the results of this study highlight the importance of integrating the engineering design process and the GRASPS model into the existing body of knowledge on STEM education, as well as its practical implications for various educational stakeholders.

In line with these objectives, the study sought to answer the following research questions:

1. What learning activities may be developed using the engineering design process with the following features: integration of the GRASPS model, use of higher-order thinking skills (HOTS), and collaborative learning?
2. What are the students' meaningful learning experiences while accomplishing the engineering design process-oriented activities?
3. What are the effects of engineering design process-oriented activities on students' conceptual understanding and cognitive process skills?

This investigation offers valuable insights into developing and implementing engineering design process-oriented activities, integrating the GRASPS model, which is considered distinct from previous literature. Likewise, this inquiry sheds light on the effects of the approach on students' conceptual understanding and cognitive process skills, including the meaningful learning experiences that occur during the engineering design process.

METHODOLOGY

This study employed a descriptive developmental research design to describe the development of engineering design process-oriented activities and to determine their effect on students' conceptual understanding and cognitive process skills. Richey and Klein (2014) defined developmental research as the systematic inquiry into the design, development, and evaluation of instructional programs, processes, and materials that meet standards of internal consistency and effectiveness. Likewise, this study was guided by the ADDIE model, which consists of stages: Analyze, Design, Develop, Implement, and Evaluate. Lotivio and Bercasio (2022) described this model as allowing instructional designers to focus on the needs, learning objectives, and learning outcomes when designing personalized learning materials. Specific to this inquiry, the developmental-descriptive method is employed to cover the analysis, design, and development stages, with an emphasis on the development of activities. The implementation and evaluation stages were then covered using a one-group pretest-posttest design to determine the effects of the activities.

The respondents consist of thirty-six Grade 11 students from one public secondary school in the province of Albay, Philippines. Specifically, the students enrolled in the Science, Technology, Engineering, and Mathematics (STEM) strand for the school year 2023-2024. This population was selected based on the available data on the least mastered competencies and standards in science subjects provided by the school. Moreover, the class engaged in engineering design process-oriented activities. Furthermore, a mixed-methods approach was employed to gain a comprehensive understanding of the effects of engineering design process-oriented activities, integrating the GRASPS model. Quantitative data were collected from pretests and posttests, measuring students' conceptual understanding and cognitive process skills. The scores were statistically analyzed using appropriate tests to determine significant changes and effect sizes.

Meanwhile, qualitative data were gathered through journal entries, classroom observations, and focus group discussions to document students' meaningful learning experiences during the activities. Thematic analysis was employed to identify recurring patterns in students' reflections, challenges encountered, and strategies used in problem-solving. Observational data provided insights into students' engagement, collaboration, and application of EDP principles, while focus group discussions allowed participants to articulate their thoughts on how the activities influenced their learning process. This research employed triangulation analysis. As described by Patton (1999), triangulation involves employing multiple methods and data sources to gain a comprehensive and in-depth understanding of a phenomenon. Overall, by integrating both qualitative and quantitative findings, this inquiry ensured a more holistic interpretation of students' learning experiences, capturing not only measurable improvements in understanding but also their attitudes, problem-solving approaches, and cognitive development throughout the EDP.

Research Instruments

Evaluation Tool for the EDP-Oriented Activities. This evaluation tool for print materials is sourced from the Learning Resources Management and Development System (LRMDS), which is utilized to assess the developed engineering design process-oriented activities, adhering to Department of Education (DepEd) standards. To elaborate on the tool, evaluation factors include content, format, presentation and organization, accuracy, and up-to-date information. Activities must score at least 21 out of 28 points to pass content validity. A minimum score of 54 out of 72 points is required for format validity. Presentation and organization demand at least 15 points out of 20 for validity. Accuracy and up-to-date information require a score of 24 out of 24 points. Additionally, an evaluation tool was developed to assess the congruence of the EDP-oriented activities based on the following criteria: (1) alignment to the objectives, (2) effective use of the EDP & GRASPS model, (3) higher-order thinking skills integration, (4) collaborative learning, (5) articulations of biological concepts, and (6) cognitive process skills involved. Five (5) evaluators reviewed the developed evaluation tool intended to evaluate the presence of features. Throughout the instrument validation process in this study, the evaluators had at least a master's degree in science education and had a minimum of five (5) years of teaching experience.

Student's Journal. One approach employed to capture students' experiences during the conduct of learning activities involves the use of journal writing, a well-established technique in qualitative research. Participants utilize journals to articulate and refine their thoughts, beliefs, and responses to the ongoing study and learning activities. In the current investigation, four (4) questions were developed to guide students in sharing their experiences and engagement across various stages of the EDP-oriented activities. The sample journal question was: "*What biology concepts did you learn during the engineering design process-oriented activity?*"

Observation Sheet. Another method for data collection for learning experiences involves using observation sheets. This non-participant observation approach involves the teacher observing students while they engage in activities without direct participation. Three (3) science teachers were involved in the observation. Moreover, the questions focused on students' understanding of concepts, their feelings and emotions, and the behaviors they displayed while completing the activities. The sample question includes, *"Based on your observation, how do students feel about the engineering design process-oriented activity?"*

Focus Group Discussion Guide. The researchers utilized this instrument to validate themes and supplement the qualitative and quantitative data in the investigation. The objective of the focus group discussion was to describe students' learning experiences and engagement after the engineering design process-oriented activities. In addition, six (6) open-ended questions were developed, including the discussion format according to the guidelines outlined by Krueger and Casey (2009) and Reichert et al. (2021). The sample question in the focus group includes, "*What do you think is the importance of your activity?*"

Likewise, five (5) evaluators classified the questions or statements on the student's journal, observation sheet, and focus group discussion guide as good/ highly relevant (4), moderate/ quite relevant (3), weak/ somewhat relevant (2), or not suitable/ not relevant (1). Moreover, evaluators provided some recommendations, and revisions were incorporated. Then, the final instruments were returned to the evaluators for final approval. To describe the content validity indices (CVI) of different instruments used in the investigation, including the journal questions, focus group discussion prompts, and teacher observation questions, three content validity indices from the studies of Rodrigues et al. (2017) and Yusoff (2019) were employed. Noteworthy, evaluators in this study reported that all the instruments have a value ranging from 0.99 to 1.00 for all indices. This value aligns with the acceptable cut-off score of Polit et al. (2007, as cited in Yusoff, 2019), which suggests that when the panel of experts or evaluators consists of three to five members, the CVI value should be 1. This indicates that all questions or statements in the instruments were relevant in assessing the intended constructs.

Conceptual Understanding Test (CUT). This test is comprised of a 50-item, four-option multiple-choice test designed to determine the students' conceptual understanding and mastery of concepts. Five (5) evaluators validated the test using the 5-point scale validation tool adapted from the study of Longasa (2019). The evaluators assessed each question using the following criteria: alignment with the table of specifications, content accuracy, organization of information, and grammar. Additionally, the CUT was piloted, and item analysis was performed. For scale-level reliability, this test had a Kuder-Richardson 20 (KR20) value of 0.78, with a standard error of measurement of 3.05. Noteworthy, for research purposes, KR20 reliability should be at least 0.70 or higher (Fraenkel et al., 2012). Overall, this suggests that the conceptual understanding test is good for classroom assessment.

Cognitive Process Skills Test (CPST). This instrument consists of 30 open-ended questions, each anchored to the identified least mastered content standards in genetics. In addition, the test items were distributed across three cognitive process skills: information processing, critical thinking, and problem-solving. Similarly, this test is validated using the same process as the previous test, and items were categorized by the evaluators as "essential," "useful, but not essential," or "not necessary." Additionally, the content validity ratio (CVR) from the study of Perdana et al. (2019) was used to assess the agreement among experts in a panel regarding how many consider an open-ended question to be "essential." The evaluators reported that all cognitive process skills test items had a CVR score of 1.00. This suggests that the CPST items were essential and appropriate to measure the students' cognitive process skills.

Data Gathering Procedure

The proponents obtained the necessary documents before conducting the study. Likewise, the researchers secured permission from the Schools Division Office to ensure the well-coordinated implementation of the activities and to comply with the Department of Education's policies and guidelines. Furthermore, this study strictly complies with the ethical guidelines outlined in the Republic Act 10173, commonly known as the Data Privacy Act of 2012. On the other hand, engineering design process-oriented activities, including tests, journal entries, and focus groups, were implemented over eight weeks or one academic quarter (Table 1).

Table 1. Implementation of engineering design process-oriented activities

Week	Activities*	Content Standards
1	Pretests	
2	Designing a Protein Model	Structures and Functions of DNA, RNA, and Proteins
3	Designing a Nanotube: Fighting Breast Cancer	Central Dogma of Molecular Biology
4	Planning and Designing an Experiment	Mendel's Law of Inheritance
5	Designing a Game	Non-Mendelian Modes of Inheritance
6	Colorblind Cat Café Design Challenge	Sex-Linked Characters
7	Genetically Modified Fruit Design Challenge	Genetic Engineering and Recombinant DNA
8	Posttest and Focus Group Discussion	

** journal entries were written during and after each EDP activity*

Alternatively, the students were grouped randomly using the fishbowl draw method since the class had an unequal number of male and female students. This method ensured that both sexes represented each engineering design team. Each team comprises seven (7) to eight (8) students. Furthermore, each member determined their roles in each activity, such as team leader, assistant leader, secretary, communicator, resource manager, timer, and inspirer. Likewise, students created group chats for more efficient communication during the activity. To highlight the implementation of the study each week, Day 1 was allocated for a short discussion using the lesson plan exemplars available in the school in genetics. Furthermore, instructions and requirements for the activity were given. Day 2 was dedicated to the first to third stages of the engineering design process, which involved identifying the problem, determining criteria and constraints, and brainstorming potential solutions.

Day 3 was allocated for selecting the design and creating the model or prototype. Day 4 was devoted to testing, refining, presenting the models or prototypes, and conducting peer reviews. The engineering design process stages and teams' responses were documented in the EDP-oriented activity packets. Teachers observed the student's performance and engagement during the activity using the observation instrument. The models or prototypes were also rated, and feedback was provided using the engineering design performance rubric adopted from Kaiser (2019). The researchers took photographs of the EDP stages of every activity for documentation and further analysis. Posttests for conceptual understanding and cognitive process skills were administered after all the EDP-oriented activities were completed. Lastly, focus group discussions were conducted in class to validate the themes and corroborate the qualitative data obtained in the investigation.

Analysis of Qualitative Data

Following the implementation, data were obtained through journal entries, teacher observation sheets, and focus group discussions. A thematic analysis was conducted to identify, analyze, and interpret qualitative patterns within the collected data. This study employed inductive coding, a bottom-up method in which codes are generated directly from qualitative sources without prior assumptions. This approach enables themes or narratives to emerge from the raw information naturally. Notably, the researchers conducted a thematic analysis guided by the frameworks of Braun and Clarke (2006) and Nowell et al. (2017). The qualitative analysis process consisted of six phases: Phase 1 involved data familiarization, record-keeping, and prolonged engagement. In Phase 2, initial codes were generated, audit trails were maintained, and code frequency was recorded. Phase 3 focused on identifying themes using diagrams and detailed notes to map concept hierarchies. In Phase 4, themes were reviewed in relation to the raw data. Phase 5 involved defining and naming themes. Noteworthy, breaks were taken throughout the process to manage the data volume and enhance pattern recognition. In Phase 6, an analytical narrative was developed, linking themes to codes and theories. Lastly, respondents validated the emerging themes to ensure the trustworthiness of the generated qualitative findings, and a peer researcher with relevant experience reviewed the process.

Statistical Treatment

The quantitative data obtained from the study was tabulated using Google Sheets™ and analyzed in GraphPad Prism version 10.2.2 (397) for Windows. The data from the conceptual understanding and cognitive process skills of students were computed using mean scores for each content standard and cognitive process skill. Performance Level (PL) was also calculated using the formula from the Department of Education to interpret student performance, categorizing mastery levels from "No Mastery" to "Full Mastery." In addition, normalized gain (g), based on the formula by Hake (1998, as cited in Rani et al., 2017), was employed, with scores interpreted as high, medium, low, or stable. Furthermore, the inter-rater reliability, as measured by Weighted Cohen's Kappa (κ), was employed to assess the consistency of agreement between evaluators in the open-ended test. Furthermore, a paired t-test was used to compare pretest and posttest means and significant differences, with a significance level of $p < .05$. Lastly, Cohen's d was calculated to interpret the magnitude of differences in scores, following the descriptors provided by Cohen (1988) and Sawilowsky (2009).

RESULTS AND DISCUSSION

This investigation aimed to develop and implement engineering design process (EDP) - oriented activities with integration of the GRASPS model. Moreover, the problem scenario had a predefined goal, role, audience, situation, product/ performance, and standards utilized in the contents of the General Biology Curriculum in senior high school, specifically in Genetics. Significantly, this investigation is also in line with the pilot implementation of the new curriculum of the Department of Education, which emphasizes the use of the engineering design process in science, mathematics, and technology and livelihood education (TLE). Furthermore, this section presents the findings and discussions in relation to the research questions.

The Developed Engineering Design Process (EDP)-Oriented Activities

The researchers were able to develop six (6) engineering design process-oriented activities. These activities were based on the least mastered content standards in General Biology 2 (Figure 2). Similarly, the proponents considered and enhanced the performance standards in the curriculum, which were suited to the current investigation, for example, in the performance standard specifically related to building models of DNA, RNA, and proteins in EDP-oriented activity one. The performance standard was improved and transformed to create a model or product using the engineering design process, focusing on the structures and functions of DNA, RNA, and proteins. Notably, the stages of the engineering design process utilized in the investigation were adopted from NASA eClips™, with permission from Dr. Sharon Bowers, the senior STEM education specialist and associate director of the Center for Integrative STEM Education (CISE) and the National Institute of Aerospace (NIA).

Figure 2. Six (6) engineering design process-oriented activities in genetics

Integration of the GRASPS model was highly evident (M = 4.97, SD = 0.03) in developed activities. The engineering design process-oriented activities are structured to ensure clear goals, provide students with a clear direction for the activity, and give students a sense of purpose in their work. Additionally, roles are crucial since this is the perspective from which the student approaches the task. The audience is considered to simulate real-world applications and is typically the client or end-users of engineering design process-oriented activities. The sample problem scenario of the engineering design process activity that integrates the GRASPS model was provided (see Figure 3). Specifically, the learners act as biomedical engineers, presenting the structural protein structure to an audience composed of the child's family, students, and educators. Furthermore, Velasco (2022) explained that the GRASPS model utilizes a structured approach and encourages the application of learned concepts to real-world situations. This approach facilitates a clearer understanding of the challenges associated with promoting scientific literacy. Moreover, students are encouraged to excel in their designs as they are accountable for their work. Lastly, situations provide the context for students to create solutions, and the final product or performance is the culmination of their collaboration.

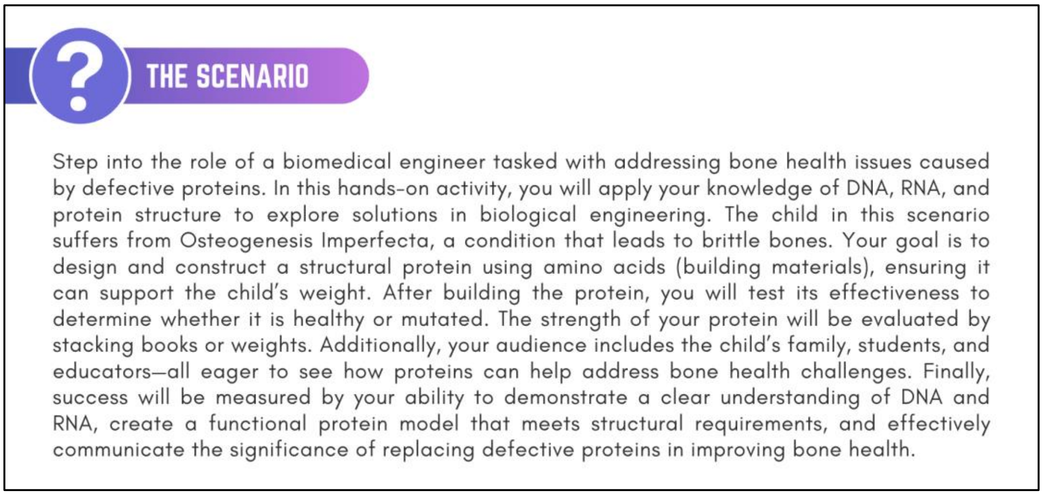

Figure 3. Sample problem scenario in GRASPS format

Higher-order thinking skills (HOTS) features were highly evident (M = 4.95, SD = 0.03) in the developed engineering design process-oriented activities. These skills are essential for comprehending the engineering design process. Higher-order thinking skills are emphasized as essential cognitive skills and are often targeted in various classroom instructions. In addition, as proposed by Krathwohl (as cited in Sopakitiboon et al., 2023), the three domains of HOTS consist of *analysis*, in which students break complex information into smaller parts to understand its components and how they relate to each other, *evaluating*, instances where students assess the value or worth of information, ideas, materials, or solutions based on criteria and standards; and *creating*, where students generate new ideas, products, or processes by combining existing knowledge in innovative ways. Similarly, critical thinking skills and problem-solving are crucial in any career to ensure future success. These skills enable learners to analyze problem scenarios specific to the EDP-oriented activities. Table 2 illustrates how higher-order thinking skills, such as analysis, evaluating, and creating are demonstrated in various engineering design process-oriented activities.

Table 2. Sample manifestations of higher-order thinking skills (HOTS) in the EDP-oriented activities

EDP-Oriented Activities Exemplars	Sample Manifestation of HOTS
Design a Protein Model	• Students ***analyze*** the building blocks (amino acids) to determine how to construct the structural protein. • In the team, learners ***evaluate*** the effectiveness of the protein design by prototype testing using weights. • In the activity, groups must ***create*** new structural proteins using the provided amino acids (household/ art materials).
Plan and Design an Experiment	• In the task, students ***analyze*** traits and their patterns of inheritance. • The EDP teams ***evaluate*** the clarity and usefulness of the instructions provided for the sample experimental design. • In the design challenge, learners must ***create*** a simple experiment using jelly beans (or chocolate balls) to represent human traits.
Genetically Modified Fruit Design Challenge	• Students ***analyze*** the challenges of agriculture, including crop yield, plant diseases, pests, shelf life, and nutritional value. • The group ***evaluates*** different genetic modifications and their potential impact on the fruit's traits, considering effectiveness, safety, and ethical implications. • The EDP team ***creates*** a genetically modified fruit with a specific trait, selects a unique feature, and identifies the source and target organisms for genetic modification.

The collaborative learning features were highly evident (M = 4.94, SD = 0.01) in the developed engineering design process-oriented activities. Collaboration is an essential aspect of 21st-century education, where students are encouraged to be active learners. Ghavifekr (2020) described that modern collaborative learning promotes cognitive thinking and peer interaction, leading to the development of social interaction skills. Collaboration among students facilitates mutual learning, idea sharing, and exposure to diverse perspectives, collectively enhancing problem-solving and critical thinking skills. Similarly, prominent scholars in education, such as Vygotsky (1978), advocate that students learn best in a social context. According to this view, teachers play a crucial role in creating an active learning environment where students engage in collaborative activities.

Turner et al. (2016) suggest that collaboration, brainstorming, and personal experiences can be effective strategies for developing projects that enhance student learning experiences. On the other hand, LaKose (2015) and Parker (2022) employed various roles in the engineering design activity to showcase collaboration. Each student in the team is assigned specific duties, including those of a manager, recorder, resource officer, and lab technician. Moreover, specific roles in an engineering design activity are crucial in promoting a sense of responsibility and accountability among team members. It also helps distribute tasks according to the strengths of the members, ensuring that all aspects of the challenge are adequately covered. These roles enhance collaboration by encouraging students to work towards a common goal. In the current study, the engineering design process-oriented activities developed by the researchers were explicitly designed to emphasize collaboration among students with specific roles, such as team leader, assistant leader, secretary, communicator, resource manager, timer, and inspirer; these various roles and perspectives can lead to more innovative and effective solutions. Similarly, Zhou et al. (2022) described collaboration as crucial in the design process, such as selecting a solution and brainstorming; it is also required to help generate various ideas and solutions. Moreover, as they progress through the stages of the EDP, they are expected to work together to complete the EDP student packets and ultimately design and test a prototype to address the given problem. Table 3 summarizes the manifestation of collaborative learning in each engineering design process-oriented activity.

Table 3. Sample manifestations of collaborative learning feature in the EDP-oriented activities

EDP-Oriented Activities Exemplars	Sample Manifestation of Collaborative Learning
Design a Nanotube: Fighting Breast Cancer	● Students work together to design and test a carbon nanotube structure for breast cancer detection using household materials with high thermal conductivity. ● The team members research what others have done to solve the problem. ● Groups identify factors that might limit the solution, such as cost, material availability, and safety concerns.
Design a Game	● Students design and test a game that simulates concepts in genetics, such as codominance, incomplete dominance, and multiple alleles. ● Each member researches the possible solutions proposed by others and generates a unique design for the game. ● Surveys and interviews with other teams or peers help improve the game.
Colorblind Cat Café Design Challenge	● Students propose a solution that accommodates both colorblind and normally sighted customers while considering various design constraints. ● The team researches what others have done to solve the problem. ● Each member provides suggestions on solutions and addresses constraints that may affect the design, such as material availability.

Noteworthy, central to the evaluators' assessments, the six engineering design process-oriented activities received high passing ratings of 28 points for content, 68 points for format, 20 points for presentation and organization, and 24 points for accuracy and up-to-date information. This suggests that the developed activities met all the criteria and are recommended for use in public schools. Additionally, two of the evaluators stated that *"..the EDP activities are understandable and engaging. It enables learners to enhance their critical thinking skills through* *a sequence of tasks that stimulate higher-order thinking skills (HOTS) and metacognition,"* and *"..the developed learning materials are highly commendable in terms of their content, alignment with learning competencies and research objectives, including the suitability for the intended level of learners."*

Student Engagement and Meaningful Learning Experiences

This study documented the meaningful learning experiences of students throughout the implementation of engineering design process-oriented activities. According to Ghazali and Nordin (2019), meaningful learning is characterized by its active, constructive, and enduring nature. Meanwhile, Kostiainen et al. (2018) described meaningful learning experiences as worthwhile experiences from the perspective of the students. Central to the current investigation, the meaningful learning experiences of students during the engineering design process (EDP)-oriented activities were described thematically. Notably, the researchers utilized students' journals, teacher observations, and excerpts from focus group discussions to identify themes associated with students' meaningful learning experiences. These themes were (1) *understanding of concepts,* (2) *student collaborative engagement*, (3) *interests and attitudes,* and (4) *development of EDP skills*, all derived from the thirteen (13) identified codes.

Understanding of concepts was manifested in three scenarios: articulations of the genetics concepts through reflections, representation of genetics concepts through models or prototypes, and applications of the concepts in real-life scenarios. In the sample excerpt, *"It made me realize how traits can be passed through generations and how patterns occur…I saw the patterns of the traits emerging from the data or results collected during the testing of the experiment."* In this instance, students express their understanding or thoughts on genetics concepts, including insights gained, questions raised, or connections made with prior knowledge. Similarly, Chang (2019) highlighted that reflecting on the design tasks can help learners perceive the interconnections within the knowledge they acquire. In the sample quote, *"…applying the concepts to design a model of protein to address the problem of brittle bone disease, and now I understand the concept of genotype to phenotype."* This demonstrates that learners create or use models or prototypes to visually or tangibly represent the concepts, demonstrating their understanding through these representations. Furthermore, this observation is consistent with the findings of Radloff et al. (2019), which emphasize the significance of modeling or prototyping in engineering design tasks in enhancing students' understanding of scientific concepts. Additionally, the excerpt also illustrates instances where students discuss or demonstrate how genetics concepts are applied or could be applied in real-world situations, showcasing the practical relevance of these concepts. Overall, the theme of understanding the concepts aligns with Koh's (2017) notion of constructive meaningful learning, which involves engaging students in divergent thinking to interpret and synthesize content, leading to the development of new insights or understanding.

The second theme that emerged from the analysis was student collaborative engagement. This general idea is manifested in two codes: individual collaborative efforts and group dynamics. Individual collaborative efforts refer to instances where students demonstrate their roles, make significant contributions, and exhibit collaborative behavior. This can be illustrated in the sample responses: *"I reviewed the allocation of resources for the EDP and also assisted in facilitating the experiment."* and *"I ensure that materials are used efficiently and effectively to meet project goals."* In addition, group dynamics refers to observations of the interactions and behaviors within the group, revealing patterns of communication, leadership, or cooperation. This response illustrates group dynamics: *"One of our strategies was to identify each member's strongest points...For example, one of our teammates is skilled and creative; therefore, we decided to assign her tasks that require drawing illustrations and other similar tasks."* Based on the sample quotation, the student indicates that group interactions would help them enhance their designs.

Similarly, according to Gale et al. (2019), students expressed appreciation for opportunities to collaborate with their peers during the engineering design task. Furthermore, when discussing the benefits of collaboration, students primarily emphasized how working together led to more successful or efficient design processes. Overall, the theme of student collaborative engagement is supported by assertions from Howland et al. (as cited in Hsbollah & Hassan, 2022), which highlight that in cooperative meaningful learning, students communicate, collaborate, and complement each other's knowledge and skills to solve problems and perform tasks.

Another theme that emerged was interests and attitudes. This general idea was highlighted in five (5) codes: "Aha!" moments during the EDP-oriented activity, challenges encountered and resolutions, individual experiences during the activity, reflection in the design process, and applications in a future-oriented context. It can noted in the quotations, *"I am amazed at how engineering together with biology find ways to fight diseases like breast cancer."* and *"I found it fascinating to use items like jelly beans or chocolate balls to explain complicated ideas."* students were able to demonstrate the moments of sudden realization, insight, or clarity related to the EDP activity or its objectives, indicating a deepened understanding or a new perspective. Additionally, learners also experience challenges and resolutions to the problems, as shown in the excerpt: *"...we encountered difficulty on how to design the prototype of the game. We addressed this by gathering information and asking for help from others such as teachers and peers."* On the other hand, learners had individual experiences and provided reflections on the design process. This scenario was documented in the sample quote: *"The activity was good and enjoyable. I have never experienced this kind of activity before. It was challenging due to the constraints."* This idea was confirmed by Precharattana et al. (2023), who also found that students enjoyed the engineering design process, even when faced with challenges.

In addition, Figure 4 shows the sample models or prototypes and redesign process of the students, where students reflect on their design process, evaluate their decisions, discuss what worked well or could be improved, and consider the implications of their choices. In the provided excerpt, *"...the aspect I would consider refining is the improvement of the testing process to ensure that the design meets the expected outcome."* It was clear that students reflected on their decisions and were open to changing the design process if given the chance. Thornburgh et al. (2020) further support this idea, suggesting that EDP activities should include reflective elements. As proposed, asking questions such as, *"After this discussion, could you redesign the model?"* and *"Are you satisfied with your design?"* emphasizes the redesign stage and highlights the importance of optimizing the prototype and its performance. Additionally, students demonstrated the applications of EDP activities in terms of future-oriented context; this can be found in the sample quotation: *"As medicine is a professional field that aligns with our Strand, it gives us a competitive advantage in college by understanding these topics thoroughly in the activity."* Students have clearly articulated how EDP-oriented activities can be applied in the future, such as in other subjects, various college courses, and their future careers. Overall, the theme of interests and attitudes is supported by the study of Smith (2016) that learning involves actively engaging with the world and demonstrating purposeful reflection on that active engagement, which enables deep learning and increases positive attitude toward engineering. Lastly, as corroborated by Howland et al. (2012), learners must articulate what they have accomplished and reflect on their activities and observations.

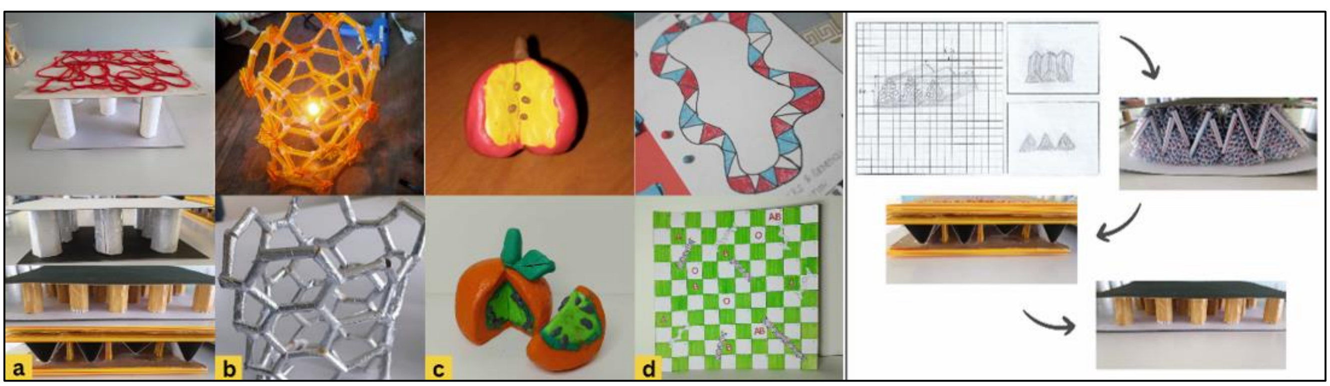

Figure 4. Sample models or prototypes (a - d) and redesign process in the protein model

Another theme that emerged was the development of EDP skills, as reflected in the following scenario, where learners demonstrated opportunities to develop problem-solving, critical thinking, and communication skills. To highlight problem-solving, it refers to the instances where students demonstrate their ability to identify, analyze, and solve problems related to the EDP activity. Notable sample responses, such as *"...our group tried to add materials to the nanotube by using aluminum foil to increase the conductivity of our model. We tested and refined the* *prototype,"* demonstrated that learners developed problem-solving skills during the EDP-oriented activities. Likewise, these statements aligned with the concept of advanced explanation, which entails designers revisiting their work to either redefine the problem, such as identifying new needs, or returning to the prototyping phase to improve their models for a revised design (Lin et al., 2021).

On the other hand, the students also demonstrated critical thinking skills during the EDP activities. By definition, critical thinking skills are the instances where participants engage in analytical thinking, evaluation, or questioning of ideas, concepts, or processes related to the EDP activity. In the provided excerpts, *"Our group considered how the structure would support heavy weights, and then we decided to incorporate a zigzag-like structure underneath to support any additional weights,"* and *"We closely examined the specifications, measurements, and experimental procedures, documenting our observations and findings."* It showed that students were able to apply critical thinking skills while completing the engineering design process-oriented activities. Specifically, the sample responses indicate that students demonstrated critical thinking skills by analyzing the provided materials, specifications, measurements, and experiment procedures before commencing the engineering design task. These qualitative data on critical thinking are consistent with the results reported by Carvajal et al. (2021) on the role of engineering design process-oriented activities in developing critical thinking skills, including higher-order thinking skills.

Another skill honed in the EDP-oriented activities is communication, demonstrated when students effectively convey ideas, thoughts, or information to others. The sample excerpts include, *"I discuss my ideas with my group members by asking for their opinions and feedback regarding the task.", "…during the activity, I helped summarize the ideas for the game."* and *"…we shared opinions on creating a firm and perfect cylinder shape."* Evidently, students were able to demonstrate their communication skills during the EDP-oriented activity. The provided responses highlight that students need to communicate to exchange ideas with one another to find the appropriate solution to the problem. The development of communication skills is supported by Putra et al. (2023), who assert that using the engineering design process enables students to communicate effectively with one another and develop more effective solutions based on scientific concepts. Similarly, Widiastuti et al. (2022) demonstrated that students' communication skills were evident throughout each stage of the engineering design process. The manner in which students approach problem-solving indicates their ability to communicate effectively in both verbal and written formats.

Enhancing Conceptual Understanding

The use of engineering design process-oriented activities with the integration of the GRASPS model demonstrates improvement in the conceptual understanding. According to Erickson and Lanning (2013), concepts are mental constructs that are abstract, timeless, and universal. Meanwhile, conceptual understanding is a crucial learning component often assessed through higher-order thinking skills such as synthesis, analysis, and evaluation. Konicek-Moran and Keeley (2015) argued that a more profound understanding of a concept emerges when students apply it in a different situation, describe or define it in their own words, and create a model. These descriptions are aligned with the implementation of engineering design process-oriented activities. Lastly, conceptual understanding involves comprehending the connections between facts and arranging them coherently.

The results showed a significant improvement in conceptual understanding after the implementation of engineering design process-oriented activities, t (35) = 8.51, p < .001 (see Table 4). Additionally, the performance level (PL) of the students was increased, with an overall mean score of 35.08, representing a PL of 70.17%, which suggests near mastery of the concepts. Notably, the third to sixth content standards (CS) were near mastery, while in the first and second content standards, students demonstrated mastery levels of 82.87% and 76.11%, respectively. This suggests that the learners had a mastery of the concepts, specifically focused on the structures and functions of DNA, RNA, and protein, including the content standard related to the Central Dogma of Molecular Biology.

Furthermore, the standard deviation of 10.49 in the posttest shows higher variability in the scores after the activities were conducted. This means that the students' performance in the posttest varied more widely compared to their performance in the pretest, suggesting that the learning activities had different levels of effectiveness for different students. Moreover, the student's conceptual understanding of genetics was enhanced after the implementation of EDP-oriented activities, demonstrating a very large effect (Cohen's d = 1.42) based on the descriptors initially proposed by Cohen (1988) and further expanded by Sawilowsky (2009).

Table 4. Pretest and posttest results on the conceptual understanding

Content Standard (CS)	Pretest			Posttest			Normalized Gain	
	Mean Score	Performance Level %	Performance Level VI	Mean Score	Performance Level %	Performance Level VI	(g)	VI
CS 1	3.75	62.50	NeM	4.97	82.87	M	0.54	Medium
CS 2	3.50	35.00	LM	7.61	76.11	M	0.63	Medium
CS 3	3.25	36.11	LM	6.00	66.67	NeM	0.48	Medium
CS 4	1.61	26.85	LM	4.03	67.13	NeM	0.55	Medium
CS 5	3.92	39.17	LM	6.64	66.39	NeM	0.45	Medium
CS 6	3.53	39.20	LM	5.83	64.81	NeM	0.42	Medium
Overall	19.56	39.11	LM	35.08	70.17	NeM	0.51	Medium
	Mean	SD	Mean Difference		t	p	d	Effect
Pretest	19.56	4.55	15.53		8.51	<.001	1.42	Very Large
Posttest	35.08	10.49						

Legend: VI (Verbal Interpretation), Performance Level: 92% and above is considered Full Mastery (FM), 83% to 91% means Near Full Mastery (NFM), 75% to 82% means Mastery (M), 51% to 74% means Near Mastery (NeM), 25% to 50% means Low Mastery (LM), and 24% below means No Mastery (NoM), Shapiro-Wilk (W) = 0.97, p = 0.51 (Passed Normality Test), Significance level: p<.05

Overall, the engineering design process-oriented activities support the improvement of students' conceptual understanding by engaging them in hands-on and authentic problem-solving tasks. In addition, according to the Cone of Experience of Dale (1969), hands-on activities such as designing models or prototyping can enhance learning, retention, and memory (Shana & Abulibdeh, 2023). Moreover, Davis and Summers (2015) explained that engaging in "action learning" techniques can result in 90% retention. Action learning (AL) involves problem-solving and experiential learning approaches. This strategy is particularly effective because it aligns with individuals' perceptual learning styles, which are sensory-based. Notably, the EDP-oriented activities engage multiple sensory channels, increasing and maximizing the likelihood of information retention.

This current investigation provided additional empirical evidence that using engineering design process-oriented activities improves understanding of science concepts. This finding is consistent with previous studies on EDP-oriented activities, such as the scholarly work of Fan and Yu (2017), who implemented a STEM engineering module in high school students. Their study found that learners demonstrated enhanced higher-order thinking skills, conceptual knowledge, and improved design projects compared to those who engaged with a technology education module alone. Meanwhile, in a study by Goldstein et al. (2018) on the implementation of engineering design projects, students were able to practice key competencies. While more in-depth design projects can enhance science learning, the study found that simply participating in a design project provides significant learning benefits. Moreover, Radloff et al. (2019) reported that integrating engineering design into pre-service elementary biology courses, particularly through life science design tasks, led to significant science learning gains. Their findings highlight students' enhanced knowledge and skills in modeling. Lastly, Chien et al. (2023) recommended that educators in both K-12 and higher education institutions create pedagogical models that provide a comprehensive and rigorous educational plan incorporating engineering design instruction to nurture STEM talent.

Development of Cognitive Process Skills

According to the Process-Oriented Guided Inquiry Learning (POGIL) Project (n.d.), cognitive process skills have three components, namely, information processing, problem-solving, and critical thinking. In addition, Navia

(2019) described that cognitive process skills are used when learning new concepts and procedures, practicing skills, and problem-solving. These cognitive process skills are crucial to academic success in the subject. Furthermore, Artuz and Roble (2021) explained that developing cognitive process skills requires learners to construct their understanding by discussing various ways to solve problems, which leads them to provide coherent reasoning to support their answers. Table 5 shows the significant improvement in cognitive process skills after the completion of engineering design process-oriented activities, t (35) = 16.62, p < .001. The data show that students demonstrated no mastery level in all the cognitive process skills in the pretest. The overall mean score is 17.92, representing a performance level of 11.94%, and problem-solving had the highest performance level of 19.33% among the cognitive process skills. Conversely, data also demonstrate that critical thinking had the lowest performance level of 5.72% during the pretest.

Table 5. Pretest and posttest results o gnitive process skills

Cognitive Process Skills	Pretest			Posttest			Normalized Gain	
	Mean Score	Performance Level %	Performance Level VI	Mean Score	Performance Level %	Performance Level VI	(g)	VI
Information Processing	5.39	10.78	NoM	25.11	50.22	LM	0.44	Medium
Problem-Solving	9.67	19.33	NoM	25.36	50.72	LM	0.39	Medium
Critical Thinking	2.86	5.72	NoM	23.61	47.22	LM	0.44	Medium
Overall	17.92	11.94	NoM	74.08	49.39	LM	0.43	Medium
	Mean	SD	Mean Difference		t	p	d	Effect
Pretest	17.92	9.43	56.17		16.62	<.001	2.77	Huge
Posttest	74.08	21.08						

Legend: VI (Verbal Interpretation), Performance Level: 92% and above is considered Full Mastery (FM), 83% to 91% means Near Full Mastery (NFM), 75% to 82% means Mastery (M), 51% to 74% means Near Mastery (NeM), 25% to 50% means Low Mastery (LM), and 24% below means No Mastery (NoM), Shapiro-Wilk (W) = 0.97, p = 0.68 (Passed Normality Test), Significance level: p<.05

It is essential to highlight that following the implementation of engineering design process-oriented activities, all cognitive process skills were improved. The group achieved a mean score of 74.08, with a performance level of 49.39%, indicating a low mastery level. This suggests that students enhance and apply their cognitive process skills after engaging in the activities, moving from no mastery to a low mastery level. Moreover, the class had a medium gain in all the cognitive process skills, with an overall value of 0.43. Interestingly, information processing and problem-solving exhibited comparable performance levels, with 50.22% and 50.72%, respectively. On the other hand, the cognitive process skills responses were evaluated using the rubric adopted from Navia (2019), in which students may earn a maximum of five (5) points for each question. Two independent evaluators assessed the cognitive process skills test responses, achieving inter-rater reliability with a weighted Cohen's Kappa (κ) value of 0.95, indicating near-perfect agreement.

Conversely, critical thinking exhibited the lowest level of performance among the cognitive process skills in the posttest, at 47.22%. Nonetheless, the medium normalized gain of 0.44 indicates that students could develop arguments or reach conclusions supported by evidence through the evaluation, analysis, and synthesis of relevant information. Moreover, the mean difference of 56.17 suggests a large mean gain after the activities. In addition, the standard deviation of 21.08 in the posttest suggests a higher variability in scores, indicating that students' performances were more spread out across the assessment. This variability suggests that while some students demonstrated strong understanding and mastery of the concepts, others struggled or needed more consistency in their knowledge and skills application. Meanwhile, the effect size for the EDP-oriented activities was calculated as Cohen's d = 2.77, indicating a huge effect size. This interpretation was based on the new effect size rule of thumb provided by Sawilowsky (2009). Notably, these findings are consistent with previous studies that highlight the impact of EDP on STEM education. Samad et al. (2023) reported that incorporating EDP stages in a chemistry module enhances computational thinking skills. Similarly, Abdurrahman et al. (2023) posited that integrating STEM-PBL with EDP, focusing on renewable energy, fosters STEM literacy and thinking skills by utilizing the engineering design thinking process. Additionally, Maryati et al. (2022) described how using an Arduino-based EDP motivated students, made learning enjoyable, and provided meaningful challenges that encouraged the development of students' problem-solving abilities. Likewise, Safitri et al. (2024) investigated the impact of STEM-based EDP on high school students and found that the model improves creative and critical thinking abilities. Collectively, these studies highlight the potential of EDP as an effective approach to developing cognitive process skills.

In essence, participation in engineering design process-oriented activities improved cognitive process skills, such as information processing, problem-solving, and critical thinking, progressing from a level of no mastery to a low mastery level. These findings suggest that the short implementation period contributed to achieving only a low level of mastery in performance based on the standards of the Department of Education. Similarly, Costa and Steffgen (2015) argued that acquiring new skills is a recurrent challenge encountered by students, thus requiring enough time and practice to master complex process skills. Defining the precise amount of time required to acquire a skill is challenging and relies on various factors, including the nature of the task, individual involvement, and abilities. Additionally, skills development can be learned by imitation, trial and error, or seeking help from teachers or learning materials. Therefore, this study argues that students require sufficient time and guidance to master specific cognitive process skills in the engineering design process.

CONCLUSION

This study developed, implemented, and examined the effects of engineering design process (EDP)-oriented activities on high school STEM students. Additionally, the investigation revealed substantial evidence of features in the developed engineering design process-oriented activities, including GRASPS model integration, higher-order thinking skills, and collaborative learning. Empirical data suggest that students found it meaningful when they understood the concepts, engaged collaboratively in EDP, and demonstrated interests and attitudes, which encouraged the enhancement of EDP skills. Lastly, the use of engineering design process-oriented activities generally improved students' conceptual understanding and cognitive process skills.

RECOMMENDATIONS

The study provided substantial evidence of the impact of implementing engineering design process-oriented activities. Likewise, the inquiry documented several meaningful learning experiences of students. To guide future investigations on the approach and practices, the following recommendations are offered for consideration:

1. The developed engineering design process-oriented activities can be utilized by educators teaching genetics in senior high school or other grade levels. Similarly, the Department of Education may use the results of this study to complement the implementation of the MATATAG Curriculum, which emphasizes the application of the engineering design process as a teaching and learning approach in STEM.

2. Biology teachers may utilize the validated conceptual understanding and cognitive process skills tests employed in the current study to assess learning outcomes in genetics.

3. In developing the same engineering design process-oriented materials, teachers must seamlessly integrate concepts and skills in science, technology, engineering, and mathematics to demonstrate holistic and meaningful learning experiences.

4. It is recommended that engineering design process-oriented activities with clear and proper guidelines be used, thereby avoiding disruptions of class discussion and ensuring coherence to the essential learning competencies. Additionally, the engineering design process should be used purposively to supplement the current instructional approaches in STEM classrooms.

5. To implement the engineering design process (EDP) more efficiently and effectively in the classrooms, several considerations must be addressed: (1) increased time should be allotted for EDP-oriented activities, (2) the availability of materials must be considered in the design task, (3) educators must be aware that some students may skip critical steps in the process, and (4) lesson plans including the activities should be cohesive and address the challenges in integrating the EDP model.

6. This research recommends integrating the EDP model by applying relevant concepts from the lesson or engineering principles in the curriculum to reduce the challenges of developing EDP-oriented activities. Additionally, curriculum guides provide performance exemplars related to EDP, which teachers can use to enhance and structure their instruction or design tasks using the GRASPS model.

7. Educators may select a core subject as the primary focus of the entire implementation, while other subjects can support problem-solving or processes within the design tasks or activities. On the other hand, teachers may explore the development of STEM-based engineering design process-oriented activities by aligning the tasks with STEM-related content and skills. They can also refer to the activities developed by Uzun and Şen (2023) as a reference.

8. As a guide for teachers, the engineering design process is not linear; it is iterative and cyclical, allowing students to progress and revisit previous stages. Noteworthy, educators should encourage students to make mistakes throughout the process, as this provides firsthand experience in overcoming challenges and developing solutions.

9. To effectively implement engineering design process-oriented activities, schools should establish structured support systems, including collaborative planning time for teachers and access to necessary materials. Moreover, clear implementation guidelines aligned with the MATATAG curriculum must be provided to ensure consistency across grade levels.

10. The Department of Education (DepEd) may also provide comprehensive training on EDP implementation in public schools to support teachers in enhancing the pedagogy relevant to their specific contexts. This training should develop theoretical frameworks for using EDP and provide practical applications for integrating the approach into teaching practices.

LIMITATIONS OF THE STUDY AND FUTURE RESEARCH

Despite the provided empirical data on the use and effects of the engineering design process (EDP) and GRASPS model, this investigation has several limitations. First, the population of the inquiry was concentrated solely in one secondary school within a particular division, which does not fully represent the situation in public schools as a whole. Secondly, the use of the one-group pretest-posttest design may not be generalizable to other contexts or settings due to the lack of a control group and the potential influence of extraneous factors. Thirdly, the study was delimited to biology, specifically genetics; thus, future research may explore similar studies involving the EDP in different subjects, such as other sciences, mathematics, technology and livelihood education (TLE), employing control and experimental groups over an extended period to assess learning outcomes. Lastly, scholars may also replicate the study in the next cohort year to assess learning variables such as redesign ability, retention, and creativity, as well as to describe the challenges faced by students in the engineering design process.

REGISTRATION AND DATA AVAILABILITY

This study has been registered with the Open Science Framework (OSF) to promote transparency and uphold research integrity. It is important to note that this registration was completed retrospectively. Additionally, all relevant materials and data associated with this investigation are available on the OSF project page at the following link: https://doi.org/10.17605/OSF.IO/ZNJ6M.

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DECLARATION OF INTEREST

The authors declare that there is no conflict of interest.

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