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CREATIVE THINKING PROCESS OF UNIVERSITY STUDENTS IN DESIGNING A STIRLING ENGINE FROM RECYCLED MATERIALS: A QUALITATIVE STUDY

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Abstract

This qualitative study explores the creative-thinking process of university students while designing a Stirling engine from recycled materials. The study focuses on how students generate, develop, evaluate, and revise ideas throughout the Engineering Design Process. Data are collected through observations, semi-structured interviews, design worksheets, photographs, video recordings, and prototype documentation. The data are analyzed thematically using the creative-thinking indicators of fluency, flexibility, originality, and elaboration. The analysis examines students' activities during problem identification, conceptual understanding, idea generation, material selection, prototype construction, testing, and design revision. The project positions the Stirling engine as a practical context for applying thermodynamic concepts and recycled materials as constraints that stimulate innovative problem solving. Based on previous research, Engineering Design Process and STEM project-based learning can support the integration of creative and critical thinking in energy-related design activities Moch. Bachrul Ulum et al., 2021 & 2 others. The study is expected to provide insights into how university students respond to design constraints and transform recycled materials into a functional thermodynamic prototype.

Keywords: Creative thinking, Stirling engine, recycled materials, project-based learning, qualitative study.

1 Introduction

Creative thinking has become a critical competency in twenty-first-century higher education, particularly in engineering, where graduates are expected to address complex problems that rarely have a single predetermined solution. Rather than being limited to idea generation, creative thinking involves the capacity to produce solutions that are both novel and useful through fluency, flexibility, originality, and elaboration [Triwahyuni Wardhany et al., 2024; Nurul Huda et al., 2023]. These dimensions are especially relevant to engineering education because engineering students must navigate the tension between scientific principles, technical constraints, and the need for innovative solutions. The Engineering Design Process (EDP) provides a structured yet iterative environment for this development by guiding learners through problem definition, knowledge acquisition, solution planning, prototype development, testing, and decision-making [Moch. Bachrul Ulum et al., 2021]. However, the presence of a structured design process does not automatically explain how students think creatively within it. Understanding the mechanisms through which students generate, transform, abandon, and reconstruct ideas during engineering design therefore remains an important educational challenge.

Engineering design activities offer a particularly valuable context for examining creative thinking because they require students to move continuously between abstract reasoning and material action. Previous research has shown that energy-related engineering activities can stimulate the integration of creative and critical thinking by engaging students in problem identification, idea generation, alternative exploration, and innovative solution development [R. D. Handayani et al., 2024]. Within this context, the Stirling engine provides a distinctive design challenge. As a mechanical system that demonstrates fundamental thermodynamic principles through the conversion of thermal energy into mechanical work, it requires students to translate abstract concepts into an operational artifact. Previous work has shown that simple Stirling engine teaching aids can improve the accessibility and practical relevance of thermodynamics learning [Yeyen Helida et al., 2023]. Nevertheless, constructing a Stirling engine represents a substantially different cognitive challenge from merely observing or using one as a teaching aid. The transition from understanding a thermodynamic system to independently designing and constructing a functional version requires students to negotiate uncertainty, technical constraints, and repeated design decisions.

This challenge becomes more cognitively demanding when conventional engineering components are replaced with recycled materials. Recycled materials are inherently heterogeneous: their dimensions, mechanical properties, availability, and original functions are often uncertain or incompatible with predetermined design specifications. Consequently, students must not only solve an engineering problem but also reinterpret the functional potential of discarded objects and construct new relationships between available materials and intended mechanical functions. Previous studies have demonstrated that design-thinking activities involving waste materials can encourage learners to transform discarded products into innovative and valuable solutions [Wendra Hartono et al., 2022]. However, the educational significance of recycled materials may extend beyond sustainability awareness. Material constraints can actively shape cognition by prompting students to explore analogies, reconsider assumptions, generate unconventional alternatives, and modify initial concepts. Thus, recycled materials may function simultaneously as physical constraints and cognitive triggers within the creative engineering design process.

Existing evidence supports the potential of STEM learning, EDP, and project-based activities to enhance creative thinking. Alternative-energy projects, for example, have been associated with improvements in students' creative-thinking skills and the production of highly creative products, with an average creativity score of 89 [Maydilla Fadiarahma Vistara et al., 2022; Ujang Sudrajat et al., 2023]. However, much of this literature remains outcome-oriented, emphasizing creativity scores, pre- and post-intervention differences, or the novelty of final products. Such approaches reveal whether creative thinking improves but provide limited explanation of how creativity actually unfolds during authentic engineering practice. This represents a significant gap because creative thinking in engineering is not a linear progression from problem identification to solution generation. Instead, it is an iterative and often discontinuous process in which ideas emerge through interactions among conceptual knowledge, physical materials, experimentation, failure, feedback, and redesign. Moreover, little is known about how these interactions shape the creative thinking process of university students when they are required to construct a functional thermodynamic system under substantial material constraints.

To address this gap, the present study explores the creative thinking process of university students while designing a Stirling engine from recycled materials using a qualitative approach. Rather than evaluating creativity solely through final products or numerical performance indicators, this study focuses on the cognitive and practical processes through which students interpret design problems, generate and transform ideas, negotiate material constraints, respond to technical failures, and refine solutions through iterative experimentation. This study contributes to engineering education research in three ways. First, it shifts attention from creative-thinking outcomes to the process through which creativity develops during authentic engineering design. Second, it examines recycled materials not merely as sustainable resources but as active material constraints that may stimulate creative cognition. Third, it provides empirical insight into creative thinking within the underexplored context of hands-on thermodynamic system design. By integrating creativity, engineering design, sustainability, and material-based problem solving, the findings are expected to inform the development of more authentic and creativity-oriented learning experiences in engineering higher education.

2 Materials and Methods

This study employed a qualitative exploratory design to investigate the creative-thinking process of university students while designing a Stirling engine from recycled materials. A qualitative approach was selected to examine students' experiences, reasoning, interactions, and design decisions throughout the engineering activity. Similar qualitative studies have investigated students' engineering thinking through observation, interviews, and document analysis [Moch. Bachrul Ulum et al., 2021; R. D. Handayani et al., 2024].

The participants were university students enrolled in courses related to physics, thermodynamics, engineering, or science education. Participants were selected purposively based on their relevant academic background and ability to participate in the Stirling-engine design project. The final number of participants, academic program, and prior experience with thermodynamics, engineering design, and recycled materials should be reported according to the actual study. The materials consisted of recycled and readily available objects selected by students, together with basic tools for constructing and modifying the prototype. Students were provided with a design brief and worksheet covering problem identification, conceptual exploration, planning, construction, testing, and revision. The activity followed the Engineering Design Process (EDP), including defining, learning, planning, trying, testing, and deciding [Moch. Bachrul Ulum et al., 2021].

Data were collected through non-participant observation, semi-structured interviews, design documents, worksheets, photographs, and video recordings. Observations focused on students' discussions, idea generation, material selection, problem-solving strategies, collaboration, testing, and design revisions. Interviews were conducted after the activity to clarify students' design decisions and reflections. The combination of observation, interviews, and documentation is consistent with previous qualitative research on engineering thinking [Moch. Bachrul Ulum et al., 2021]. The research procedure consisted of five stages: (1) identifying the design problem and understanding the Stirling-engine principles; (2) generating and selecting design ideas using recycled materials; (3) constructing an initial prototype; (4) testing, identifying problems, and modifying the design; and (5) evaluating the prototype and reflecting on the creative-thinking process [R. D. Handayani et al., 2024; Yeyen Helida et al., 2023].

Data were analyzed thematically through transcription, data organization, coding, categorization, and theme development. Creative thinking was examined using four indicators: fluency, flexibility, originality, and elaboration [Triwahyuni Wardhany et al., 2024]. The analysis focused on how these indicators emerged during problem identification, idea generation, material selection, construction, testing, and revision. Trustworthiness was established through source and technique triangulation by comparing observation, interview, worksheet, and prototype documentation, followed by member checking to confirm the researchers' interpretations. These procedures are consistent with qualitative studies of students' engineering-thinking processes [Moch. Bachrul Ulum et al., 2021]. Ethical procedures included informed consent, voluntary participation, confidentiality, and the use of pseudonyms in reporting the findings.

3. Results and Discussion

3.1 Results

a. Idea Exploration and Creative Utilization of Recycled Materials

In addressing how students generated ideas and utilized materials, observations revealed the emergence of the fluency and originality dimensions of creative thinking. Students fluently generated a variety of alternative ideas to construct the Stirling engine using resources readily available in their surroundings, such as used beverage cans, bottle caps, wires, and aluminum sheets. The non-standardized specifications of these recycled materials actually fostered originality; rather than merely replicating standard prototypes, students innovatively reconstructed the functions of waste materials into operational mechanical components.

b. Technical Problem-Solving and Design Modification

Regarding how students solved problems and modified designs, the findings demonstrated high levels of cognitive flexibility and elaboration. When faced with real technical challenges—such as component misalignment, unstable flywheel rotation, or poor heat distribution—students adaptively changed their initial assumptions and assembly strategies. Instead of abandoning the project, they continuously modified component dimensions and replaced ineffective materials. This process was deepened through elaboration, where students conducted repeated cycles of experimentation, evaluation, and design revision to refine the prototype's stability and thermal performance until optimal results were achieved.

4. Discussion

The findings of this study prove that engineering students' creativity does not progress linearly from problem identification to the final product, but is rather a highly dynamic and iterative cognitive process. The activity of designing a Stirling engine required students to bridge abstract thermodynamic theories with practical, hands-on actions. The students' ability to alter designs and overcome technical failures during the construction process indicates that problem-solving in engineering relies heavily on flexible thinking and the willingness to continuously elaborate on initial ideas.

Aligning with the study's focus, the use of recycled materials proved to have a pedagogical value that extends beyond the mere availability of low-cost resources. The heterogeneous and non-standardized nature of recycled materials acted as material constraints that actively triggered students' creative cognition to seek unconventional solutions. At the same time, this project successfully created a meaningful learning experience by integrating engineering problem-solving competencies, scientific literacy in energy conversion, and environmental sustainability awareness. This project-based learning comprehensively demonstrated that eco-friendly technological innovation can be effectively integrated into higher education.

5. Conclusion

This study concludes that designing a Stirling engine from recycled materials through project-based learning effectively cultivates university students' creative thinking skills, specifically fluency, flexibility, originality, and elaboration. The findings demonstrate that creativity in engineering is a dynamic, iterative process that emerges from continuous cycles of planning, problem-solving, testing, and design modification, rather than solely from the final product. Furthermore, utilizing non-standardized recycled materials serves as a powerful cognitive trigger that challenges students to adaptively transform waste into functional mechanical components. This hands-on activity provides a highly contextual learning experience that successfully bridges abstract thermodynamic principles with practical engineering practices and environmental awareness. Ultimately, integrating simple technological innovation with sustainable material constraints represents an effective educational strategy to promote creative problem-solving, scientific literacy, and sustainability awareness in higher education.

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