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Applying solver in the engineering design process to enhance critical thinking and innovation skills

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Abstract

This study aimed to develop and evaluate an instructional model that integrates Microsoft Excel's Solver into the engineering design process to enhance critical thinking and innovation skills among undergraduate engineering students. Addressing the need for graduates with strong problem-solving abilities, the study introduced a technology-enhanced learning approach grounded in real-world engineering tasks. Using a Research and Development (R&D) methodology, the study involved 30 students from an Optimization Analysis course, selected through purposive sampling. The instructional model combined Solver with the engineering design process to solve linear programming problems. Research instruments included a lesson plan, critical thinking and innovation assessments, behavior observation checklists, and a learner satisfaction survey. Quantitative data were analyzed using descriptive statistics, paired t-tests, and reliability analysis, while qualitative data were examined through content analysis. Results showed a significant improvement in students' critical thinking and innovation skills after the intervention ($p < .05$). Observations revealed active engagement, analytical thinking, and creative problem-solving. Students also reported high satisfaction with the learning experience. In conclusion, integrating Solver into the engineering design process effectively promotes critical thinking and innovation. This model offers practical value for educators seeking to enhance active, student-centered learning with digital tools in engineering education.

Keywords: Critical thinking, Engineering design process, Innovation skills, Linear programming, Solver.

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1. Introduction

In the era of Industry 4.0 and the ongoing digital transformation, engineering education is increasingly required to cultivate not only technical expertise but also essential 21st-century competencies such as critical thinking, data-informed decision-making, creativity, and complex problem-solving [1, 2]. Traditional lecture-based pedagogies, while effective for foundational knowledge delivery, often fall short in promoting these higher-order cognitive skills. To address this challenge, engineering curricula are shifting toward experiential and project-based learning approaches that prioritize active engagement, iterative design, and real-world problem-solving. The Engineering Design Process (EDP) is a prominent model in this domain, offering a structured yet adaptable framework that guides students through phases including problem definition, ideation, prototyping, analysis, and testing [3]. Despite its pedagogical advantages, studies have highlighted that students often encounter challenges in applying quantitative reasoning within the EDP, especially when faced with complex decision-making scenarios involving multiple variables and constraints [4]. This limitation underscores the need for tools that can support computational thinking and enhance data-driven decision-making capabilities. Microsoft Excel's Solver add-in, widely utilized in business and operations research for optimization tasks, has demonstrated potential for educational use [5]. Solver enables users to construct mathematical models, define constraints, and determine optimal solutions based on objective functions. Its interactive nature not only supports mathematical comprehension but also fosters experimentation and the evaluation of alternative design strategies [6]. Integrating Solver into the EDP framework presents a promising opportunity to strengthen systematic reasoning and encourage innovation in engineering design. For instance, in sustainable construction projects, students can use Solver to optimize energy consumption or material usage by balancing technical, economic, and environmental criteria [7].

1.1. Problem Statement

Although Solver offers clear potential for use in engineering education, its instructional integration remains limited. Students often lack opportunities to apply optimization tools in authentic problem-solving scenarios, especially within structured design processes like the EDP. This disconnect hinders the development of essential skills such as quantitative analysis, critical evaluation, and data-informed decision-making.

1.2. Research Objectives

This study was conducted with the following objectives:

- To design an instructional model that integrates Microsoft Excel's Solver into project-based learning tasks aligned with the Engineering Design Process.
- To evaluate the effectiveness of the model in enhancing students' critical thinking, quantitative reasoning, and problem-solving abilities in real-world engineering scenarios.

1.3. Research Gap

While prior research has demonstrated the pedagogical strengths of EDP and the utility of Solver in business contexts, few studies have investigated how the integration of Solver into engineering design activities can foster deeper learning, especially regarding the development of critical and innovative thinking skills. This research addresses that gap by proposing and testing an integrated instructional framework within higher education engineering programs.

1.4. Research Questions

This study seeks to answer the following research questions:

- How can Solver be effectively integrated into project-based learning activities grounded in the Engineering Design Process?
- What are the impacts of this integration on students' ability to perform quantitative analysis and make evidence-based decisions?
- How does the use of Solver influence the development of students' critical thinking and innovation in engineering problem solving?

1.5 Research Steps

To achieve the stated objectives, the study followed a systematic research process comprising four key steps:

- Needs Analysis – Identifying existing challenges and learner needs regarding
- quantitative reasoning and problem-solving in engineering education.
- Instructional Model Design – Developing a pedagogical framework that
- integrates Solver into EDP-based project learning tasks.
- Implementation – Applying the instructional model in a real-world classroom
- setting involving higher education engineering students.
- Evaluation – Assessing the effectiveness of the model using qualitative and quantitative data to measure learning outcomes in critical thinking, innovation, and optimization skills.

This structured approach offers new insights into how digital tools like Solver can be harnessed to promote 21st century competencies in engineering education through innovative instructional design.

2. Literature Review

The application of Solver in the engineering design process serves as an effective approach to fostering students' critical thinking and innovation skills. Through computational tools and systematic problem-solving, learners are able to engage in analytical reasoning and decision-making in authentic contexts. Relevant literature plays a crucial role in supporting this pedagogical approach.

2.1. Engineering Design Process (EDP)

The Engineering Design Process (EDP) provides a learning framework that encourages students to develop systematic problem-solving skills through stages such as problem identification, constraint analysis, solution generation, prototyping, and evaluation [8]. This approach emphasizes interdisciplinary knowledge integration to promote higher-order thinking and decision-making abilities within real-world contexts. EDP is frequently employed to solve problems or create innovations using engineering principles of analysis, experimentation, and iterative improvement to develop effective solutions or products [3].

EDP is inherently iterative in nature National Research Council [9] and Hynes et al. [10] typically consisting of the following core stages: Identify the Problem, Research and Explore, Specify Requirements and Constraints, Brainstorm Possible Solutions, Select the Best Solution, Develop and Prototype the Solution, and Test, Evaluate, and Refine. Beyond being a technical framework, EDP is a powerful tool for cultivating higher-order thinking skills such as critical thinking, complex problem solving, and innovation in learners [11]. Integrating EDP into higher education facilitates authentic practice aligned with professional engineering and design contexts, enhancing deep learning rather than rote memorization.

2.2. The Application of Solver in Quantitative Problem Solving

The application of Solver in solving quantitative problems is highly significant in education, particularly in STEM disciplines (Science, Technology, Engineering, and Mathematics). Solver enables learners to analyze large data sets and solve complex problems efficiently, promoting active learning by encouraging student engagement in thinking, analysis, and decision-making [12]. From an educational perspective, Solver is not merely a tool for obtaining correct answers; rather, it fosters understanding of quantitative reasoning and promotes systematic thinking and problem-solving, which are essential skills for 21st-century learning [13]. It also nurtures technological proficiency and real-world problem-solving skills applicable to students' future careers and everyday lives.

Microsoft Excel's Solver add-in is widely used for mathematical and managerial problem-solving, particularly in linear programming, where it aids in finding optimal solutions within defined constraints. Zhang and Patel [7] demonstrated that Solver improves students' understanding of applied mathematical concepts, especially when integrated with simulations or real-world scenarios. It enhances accuracy and efficiency in students' analytical and decision-making processes. Solver automates complex calculations that would traditionally require time-consuming or specialized expertise, thereby allowing students to focus more on conceptual development, innovation, and hypothesis testing [1]. Furthermore, combining design processes with Solver enhances critical thinking an essential skill in the 21st century.

In higher education contexts, Solver is recognized as a vital tool for addressing quantitative problems, particularly in disciplines such as management, engineering, economics, and statistics. It can simulate scenarios and solve both linear and nonlinear mathematical problems, including resource allocation, cost reduction, and profit maximization. Chang [14] found that Solver supports analytical thinking and the application of mathematical knowledge to real-world problems. It also promotes active learning by allowing students to experiment and interpret outcomes independently. Supporting this view, Mokhtar and Ismail [15] reported that students using Solver had a better understanding of optimization concepts compared to those in lecture-based classes, as the tool concretely illustrates variable interactions. Moreover, Solver enhances instruction on complex topics such as Markov models, transportation models, and project planning techniques like PERT/CPM. However, to maximize the effectiveness of Solver, instruction must be designed appropriately employing real-world problems and fostering classroom participation which supports both quantitative knowledge and technological competence in the digital era.

2.3. Critical Thinking Skills

Critical thinking has become a core competency in 21st century education. It refers to the capacity to analyze, synthesize, and evaluate information logically and comprehensively [16]. Numerous studies have demonstrated that problem-based learning, engineering design processes, and the integration of technology can significantly enhance critical thinking skills [17]. In an era marked by rapid technological transformation, education must emphasize the development of skills such as critical thinking and innovation, which form the foundation of lifelong learning and the ability to solve complex problems.

The Engineering Design Process (EDP) offers a systematic framework for problem-solving. It includes clearly defined steps such as problem identification, questioning, brainstorming, designing, prototyping, testing, and refinement. Students play active roles as thinkers, practitioners, and evaluators. This aligns with principles of constructivist and hands-on learning, fostering reasoning, analysis, and knowledge synthesis for innovative creation. Integrating EDP into classrooms enables learners to engage with real-world problems and practice systematic decision-making through trial and error, a hallmark of critical thinking. Students are encouraged to pose reflective questions such as, "Is this option viable?" or "Is there a better alternative?" Through this process, they must evaluate the pros and cons of various solutions and choose the most rational path.

Moreover, when students create products or artifacts based on their imagination and knowledge especially in collaborative group settings they expand their perspectives and develop sustainable innovation. According to [10], the EDP enhances analytical, systematic, and creative thinking. Daugherty [18] similarly emphasizes that this process deepens learners' understanding of technological issues and cultivates effective critical thinking. Hence, the EDP is not merely a tool for science or technology instruction, but a powerful method for developing 21st-century skills: critical thinking and innovation.

2.4. Linear Programming in Education

Linear Programming (LP) is a mathematical optimization technique used to determine the best possible outcome under specific constraints, such as minimizing costs, efficiently allocating resources, or maximizing productivity. These problems are frequently encountered in real-life scenarios, including material allocation, production planning, and project management. LP is a key topic in applied mathematics, industrial engineering, and logistics. Traditionally, instruction has focused on computational procedures like the Simplex Method without linking content to authentic contexts, limiting students' conceptual understanding.

Recent research advocates for integrating simulations, Solver software, and problem-based learning to provide more meaningful learning experiences [5]. LP tasks inherently require critical thinking skills such as analytical reasoning, identifying constraints, and selecting the best alternative based on quantitative logic closely aligned with Facione's [19] conception of critical thinking.

In today's digital world, critical thinking and innovation are essential competencies for both education and industry. One effective strategy for cultivating these skills is the application of LP through technological tools such as Solver in the context of EDP. Solver, a Microsoft Excel add-in, allows learners to model LP problems by defining variables, objectives, and constraints. It then calculates optimal solutions. Using Solver not only enhances understanding of theoretical concepts but also promotes systematic planning and rational decision-making—hallmarks of critical thinking.

When LP problem-solving via Solver is embedded within the EDP through stages like problem definition, questioning, design, testing, and revision students engage in both system-level thinking and hands-on application. Examples include designing cost-efficient transportation systems or optimizing production plans. Learners must analyze constraints, interpret data, and consider alternatives, thereby fostering innovation rooted in data-driven reasoning. Williams [20] found that integrating technology into engineering problem-solving positively impacts higher-order thinking, especially critical thinking and problem-solving. Similarly, Suppapittayaporn et al. [21] revealed that students using Solver to tackle quantitative problems showed marked improvement in decision-making and systems thinking.

Therefore, LP through Solver under the EDP is not only a vehicle for teaching mathematics or technical planning but also an effective pedagogical strategy to foster critical thinking and systematic innovation skills vital for 21st-century learners to address real-world challenges.

2.5. Innovation in Learning and Design

Innovation is defined as the creation of new or improved solutions that generate real value whether in the form of products, processes, or ideas [22]. In the educational context, innovation extends beyond technology to encompass pedagogical shifts, such as hands-on learning, digital tools, and creative learning environments [23]. In engineering, innovation is central to designing effective solutions. Engineers must analyze, invent, and creatively use technology to generate new value [24]. The integration of innovation into learning via problem-based learning and design-based learning cultivates design thinking, critical reasoning, and ideation, all of which are essential for innovative engineers in the 21st century.

The innovation process consists of four key stages [25]:

1. Inspiration & Problem Identification – Identifying opportunities or user needs from existing challenges or research data [26].
2. Ideation – Generating creative and critical ideas through brainstorming and questioning [24].
3. Development & Prototyping – Testing selected ideas through prototypes, evaluating technical feasibility and user relevance.
4. Implementation & Iteration – Deploying solutions in real contexts and refining them based on feedback.

These steps not only focus on creating new ideas but also serve as frameworks for sustainable learning and development. Innovation skills, therefore, are essential in engineering, technology, and industry requiring learners to be creative, adaptable, and capable of turning ideas into practical innovations [27].

Effective development of innovation skills should involve authentic or simulated complex scenarios, enabling students to think, design, test, and iterate in a structured manner. Design-Based Learning (DBL) is one promising approach that enhances analytical thinking, planning, decision-making, and communication through the creation of products or solutions [28]. Technological tools like simulations, CAD/CAM, or Solver software also help students connect abstract concepts to measurable outcomes [29]. Furthermore, designing activities focused on complex problem-solving supports critical and systems thinking, core components of innovation within constrained environments like limited resources, time, or user demands [30].

By integrating design activities, technology, and complex problem-solving, educators can cultivate innovation skills that not only enhance learning but also prepare students for the demands of future workplaces.

3. Methodology

3.1. Research Design

This study employed a research and development (R&D) methodology aimed at designing, developing, and evaluating an engineering design-based instructional model that integrates Microsoft Excel's Solver add-in for solving linear programming problems. The primary objective was to cultivate critical thinking and innovation skills among undergraduate students by embedding active and problem-based learning principles into the learning process.

Unlike previous studies that focused solely on teaching Solver as a computational tool (e.g., for spreadsheet optimization or isolated exercises), this research integrated Solver within a broader engineering design learning cycle emphasizing real-world applications, collaborative problem-solving, and reflection. Furthermore, it incorporated both quantitative and qualitative assessment tools to holistically evaluate student outcomes, addressing a gap in prior studies that often relied exclusively on test scores or final solutions.

The research was conducted in three sequential phases:

Phase 1: Analysis and Design Phase

This phase focused on identifying instructional needs and creating a preliminary learning framework.

3.2. Problem and Contextual Analysis

The researcher conducted a review of course syllabi, instructional materials, and academic performance records to identify common student difficulties in courses such as production planning, resource management, and operations scheduling. Particular attention was paid to gaps in students' understanding of quantitative reasoning and their limited ability to use Solver effectively.

3.3. Interviews and Needs Assessment

Semi-structured interviews were conducted with three instructors who had at least five years of experience teaching linear programming. Additionally, structured surveys were distributed to 30 undergraduate students to assess their learning challenges, perceived skill gaps, and preferred instructional strategies.

3.4. Preliminary Learning Process Design

Based on the findings, a draft instructional process was developed, informed by Active Learning and Problem-Based Learning (PBL) approaches. The framework featured the following five steps:

- Problem Definition – Students engage with authentic or simulated real-world problems that involve constraints such as budget, time, or resource limits.
- Model Design – Students translate problems into mathematical models, defining variables, constraints, and objective functions.
- Solver Modeling – Students apply the Solver add-in to computationally solve their models.
- Results Analysis – Students interpret Solver outputs and evaluate the feasibility of proposed solutions.
- Reflection – Students reflect on their process, assess alternative strategies, and consider potential real-world implications.

The initial framework was reviewed by three experts in engineering education and instructional technology using a standardized evaluation rubric.

Phase 2: Development Phase

This phase involved producing instructional materials and validating research tools.

3.5. Learning Activity Development

A full set of experiential learning activities was created to align with each step of the instructional framework. These activities centered on realistic industrial problems such as optimizing production lines or scheduling resource use encouraging students to apply learned concepts in authentic contexts.

3.6. Development of Learning Materials and Solver Manual

Supporting materials included a learner's guide, worked examples, step-by-step solver tutorials, and video demonstrations suitable for both in-person and online instruction.

3.7. Construction and Validation of Research Instruments

Multiple research tools were developed, including:

- Critical Thinking Skills Test
- Innovation Ability Rating Scale
- Learning Satisfaction Questionnaire
- Semi-structured Interview Protocol

Each instrument was validated through expert review, and a pilot study (n = 10) was conducted to assess reliability using statistical indices such as Cronbach's alpha, item-total correlations, and difficulty indices.

Phase 3: Implementation and Evaluation Phase

The instructional model was implemented with 30 third-year undergraduate students enrolled in decision-making and production planning courses. A one-group pretest-posttest design was utilized:

- Pretest: Students completed the Critical Thinking Skills Test and Innovation Ability Rating Scale.
- Intervention: Students participated in the learning activities over a 4-week period.
- Posttest: The same instruments were re-administered, and students also completed a satisfaction questionnaire. Follow-up interviews were conducted with 10 volunteers.

3.8. Sample/Participants

This study employed a purposive sampling method to select a total of 30 undergraduate students who participated during the second semester of the 2024 academic year. The sample consisted of 8 students from the Industrial Business Data Innovation program and 22 students from the Electrical Engineering program. All participants possessed basic competencies in using Microsoft Excel and had prior exposure to fundamental concepts of engineering design. These qualifications ensured that all students had an adequate foundational background, allowing them to fully engage with the instructional intervention involving Solver-based problem-solving within an engineering design framework.

3.3. Research Instruments

3.3.1. Learning Module

The developed learning module was structured in alignment with the engineering design process, systematically integrating Microsoft Excel's Solver tool across five instructional phases: (1) problem definition, (2) idea generation, (3) development and evaluation of solutions, (4) testing and iterative improvement, and (5) communication of results. This structure aimed to enhance students' problem-solving capabilities through active engagement with real-world scenarios. The content validity of the module was assessed using the Index of Item-Objective Congruence (IOC) with evaluations from three subject-matter experts. A pilot implementation was conducted to gather student feedback and expert commentary, which informed subsequent refinements to ensure clarity, usability, and instructional effectiveness.

3.3.2. Critical Thinking Skills Test

This 20-item test was based on Dym et al. [3] critical thinking taxonomy. It covered five domains: interpretation, analysis, evaluation, inference, and explanation. Test items were scenario-based, requiring Solver use. Validity was reviewed by experts, and reliability was calculated using item discrimination and internal consistency metrics.

3.4. Innovation Skills Assessment

To evaluate students' innovation-related competencies, this study employed an assessment instrument developed in alignment with the Partnership for 21st Century Skills (P21) framework. The instrument consisted of 15 items structured on a five-point Likert scale, targeting three core dimensions: (1) idea generation, (2) creative product development, and (3) risk-taking and iterative design. The assessment was administered in two forms: student self-assessment and instructor evaluation to ensure a more comprehensive appraisal of innovation skills from multiple perspectives. The internal consistency of the instrument was verified through the calculation of Cronbach's alpha coefficient, indicating a high level of reliability.

3.5. Engineering Problem-Solving Observation Form

An observation form was developed to systematically assess students' problem-solving behaviors throughout the instructional process. The instrument was designed in alignment with the key phases of the engineering design-based learning model and included the following observable indicators: (1) accurate problem definition, (2) effective construction of mathematical models, (3) proficient use of the Solver tool, (4) engagement in collaborative problem-solving, and (5) evidence of iterative refinement of solutions. Data collection was conducted by the course instructor and three trained research assistants during classroom activities. To ensure the reliability of the observational data, inter-rater agreement was established using Cohen's kappa coefficient, which confirmed a satisfactory level of consistency among raters.

3.6. Satisfaction Questionnaire and Interview Protocol

A structured questionnaire employing a 5-point Likert scale was designed to measure students' levels of satisfaction across three dimensions: (1) content quality and instructional methods, (2) usability and accessibility of the Solver tool, and (3) engagement and motivation throughout the learning process. In addition, semi-structured interviews were conducted to gain deeper insights into students' learning experiences, particularly regarding their application of Solver in problem-solving contexts and the development of critical and innovative thinking skills. To enhance the credibility and validity of the findings, data triangulation was employed by integrating quantitative results with qualitative insights derived from the interview responses.

3.7. Data Analysis Methods

This study utilized a mixed-methods design to evaluate the instructional intervention's effectiveness. Quantitative data from pretest-posttest scores and satisfaction ratings were analyzed using descriptive statistics and paired-sample t-tests, while reliability was confirmed through Cronbach's alpha and item analysis. Qualitative data from interviews and open-ended responses were analyzed using content analysis to identify key themes related to critical thinking, Solver application, and innovation. Triangulation of data sources strengthened the validity and depth of the findings.

4. Results

This study aimed to develop an engineering design-based learning process by integrating the Solver program for solving linear programming problems in order to enhance learners' critical thinking and innovation abilities. The findings are presented according to the three phases of the study as follows:

4.1. Results from the Development and Validation of the Learning Process (Phases 1–2)

Following the contextual analysis and instructional design, the learning process was evaluated by three experts (Table 1).

Table 1.
Development and Validation of the Learning Process (Phases 1–2).

Evaluation Criteria	Mean ($\bar{x}$)	Standard Deviation (S.D.)	Suitability Level
Content accuracy	4.67	0.47	High
Alignment with learning objectives	4.73	0.45	High
Feasibility of implementation	4.60	0.50	High
Engagement of learning activities	4.53	0.52	High
Overall average	4.63	0.49	High

The experts in engineering and educational technology rated the developed learning process as highly suitable in all evaluated aspects. The highest rating was given for its alignment with learning objectives, indicating that the instructional design effectively supported the intended learning outcomes. The accuracy of the content also received high validation, reinforcing the reliability of the instructional material. Although the engagement of learning activities was the lowest-rated aspect, it still fell within the "high" suitability level. Overall, the process was deemed highly appropriate, as indicated by the low standard deviations across all items, suggesting consistency among expert evaluations.

4.2. Results from the Implementation with the Sample Group (Phase 3)

4.2.1. Results from the Comparison of Pretest and Posttest Scores (Table 2).

Table 2.
Comparison of Pretest and Posttest Scores.

Assessment Criteria	Pretest Mean ($\bar{x}_1$)	Posttest Mean ($\bar{x}_2$)	Standard Deviation	t-value	p-value
Critical thinking skills	15.20	22.87	3.12	11.43	0.000*
Innovation capabilities	14.90	21.40	3.37	9.67	0.000*

The comparison revealed statistically significant improvements ($p < .05$) in both critical thinking and innovation skills. The mean score for critical thinking increased from 15.20 to 22.87 ($t = 11.43$, $p = 0.000$), while innovation scores rose from 14.90 to 21.40 ($t = 9.67$, $p = 0.000$). These findings suggest that the learning process had a significant positive impact on students' learning outcomes.

4.2.2. Learners' Satisfaction with the Learning Process

Learners' satisfaction with the use of Solver in the engineering design learning activities (Table 3).

Table 3.
Learners' Satisfaction with the Learning Process.

Item	Mean ($\bar{x}$)	Standard Deviation	Level of Agreement
Understanding of Solver usage	4.60	0.55	High
Clarity of problems and activities	4.50	0.58	High
Engagement and enjoyment	4.47	0.60	High
Promotion of analytical thinking	4.63	0.49	High
Applicability to real-world situations	4.57	0.51	High
Overall average	4.55	0.55	High

Overall, learners expressed a high level of satisfaction ($\bar{x}$ = 4.55, S.D. = 0.55). The highest satisfaction was with the promotion of analytical thinking ($\bar{x}$ = 4.63), followed by understanding of Solver usage ($\bar{x}$ = 4.60), and applicability to real-world situations ($\bar{x}$ = 4.57). Although the "engagement and enjoyment" dimension received the lowest mean score ($\bar{x}$ = 4.47), it was still considered at a high level.

4.2.3. Qualitative Analysis from Interviews

Content analysis of semi-structured interviews revealed three major themes related to learners' experiences with Solver integration (Table 4).

Table 4.
Key Themes from Learners' Interviews on Using Solver in Learning Activities.

Emergent Theme	Learner Reflections	Suggestions for Improvement
Simulation enhances conceptual understanding	Realistic scenarios helped learners better grasp Solver usage and its application in authentic contexts.	Design activities to closely mirror real-world situations.
Development of analytical thinking	Learners demonstrated improved interpretation and decision-making, especially in handling complex outputs.	Facilitate in-class discussion of results to foster critical thinking.
Potential for cross-disciplinary application	Learners suggested the approach could benefit other subjects involving complex problem-solving.	Develop modular content adaptable for other disciplines.

These qualitative findings support the quantitative results by highlighting learners' engagement, conceptual growth, and suggestions for broader implementation of the learning model.

5. Discussion

The findings of this research can be discussed through the following key aspects:

5.1. Appropriateness of the Developed Learning Process

Evaluation by experts in engineering and educational technology indicated that the developed learning process was highly appropriate in all dimensions, particularly in alignment with learning objectives. This corresponds with Jonassen's [31] perspective that design-based learning should be clearly connected to learning goals, and learners should have opportunities to apply their knowledge in complex and realistic situations. The consensus among experts, as indicated by low standard deviation scores, supports the conclusion that the process is systematic and applicable in real-world contexts. This finding aligns with Merrill [32], which emphasizes problem-centered learning and structured activities that foster analytical thinking and knowledge integration.

5.2. Learners' Learning Achievement

The implementation of the developed learning process resulted in statistically significant improvements ($p < .05$) in learners' critical thinking and innovation capabilities. This supports Facione's [19] argument that practicing systematic thinking and decision-making in complex scenarios effectively enhances critical thinking. Likewise, the use of the Solver program, which requires solving problems with multiple constraints, promoted analytical thinking and alternative evaluation, key elements in creative problem solving. As Sternberg [33] posited, innovation does not arise solely from creativity but also requires the abilities to analyze, synthesize, and make reasoned decisions.

5.3. Learners' Satisfaction with the Learning Process

Learners reported high levels of satisfaction across all aspects, especially in terms of fostering analytical thinking. This finding is consistent with Schraw and Dennison [34] proposition that when learners perceive they can regulate their learning and interpret information systematically intrinsic motivation and satisfaction are enhanced. Although enjoyment and engagement scored the lowest among the evaluated dimensions, they remained at a "high" level, indicating that the use of meaningful, real-world connected activities can still effectively support experiential learning [2].

5.4. Qualitative Findings

Three key themes emerged from student interviews: (1) scenario simulations enhanced understanding, (2) development of analytical thinking skills, and (3) potential for learning transfer. These findings suggest that students not only acquired theoretical knowledge but were also able to connect it with real-world contexts and apply it meaningfully. This aligns with [2]. Experiential Learning Cycle, particularly the stages of reflective observation and active experimentation. The learners' suggestions to apply this learning approach in other subjects demonstrate metacognitive awareness of its value and readiness to expand their knowledge into new contexts. This reflects what Perkins and Salomon [35] referred to as the "transfer of learning."

The design-based engineering learning process utilizing Solver proved to be highly effective in fostering students' critical thinking and innovation skills both quantitatively and qualitatively. This supports [31] assertion that problem-based learning and authentic simulations enhance high-level analytical and problem-solving abilities. Hands-on activities combined with technological tools facilitated deeper and more meaningful learning. Furthermore, learners demonstrated potential to apply this instructional model to other courses involving complex decision-making, consistent with Savery's [36] suggestion that learning processes should be transferable and applicable to diverse contexts to promote 21st-century skills.

Nevertheless, effective learning design must consider learner contexts, teacher readiness, and institutional support. Voogt and Roblin [37], along with the OECD [38], emphasized that these environmental factors significantly influence the success of technology-enhanced, learner-centered instruction. Thus, the development of learning processes should be accompanied by teacher professional development, particularly in the areas of educational technology, cognitive engagement, and participatory learning, to ensure students' effective learning and foster their potential as future innovators.

5.5. Effectiveness of the Design-Based Engineering Learning Process Using Solver for Linear Programming Problem Solving

Key findings can be discussed in the following dimensions:

5.5.1. Development of Critical Thinking Skills

Comparative results between pre-test and post-test scores revealed statistically significant improvements in learners' critical thinking, indicating that the learning process emphasizing systematic problem-solving using Solver stimulates higher-order thinking. Learners engaged in data analysis, interpretation of results, and consideration of appropriate alternatives—hallmarks of critical thinking, as defined by Facione [16]. This also aligns with Saavedra and Opfer's [39] view that 21st-century learning should promote analytical thinking through complex, technology-integrated situations.

5.5.2. Enhanced Innovation Capacity

The study found an increase in students' innovation abilities following the learning intervention that incorporated real-world data in simulated problem scenarios. Hennessey and Amabile [40] explained that innovation thrives when learners are provided with opportunities to explore novel solutions and think creatively within practical contexts. The use of Solver allowed learners to learn from errors and refine their thinking through self-reflection, key elements in creative problem solving.

5.5.3. Learners' Satisfaction and Positive Interaction

Learners reported high satisfaction, especially in terms of improved analytical thinking and understanding of Solver. This is consistent with Jonassen's [31] research, which suggested that problem-based learning supported by technology enhances intrinsic motivation and promotes meaningful intellectual interaction between learners and content.

5.5.4. Qualitative Analysis and Developmental Insights

Interview data revealed that learners successfully connected Solver with real-world scenarios and gained deeper insights into data analysis and decision-making processes. This supports the [2] model of linking theory with practice and aligns with Bell's [41] findings, which emphasized the value of authentic simulations in fostering deep learning and applicable skills.

6. Conclusion

The initial phase of this study revealed that the developed instructional process was rated as highly appropriate by experts, particularly in terms of content accuracy, alignment with learning objectives, feasibility of implementation, and the engagement of learning activities. Among these, alignment with learning objectives received the highest evaluation score, indicating that the instructional design effectively addressed the intended educational goals.

Following implementation, students in the target group exhibited statistically significant improvements in critical thinking skills and innovation capabilities, as reflected in the increased post-test scores. These outcomes suggest that the instructional process effectively enhanced learners' ability to analyze and creatively solve complex problems. Additionally, students reported high levels of satisfaction with the use of the Solver program, particularly in promoting analytical thinking and operational comprehension. This reflects a readiness and interest in integrating technology into learning environments.

Qualitative analysis from student interviews supported these findings, revealing that realistic scenario simulations greatly contributed to their understanding of Solver principles. Learners demonstrated the ability to interpret complex outputs and connect them to decision-making processes. Furthermore, students recognized the potential to extend the instructional model to other disciplines involving systems thinking or multi-criteria decision-making. Suggestions included incorporating more realistic scenarios and promoting ongoing in-class discussions to further support analytical development.

6.1. Implications

This study provides empirical support for the use of design-based engineering instruction combined with Solver technology to enhance critical thinking and innovation among learners. Educators are encouraged to integrate authentic problem scenarios into instructional design, emphasizing real-world applications and fostering collaborative discussions to deepen analytical engagement. The flexibility and adaptability of the developed instructional modules suggest their utility across diverse educational contexts and disciplines.

6.2. Limitations

While the results are promising, the study was conducted with a specific target group, which may limit the generalizability of the findings. Additionally, the research focused on a single technology (Solver program) and a specific instructional context, which may not fully represent diverse classroom environments or learner needs.

6.3. Future Research Directions

Future studies should explore the application of this instructional model across various educational settings and learner demographics to validate its broader effectiveness. Investigations into environmental and contextual factors that influence the success of technology-integrated instruction are also warranted. Furthermore, longitudinal studies could examine the sustained impact of the instructional process on learners' problem-solving abilities, creativity, and technological proficiency.

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