

A Grounded Theory on the Research Conceptualization Process of Mechanical Engineering Research Students

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ABSTRACT

Research conceptualization refers to the entire process of developing a research proposal. Although there is ample research on students' experiences and outcomes in undergraduate engineering research, little is known about the specific processes that students undertake when conceptualizing their research. This study aimed to explore the unique processes involved in research conceptualization among mechanical engineering students. Understanding these processes can facilitate the development of effective interventions to enhance undergraduate research experiences. The researchers analyzed data obtained from interviews with eight undergraduate mechanical engineering research students regarding their experiences with research conceptualization. A constructivist grounded theory approach was employed to identify and analyse statements from the interviews and develop a conceptual model of research conceptualization. Three major categories emerged in the analysis of the data: encountering barriers, expressing influencers, and employing strategies throughout the process. The barriers encountered by the students include personal challenges, technical challenges, and research management challenges. The following strategies are being employed: Establishing Criteria for Decision-Making, Developing Concept and Design, Identifying and Validating Problems, Literature Review, Utilizing Technology, Managing Tasks, Consulting People, and Modification of Existing Technology. Influencers can be classified as internal influencers and external influencers. The grounded theory of the conceptual model of research conceptualization offers a comprehensive understanding of the research process among engineering students. It emphasizes the dynamic and cyclical nature of research conceptualization, emphasizing the interplay between barriers, influencers, and strategies. Further research is required to explore the limitations and expand the applicability of this model.

Keywords: *undergraduate academic research, mechanical engineering, research conceptualization, qualitative research, constructivist grounded theory*

Introduction

Academic research is a type of original inquiry done to acquire and understand concepts in important subject areas of competence. It also covers the growth of concepts and knowledge that results in fresh or significantly improved scientific findings connected to societal needs. Research conceptualization, conducting experiments, tabulating and analyzing data, and putting together a thesis or paper for publishing are the four key components of a research project (Jagadeesh, Balakumar, & Inamdar, 2013). Because it establishes the framework for the entire investigation, research conceptualization is a crucial step in the process of research. The success of a research project depends greatly on how well the proposal is conceptualized.

In this study, research conceptualization refers to the entire process of developing a research proposal. Although there is no universally agreed-upon definition for "research conceptualization," Badenhorst (2021) identifies three genres in which it commonly appears: problem statements, research proposals, and introduction sections or chapters. According to Aurini et al. (2016), the process of conceptualization involves not only selecting a topic but also constructing a justifiable and feasible research problem. Without a clear conceptualization, researchers run the risk of collecting irrelevant data, failing to address their study objectives, or arriving at incorrect conclusions.

Considerable research has been conducted on various aspects of research conceptualization that typically focus on challenges encountered by students. These difficulties may include difficulty choosing a topic, writing a research proposal, lacking research experience, lacking knowledge of research methodology, being unable to locate fresh, unique, and pertinent sources of information, lacking interest in or comprehension of the subject matter, having limited time, and lacking research direction (Bodi, 2002; Widiastuti, 2010; Rempel, Buck, & Deitering, 2013; Imafuku, Saiki, Kawakami, & Suzuki, 2015; Kheryadi, 2017; Daniel, Kumar, & Omar, 2017; Qasem & Zayid, 2019). Also, previous research has identified factors that may affect the process of research conceptualization, such as the researcher's motivations, personal and professional interests, goals, values, abilities, experiences, proficiency in information and communication technology, psychological, socio-cultural, linguistic, and cognitive factors, as well as the influence of

supervisors and problem-solving skills (Pennanen & Vakkari, 2003; Widiastuti, 2010; Mohamed & Nordin, 2013; D'Couto & Rosenhan, 2015; Mosyjowski, Daly, & Peters, 2017; Fila & Purzer, 2017; Noguez & Neri, 2019; Suyadi, Husnaini, & Elvina, 2020; Housseine, 2021; Ashipala & Livingi, 2021). The breadth of studies about research conceptualization shows its importance and relevance.

However, limited research has been conducted investigating the processes that students undergo during research conceptualization. To date, the closest studies have focused specifically on the problem-identification phase of the research process (Meyer, Shanahan, & Laugksch, 2005; Watkins, Spencer, & Hammer, 2014; Rubenstein, Callan, Speirs Neumeister, & Ridgley, 2020). Also, despite the abundance of research on the student's experiences and outcomes in undergraduate engineering research (URE), little is currently known about the actual processes that students undergo when conceptualizing their research. Specifically, there is a dearth of information regarding how mechanical engineering students identify research topics, craft problem statements, and propose appropriate methodologies for their research projects. To the best of the researcher's knowledge, there are no existing papers that investigate this area.

This investigation on research conceptualization is focused on the field of mechanical engineering. Although it is already an established field, recent transformations due to globalization and the industrial economy have caused changes within the field (Teixeira, Silva, & Flores, 2006). With Industry 4.0, there is a need for professionals who can construct and maintain modern enterprises, which necessitates that student be competent in both conventional mechanical engineering and information technology. As a result of the digitization of the value chain, the mechanical engineering sector will undergo changes, and universities are thus preparing students for these new challenges and opportunities (Fernández-Miranda, Marcos, Peralta, & Aguayo, 2017).

Engineering research, including mechanical engineering research, differs from research in other fields in that it places a strong emphasis on applied research, including conducting tests, advancing new technology, and conducting case studies (Tang, 2020). Consequently, there will be a shift in research in the field, which could impact how students approach research. This study aims to explore the unique processes that mechanical engineering students use to conceptualize research. Understanding the challenges and opportunities that these students face during research conceptualization can help in developing effective interventions to enhance their undergraduate research experiences.

This grounded theory study explored the research conceptualization in the field of mechanical engineering. This research question was answered in the context of these conditions as experienced by the participants: (a) the process of research conceptualization is understood from the perspectives of mechanical engineering students in this study, and (b) these students are currently enrolled in a mechanical engineering research course at a Philippine university.

The findings can be used to develop guidelines for carrying out research efforts in mechanical engineering by offering insights into the research conceptualization process.

Literature Review

The benefits of undergraduate research have been thoroughly investigated and are a crucial part of engineering education. Alumni who participated in research projects showed considerable improvements in their cognitive and personal skills, such as better public speaking, understanding of scientific discoveries, literary analysis skills, and a clear sense of their career aspirations, according to prior research (Zydney et al., 2002). Faculty members who had undergraduates under their supervision for a longer period and who changed their research plans to include undergraduates felt that these students had improved significantly in terms of their cognitive and interpersonal abilities (Zydney et al., 2002). Recent study has also demonstrated the advantages of research experience to engineering education, showing that engineering students that participate in undergraduate research typically have superior communication, cooperation, and leadership abilities (Carter, Alcott, & Lattuca, 2015).

Challenges in the Research Conceptualization Process

Although there are no studies specifically focused on research conceptualization in mechanical engineering education, research studies from other disciplines have investigated the factors and challenges that may influence research conceptualization. In terms of the challenges, Bodi (2002) identified that undergraduate students, in general, are untrained and inexperienced, with few skills. They struggle to understand the goals of conducting research and have difficulty narrowing down their topic choices. Moreover, they lack an extensive knowledge base and are unfamiliar with the ideas, paradigms, techniques, and questions related to a particular field of study.

While undergraduate students may feel inclined to conduct research, they may lack confidence in their ability to do so effectively. This lack of confidence could be due to a lack of expertise or insufficient prior experience with research (Mohamed & Nordin, 2013). According to Mohamed et al. (2013), Shaffer et al. (2006) indicated that most students lack proficiency in at least one of the following domains: technical writing abilities, oral and written communication skills, fundamental statistics, and a broad comprehension of the research process.

These findings were supported by Kheryadi's (2017) study, which revealed that students had trouble justifying their reasons, and most of them were unaware that there are established formats for submitting research proposals. Additionally, research students often face several common obstacles during proposal conceptualization, such as struggles with selecting a research topic, insufficient understanding of research methodologies, difficulty finding current

and relevant sources, disinterest in the subject matter, insufficient grasp of the subject material, time constraints, and a lack of guidance during the research process (Qasem & Zayid, 2019).

Daniel et al.'s (2017) research revealed difficulties in relation to conceptualizing methodology. The challenges outlined in the study include struggles with (a) formulating appropriate research questions, (b) lacking a thorough understanding of how to utilize specific research methods, such as mixed-methods research, and justifying their use, (c) being unfamiliar with commonly used terminology to describe fundamental concepts, (d) associating quantitative methods with mathematical and statistical knowledge, (e) encountering obstacles when performing a comprehensive literature review, (f) aligning research methods with data analysis, and (g) facing difficulties when selecting an appropriate sampling strategy and dealing with low response rates.

Furthermore, research students encounter various obstacles, such as limited access to library resources, inadequate education on information literacy and how to conduct effective research, difficulties in managing personal time, lack of proficiency in writing, struggles in finding suitable topics for approval, the dominance of practical work, limited time due to numerous tests, limited exposure to academic writing beyond the first year, etc. (Ashipala & Livingi, 2021).

Therefore, previous studies have identified some challenges that students faced during research conceptualization such as a lack of skills, experience, knowledge, and confidence. Other common obstacles include difficulty selecting a research topic, insufficient understanding of research methodologies, and time constraints. Students may also encounter difficulties in conducting literature reviews, aligning research methods with data analysis, and selecting appropriate sampling strategies. In addition, there may be limitations in access to resources and inadequate education on information literacy and effective research.

Factors Influencing Research Conceptualization Process

In terms of the factors, research findings indicate that when students were creating research proposals, their success in finding relevant information was influenced by certain aspects of their understanding of the topic. Specifically, their ability to use the right words in their searches had the greatest impact on their success throughout the process (Pennanen & Vakkari, 2003).

Also, Imafuku et al. (2015) mentioned four factors affecting students' engagement with undergraduate research: prior learning experience, values towards interpersonal communication, understanding of the research process, and social relationships with tutors and peers. Students found a discrepancy between undergraduate research and their earlier learning experiences in teaching strategies. They also tended to hesitate in active self-expression in the group due to their concern that they might interfere with the group's work. During the data collecting, analysis, and literature review stages of the study process, students encountered practical challenges, which made it difficult for them to get a clear understanding of what research is and what to do next. Moreover, the presence and direction of their instructors sometimes limited their participation.

Furthermore, Faber, Vargas, and Benson (2016) found that students' duration in research, personal goals, the culture of the research group, and the nature of the research project influence the methods they use when making research-related decisions.

In addition, Mosyjowski et al. (2017) mentioned that most of the research students they talked to were influenced by factors outside of themselves when choosing their research topic. However, some had more control over the decision than others. Those who had personal interest or passion for their topic often had previous experience in that area. Money was also a significant factor in their decision-making, given how expensive engineering work can be. Nonetheless, they found that there are still chances for students to pick topics that are meaningful and engaging to them.

Furthermore, the study of Fila & Purzer (2017) found that research project characteristics influence how engineering students perceive innovation, especially for those who are new to it. Students tend to seek out experiences that align with their interests, goals, and values.

The peculiarities of the academic subject and the research problem, personal experience and comfort with a certain approach, and advice from the research supervisor are other elements that affect the choice of methodology (Daniel, Kumar, & Omar, 2017).

Students also frequently struggle to obtain resources, with a dearth of materials in the library being a prevalent complaint. Using the internet to look for materials like journals, e-books, and e-theses is advised by Suyadi, Husnaini, and Elvina (2020).

Therefore, a variety of elements, including prior learning experiences, personal goals, social connections with teachers and peers, knowledge of the research process, and the nature of the research project, influence students' participation and success in conceptualizing research. Other considerations, such as prior experience and advice from the study supervisor, have an impact on the choice of methodology. Students frequently complain about the lack of resources in the library and the difficulties they have locating them, which advocates using the internet to look for information.

The result of this literature review showed little information about the actual procedures that students go through when conceptualizing their research, despite the wealth of data on the student's experiences and outcomes in undergraduate research. Information on how mechanical engineering research students conceptualize research is still scarce. There are no current studies that explore this topic, as far as the researcher is aware.

Methodology

This study examined the process of research conceptualization in mechanical engineering. A constructivist grounded theory technique was used in this study to examine how mechanical engineering students conceptualize research. This approach is suitable for investigating research conceptualization and creating a hypothesis. Charmaz (2006) developed this technique to offer a framework for gathering and examining qualitative data. Lincoln, et al. (2013) and Charmaz (2006) emphasized the importance of gathering diverse opinions and data types, as well as prioritizing participants' voices. By utilizing the constructivist grounded theory, the researcher will be able to generate new insights from the data in collaboration with the participants (Charmaz, 2006). This approach is appropriate since the principal investigator is also a mechanical engineering research teacher and researcher.

Participants

In this study, the participants consisted of eight (8) undergraduate mechanical engineering students at a Philippine university who were enrolled in the research subject and had completed the research conceptualization phase, indicating that they were in the process of implementing their project proposal. The selection of participants was based on two criteria: (a) current enrollment in the research subject, and (b) completion of the research conceptualization phase. The sampling approach employed in this study was theoretical sampling, which allowed for the attainment of saturation to guide the sampling strategy, as proposed by Charmaz (2006). The sample size in this study was deemed sufficient as data saturation was achieved after interviewing the fifth participant, where no new information emerged, and redundancy became apparent. Additionally, three additional participants were interviewed to validate the attainment of data saturation.

Data Collection

To ensure ethical considerations, the researcher obtained ethics clearance from the university's institutional review board and sought approval from the department head to conduct interviews with selected students. Informants who met the inclusion criteria were contacted through online chat, offering convenience and flexibility. Students were informed that their participation was voluntary, and they were provided with a detailed explanation of the interview's purpose and how the collected data would be utilized to obtain informed consent. To formalize their consent, students were asked to submit a consent form via MS Form. Throughout the study, the researchers emphasized that participants had the right to withdraw from the study at any time without facing any consequences. They reassured participants that they would still receive the agreed-upon incentive even if they chose to withdraw. Interviews were conducted based on each informant's preferred method and schedule, either face-to-face or online, with the informant's permission to record the interview (audio or video). The initial five interviews began with the prompt, "Describe your experience in developing your research proposal," followed by additional questions tailored to each student's responses such as "How do you make the decision on what topic to propose?", "How do you make the decision on what problem to solve?", "What are the things you went through in crafting your methodology?" In the last three interviews, the researchers asked probing questions to validate the result of the data analysis after data saturation was reached. Questions such as "What are your approaches or strategies during research conceptualization?", "Many participants mentioned that they set criteria for the decisions that they make during research conceptualization, for you, what are the criteria you set? How does it help you in addressing the challenges you faced during research conceptualization? Can you provide specific examples?" were asked. All interviews were audio recorded, lasting between twenty minutes to forty minutes. As a token of gratitude, students were compensated through e-wallets after the completion of the interview.

Data Analysis

The researchers transcribed the recordings of each individual interview. Following Charmaz's (2006) constructivist grounded theory methodology, the analysis of the data was conducted simultaneously with the data collection process. Initially, the interview recordings were transcribed accurately, and then the researcher began the initial coding process to identify themes, concepts, and patterns. Once the initial coding process was completed, the researcher proceeded to focused coding, delving deeper into the data to identify the most significant themes and ideas. Similar codes were grouped together to create sub-categories, and axial coding was then employed to examine relationships between sub-categories and categories. Once data saturation was achieved, selective coding was used to integrate and refine categories, ensuring they were connected to the core category that formed the basis of the grounded theory. Finally, theoretical integration was employed to elucidate the narrative. Throughout each step, the researchers maintained memo writing, which facilitated comparisons between data and data, data and codes, codes and other codes, codes and categories, and categories and concepts, aiding in formulating hypotheses about these comparisons (Charmaz, 2006). The constructivist grounded theory approach prioritizes maintaining an open mind to new ideas and perspectives, while allowing the data to guide the study.

Findings

The conceptual model for research conceptualization that was generated from the analysis is shown in Figure 1. This model highlights the dynamic interplay between encountering barriers, expressing influencers, and employing strategies throughout the process of developing the research concept. It acknowledges that research conceptualization is not a linear or fixed path but rather a cyclical and evolving journey for engineering students. In the next sections, we describe each of these categories in more detail.

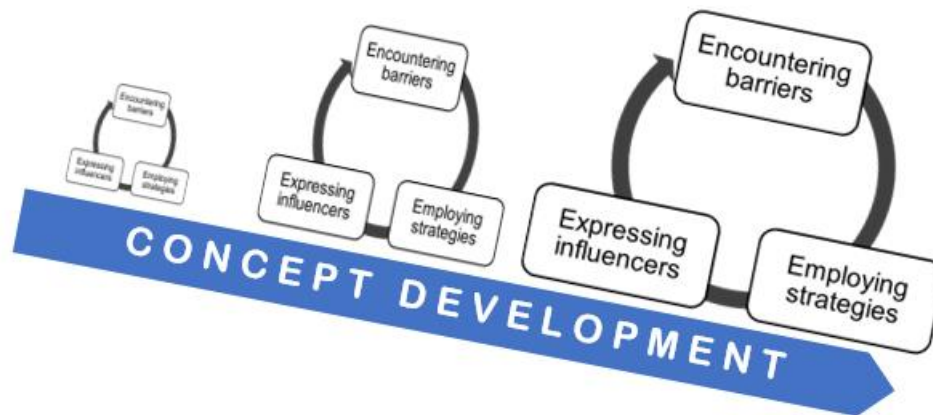


Figure 1: Conceptual model for research conceptualization in mechanical engineering

Category 1: Encountering Barriers

Research students encounter various difficulties while trying to conceptualize their research projects. These challenges are barriers to research conceptualization and may include personal challenges, technical challenges, and research management challenges. Recurring among these challenges are related to design calculation, topic ideation, time and task management, academic challenges, machine design, and finding or integrating theories. Students may feel overwhelmed or uncertain about how to proceed, leading to feelings of frustration and self-doubt as Erik mentioned, "It [the experience of research conceptualization] is really challenging."

Subcategory 1: Personal Challenges

During the process of research conceptualization, students encounter personal challenges that can impede their concept development. One such recurring challenge is the impact of their academic subjects, as highlighted by Marco. He expressed, "We also struggle with our other subjects, which affects our research... Our professors from other subjects need to realize that we are also conducting research for them, so they shouldn't burden us with excessive assignments or tasks." Apart from the academic hurdles, students also mentioned a lack of essential experience, immersion, and confidence in their skills as additional barriers to research conceptualization. Marco explained, "In addition to proposing a solution without a clear problem, we also lacked immersion within the community." Karen attributed this challenge to their experience of conducting research during the pandemic, stating, "Due to the pandemic, we lack awareness that studies can be based on laboratory equipment. We have relied on what our instructors provided us with and what we could find on the internet."

Moreover, students expressed feeling overwhelmed by the demands and nature of research in mechanical engineering. They grapple with vast amounts of information, numerous innovations, and complex research problems they must confront. Marco voiced his concerns by saying, "To be honest, it's overwhelming to think that we can make innovations in mechanical engineering because the discipline is so broad. We can focus on industries, small technologies or gadgets, or analyze the performance of various systems." Bea added, "Finding a research topic has been difficult for me because there are already numerous innovations out there." Mark further elaborated, "With the abundance of information available, we often feel overwhelmed and confused about which direction to pursue."

Students also encounter difficulties when it comes to finding and comparing their ideas with relevant prior work, connecting concepts, and aligning their chosen topic with their field of expertise. This often leads to generating ideas randomly, proposing topics without a clear problem statement, or reinventing existing solutions. Erik pointed out, "Most of the ideas we've come up with already exist... When we design and calculate, the challenging part is comparing our project with existing ones." Mark echoed this sentiment, stating, "I find it difficult because there are already numerous existing problems and solutions, and it's hard to find something that aligns with my prior knowledge." Additionally, Marco explained, "My problem is that I often come up with a solution even before the problem is clearly defined... We proposed a machine that already exists, and when it was rejected, I understood why. Why reinvent something that already exists?"

Finally, students experienced doubts, insecurities, and fear of rejection regarding their chosen topics. Some admitted to lacking a personal topic of interest and settling for less than their potential. Mark expressed, "Once I settle on a research topic, I can't help but doubt and lose trust in our choice."

Subcategory 2: Technical Challenges

During the process of research conceptualization, technical challenges can arise, affecting the overall concept development. These challenges encompass several crucial aspects, such as ideation. As Alex pointed out, "The most challenging part of the research proposal stage was the ideation phase." The ideation phase, as Marco mentioned, consumed a significant amount of time during the proposal writing stage. He stated, "Coming up with a title was the most time-consuming part for us." This difficulty in ideation can be attributed to various factors. Bea emphasized the challenge of ensuring innovation, saying, "Finding a research topic becomes difficult when we consider the abundance of existing innovations." Alex further highlighted the struggle to integrate novelty, explaining, "Our patent search revealed numerous machines similar to ours, making it challenging to incorporate something new when the field is already well-established."

Once students overcome the hurdle of identifying a research topic, they face another challenge: determining performance parameters. Erik expressed his difficulty in this area, noting, "I find it challenging to establish performance parameters that don't require statistical analysis."

Design conceptualization poses a major challenge, encompassing tasks such as finding relevant theories to support design decisions, performing calculations, creating drawings, and conducting simulations. Erik emphasized the complexity of design calculations, saying, "Design calculations are the most challenging part. Unlike in our class where design criteria are provided, in our project, we need to develop assumptions backed by theories." The importance of design is underscored by Marco, who explained, "Designing the machine to ensure proper measurements and compatibility of mechanical parts is crucial before fabrication. It presents a significant challenge for us." Furthermore, Bea highlighted the difficulty of finding theories applicable to their design, stating, "The most challenging part is finding theories that can be utilized in our design, such as crushing theory."

These challenges require students to navigate complex calculations, create accurate drawings, generate innovative ideas, incorporate novel elements into their research, design effective machines, utilize simulations for experimentation, identify and apply relevant theories, and establish appropriate performance parameters. Addressing these technical challenges is essential for engineering students embarking on their research conceptualization journey.

Subcategory 3: Research Management Challenges

During the research conceptualization phase, researchers often encounter challenges related to research management, which can significantly impact the process. One such challenge is grappling with group dynamics, which involves navigating team interactions and ensuring effective collaboration. Greg, reflecting on his experience, mentioned the difficulties of handling group members who lack cooperation and overly rely on him. He stated, "As a leader, one of the challenges is managing group members. Some individuals in the group are not cooperative and tend to depend on me." Marco echoed similar sentiments, highlighting the challenge of coordinating schedules within the group. He explained, "In our team, we face difficulties due to different schedules. Most of the time, only a few members can work on the research when we decide to meet, leaving the remaining members unaware of progress. As a result, we are not well-updated with each other."

Additionally, there is a struggle in managing time and tasks efficiently to meet deadlines and maintain productivity. Mark emphasized this challenge, stating, "Time management is a significant problem." Ana agreed, expressing the difficulty in finding time to dedicate to research work. She added, "We find it hard to carve out time for our research activities." These challenges in managing time and tasks can impact the research conceptualization process. As Greg noted, the limited time available led their group to propose topics that were not necessarily innovative but merely served the purpose of having a topic to present. He explained, "Due to our time constraints, we no longer prioritize innovativeness. We simply want to expedite the process."

Furthermore, the issue of time management is closely connected to the difficulty in seeking expert advice to address complex research questions and make informed decisions. Mark pointed out the challenge, saying, "When seeking advice from professionals, they are often inaccessible due to time constraints. It is also challenging to find someone who can provide us with valuable guidance." Karen shared a similar struggle, particularly in contacting their thesis adviser. She mentioned, "Another problem we face is the difficulty in reaching out to our thesis adviser. Our schedules do not align, and our available time is usually at night, which is not an ideal time to approach them as it is their rest time."

Category 2: Employing Strategies

Research students employ a variety of strategies to enhance their research conceptualization process. These strategies encompass a range of activities, including engaging in conversations with different individuals, establishing decision-making criteria, identifying and validating research problems, modifying existing technology, adopting effective task management strategies, developing concepts and designs, conducting comprehensive literature reviews, and utilizing

diverse tools and resources to support the research process. By implementing these strategies, students can effectively overcome challenges, make well-informed decisions, and refine their research conceptualization.

Subcategory 1: Establishing Criteria for Decision-Making

One key strategy employed by researchers is establishing criteria to guide their decision-making process during research conceptualization. Recognizing the importance of setting clear criteria and guidelines, students develop structured frameworks to make informed decisions and navigate the complexities of research conceptualization. Ana explained, "In the beginning, we found it challenging to finalize a topic due to the multitude of ideas. By establishing common ground as criteria, we helped one another in defining our tasks."

Researcher's Capability & Resources. When making decisions, researchers consider their own capabilities and available resources during the research conceptualization stage. They assess the expertise and skills of their team members to determine the feasibility of pursuing specific research topics. Bea mentioned, "We decide through agreement with our team members, getting everyone's thoughts on whether the project is doable for the team." Mark also emphasized the importance of considering their team's expertise, stating, "Our group decided not to pursue automation because we have less experience in programming." Additionally, researchers consider their familiarity with the chosen topic. As Mark noted, "All of us must be knowledgeable about the topic and able to relate to it." Availability of experts and time constraints are also considered factors, as Erik mentioned, "We consider if we can finish it within the timeframe and whether there are people we can seek help from."

Problem-Solution Fitness. Researchers also prioritize the fitness of the solution to the identified research problem when making decisions during research conceptualization. They are focused on solving real-world problems and creating useful outcomes. Alex stated, "We aim to propose topics that address specific problems rather than passing titles that do not offer solutions." Bea echoed this sentiment, emphasizing their desire to create projects that have practical value, saying, "We want our machine to be useful and not just end up being discarded." To achieve this goal, researchers prioritize proposing original, appropriate, and effective solutions. Alex expressed concern about proposing topics that have already been explored by previous students, stating, "Originality is crucial because we fear rejection if the topic has already been proposed." Marco highlighted the importance of their chosen technology, stating, "The technology we apply should not be forced; instead, we make indirect measurements of weight using a camera."

Stakeholder Consideration. Researchers also consider the context, needs, and preferences of stakeholders when making decisions during research conceptualization. Marco emphasized this approach, stating, "When setting our objectives, we imagine ourselves as end-users. We ask ourselves, 'If we had this machine in front of us, what would we want it to do?'" Bea added, "We consider who the end-users will be because we might need to travel to distant places to consult them." They believe that involving end-users strengthens their project's relevance to the community. Mark supported this by stating, "I identify the project's usefulness and significance to the target end-users or the changes it can bring."

Design and Complexity. The level of complexity involved in developing and implementing the design is another factor considered by researchers when making decisions during research conceptualization. Some researchers prefer more complex designs, as Alex mentioned, "We consider topics like trash segregation machines to be simple because they don't involve motors and gears. Those are too simple to be considered as research for mechanical engineers." Others take a more conservative approach, considering the feasibility and manufacturability of the design, as stated by Mark, "We also consider the difficulty of designing and whether it is doable or possible to manufacture." Karen highlighted the importance of simplicity in design, stating, "Simplicity is also a criterion because even if it looks simple, the design can still be complex." Regardless of the approach, complexity is considered an important criterion for decision-making.

Financial Consideration. Financial implications, such as potential revenue generation and project costs, are also considered when making decisions during research conceptualization. Bea mentioned, "Aside from the fact that there are already many innovations, we also face the challenge of considering the project's cost." Greg emphasized their aim to develop a cost-effective design, saying, "For the design, we consider budget constraints. Our goal is to have a cheap but effective generator." Considering the project's financial aspects helps researchers identify constraints and seek affordable materials, as Greg mentioned, "It makes it easier for us to generate ideas on how to manufacture the project."

Personal Consideration. Researchers also consider personal factors, such as their own interests and passions, when making decisions during research conceptualization. Marco explicitly expressed his personal interests, stating, "Good topics in engineering for me are those related to agriculture and those that can help people with disabilities." Greg supported this perspective, saying, "I became interested in this topic by recognizing the rapid decline of natural resources on Earth due to high demand. So, I thought of sustainable and effective ideas."

Subcategory 2: Developing Concept and Design

Several strategies are employed to facilitate the development of concepts and designs. One approach is benchmarking prior art designs to gain insights. Marco explained, "Reviewing prior art allows us to observe and adapt their design principles to our own. We also draw inspiration from previous student projects for our design mechanisms." Similarly, Bea mentioned, "We conducted searches to explore additional features that we could incorporate into our machine."

Moreover, students adopt a structured approach by utilizing scientific methods, conducting calculations before creating drawings, and applying machine design theories and concepts. Mark expressed his trust in the scientific method, stating, "I rely on the scientific method to identify the topic and establish factors and criteria for decision-making." Alex highlighted the sequential nature of their process, saying, "We finalize our calculations before proceeding to the drawings." Erik added, "We also consult machine design books and study finished works to enhance our understanding." Students also recognize the importance of brainstorming to generate design ideas and embrace an iterative design process. Erik explained their approach, "We begin by sketching the initial design and allow ideas to flow naturally. We then apply these ideas and continue refining the design until it reaches its final form."

Subcategory 3: Identifying and Validating Problem

To bolster their research proposition, the researchers dedicated efforts to identifying and validating the problem they aimed to address. They employed various methods to ensure the problem's legitimacy and significance. One crucial step was gathering feedback from the end users. Bea emphasized the importance of end-user input, stating, "Considering the end-users is vital as they provide strong evidence of the community's need for our project... We also conducted background studies on glass waste and discovered that other companies struggle to recycle it." This process of gathering feedback and conducting investigations helped solidify their understanding of the problem, as Bea mentioned, "It strengthened our proposition that there is indeed a problem with glass waste." In addition, the researchers visited relevant sites to gather firsthand information. Mark highlighted their investigative approach, saying, "We visited the site and learned from the workers." This hands-on experience contributed to the clarity and specificity of their research objective. Mark further added, "After the interviews, our objective became more defined, specific, and quantifiable." The researchers also considered the broader societal context in identifying and validating the problem. Alex emphasized drawing inspiration from societal needs, stating, "We look at the needs of society as a source of inspiration for a concrete invention." Bea reinforced this perspective, mentioning their focus on addressing the needs of organizations such as CENRO (City Environment and Natural Resources Office), saying, "We aimed to provide a solution to a problem identified by CENRO by connecting with them." Moreover, the researchers examined the limitations of existing devices and solutions to validate the problem's existence. Marco highlighted the shortcomings of currently used methods, such as strain gauges or manual weighing, which require extensive maintenance and calibration. By recognizing the flaws in existing technologies, they reinforced the necessity of their proposed solution. Through these comprehensive approaches, the researchers successfully identified and validated the problem, ensuring that their research proposition aligns with real-world challenges and societal needs.

Subcategory 4: Literature Review

To gain comprehensive insights into their research topic, the researchers employed various strategies to conduct an extensive literature review. These strategies involved consulting library resources, filtering topics, and evaluating the gathered information. The literature review process allowed them to explore previous studies and gather valuable knowledge to inform their own research. Mark emphasized the importance of studying related research and learning from existing problem-solving approaches. He stated, "We read related studies and examined how they addressed existing problems and found solutions." Erik echoed this sentiment, noting the utilization of prior arts to generate ideas for their project's mechanisms. He mentioned, "We looked at previous works to identify which mechanisms we could incorporate into our own project." The researchers also drew inspiration from the work of their peers who were further along in their research. Greg explained, "This idea was inspired by the research of our friends whom we approached for insights into different applications of their research." By leveraging the expertise of their peers, they expanded their understanding and generated innovative ideas. During the process of locating relevant prior arts and studies, the researchers sought assistance from library resources. Bea highlighted the challenge of finding reliable resources for specific theories, such as crushing theory. However, by turning to the library, they were able to access valuable assistance. Bea shared, "We encountered difficulty when relying solely on online resources, but the library provided us with the help we needed." Throughout their literature review, the researchers were aware of the importance of evaluating the information they discovered. Mark emphasized the need to filter and prioritize the obtained information. He explained, "It is necessary to discern and filter the necessary information because at times, we may initially perceive certain information as essential, only to later realize it is not."

Subcategory 5: Utilizing Technology

The researchers adopted various technologies, such as productivity tools and software, to enhance their research process. These technologies were proven helpful in ideation, calculation, and design. Alex stated, "The topic identification is not hard for me because there are plenty of inspirations from Google." Mark shared a similar experience, saying, "This information started as a hunch and then we searched Google about it, checking previous studies or published articles and the different approaches that they took." Simple technologies like Excel have also become handy in performing calculations. Alex mentioned, "In our calculations, we used Microsoft Excel to double-check the accuracy." When it came to designing, they relied on specific software. Bea explained, "Regarding our design, we used Solidworks." Marco expressed gratitude for their knowledge of Solidworks, saying, "We are thankful that we have knowledge in Solidworks because we can use it to iterate our design."

Subcategory 6: Managing Tasks

The researchers implemented effective task management strategies to ensure the successful completion of their research. They employed various approaches such as task delegation, setting manageable objectives, and filtering topics. Greg highlighted the importance of task delegation, stating, "Initially, each member proposed certain areas to tackle, and then we selected..." This emphasizes the significance of dividing responsibilities among team members. Collaboration and teamwork were key aspects of their task management. Karen emphasized the importance of working together as a group, stating, "We decide as a group on what research to pursue, what new things to add, what innovations to incorporate..." Marco further supported this by explaining the collaborative decision-making process in selecting materials, saying, "For the selection of materials, we really have to talk to each other and consult on which material to use." Bea added, "We decide through agreement with our team members," highlighting the collective nature of their decision-making process. In addition to optimizing human resources, they managed tasks by setting manageable objectives. Alex mentioned, "We intentionally propose a general objective so that we will have more freedom once we fabricate the machine." This approach allowed them flexibility in their research process. They also considered the strengths and weaknesses of each topic to ensure they could handle the chosen research direction, as Ana mentioned, "We identified the strengths and weaknesses of each topic to determine if we could really pursue it."

Subcategory 7: Consulting People

One of the key strategies employed by the researchers was seeking expert advice and consultation to guide their research process. They recognized the value of consulting technical experts, fabrication experts, and their thesis advisers to gain valuable insights and guidance. Ana highlighted the positive impact of consulting technical experts, explaining, "We used advice from people we know to get better ideas and specify our objectives. One of which is the adviser of one of our members during OJT. We asked him for ideas for our thesis, and we followed his suggestions." This demonstrates their proactive approach to gathering input from knowledgeable individuals who could provide valuable insights. Marco also recognized the importance of consulting his thesis adviser, especially when his ideas were not clear. He shared, "We consulted our adviser, who suggested simulating using cardboard to test the feasibility of our ideas since we couldn't find prior examples to validate them." Seeking guidance from their adviser helped clarify their concepts and ensured they were on the right track. Bea also sought help from her thesis adviser, particularly in studying Solidworks and determining what to simulate. She mentioned, "We consulted our adviser to understand how to use Solidworks effectively and gain insights on what aspects to simulate." By consulting their adviser, they could leverage their expertise and make informed decisions in their research. Furthermore, the researchers went beyond thesis advisers and consulted fabrication experts. Marco explained, "We reached out to fabrication shops and received assistance in selecting the appropriate materials... Consulting someone with fabrication expertise proved highly beneficial as they possessed practical experience in carrying out fabrication processes effectively."

Subcategory 8: Modification of Existing of Technology

In this subcategory, the research students focused on modifying existing technology to enhance or transform its purpose or application. Instead of starting from scratch, their goal was to improve upon existing technology by making modifications and introducing new features. This approach was influenced by the realization that similar studies had already been conducted, as Ana explained, "There are also similar studies to ours which we could take advantage of, but we decided to change our objectives upon realizing that we could enhance the prior works." Marco also emphasized their objective of enhancing existing technology, stating, "Since the egg sorter is no longer a new technology, we aimed to introduce a new feature that would make it an improvement over the previous iteration. We set the goal for it to be faster and more accurate, emphasizing the aspect of improvement." This clearly demonstrates their intention to push the boundaries of existing technology. While modifying the application of existing technology, Erik mentioned, "Since our project falls within the general category of press machines, which already employ various mechanisms, we focused on finding ways to make our project suitable for specific purposes with specific dimensions." This highlights their intention to tailor the technology to meet specific requirements, suggesting a targeted approach to their modifications. Additionally, the researchers focused on altering the purpose of the technology. Erik explained, "Unlike existing solutions that cater to general use, our application is very basic." This suggests that their modification aimed to simplify the technology's purpose, possibly targeting a specific use case or streamlining its functionality. To differentiate their project from prior works, the researchers added additional features. Ana mentioned, "In coming up with the objective, we added additional features which could improve the design and also the performance." Karen also stated, "We decided as a group on what research to pursue, what something new to add, what innovation to add." These statements indicate their commitment to innovation and improving upon existing technology. Overall, the researchers chose to modify existing technology instead of starting from scratch. Their motivation was to enhance and improve upon prior works by modifying the application, purpose, or both. Through their modifications, they aimed to achieve greater efficiency, accuracy, and specificity in their modified technology.

Category 3: Expressing Influencers

There are influencers in engineering students' research conceptualization process. These influencers can be internal or external. Internal influencers may include personal interests, prior knowledge, and individual motivation. External

influencers may involve guidance from supervisors, feedback from peers, institutional requirements, or disciplinary norms. Recognizing and understanding these influencers is crucial for students as they shape their research conceptualization process and make informed choices.

Subcategory 1: Internal Influencers

Internal influencers play a significant role in shaping research conceptualization, and they can include personal interests, prior experience, and individual motivation, among others. Greg expressed his personal interest in the topic by stating, "I got interested in this topic knowing that the natural resources of the earth are rapidly declining because of the high demand. So, I thought of ideas that are sustainable and effective." This demonstrates how his concern for the environment influenced his research direction. Marco shared a similar sentiment, mentioning, "Good topics in engineering are those that cover agricultural, and also something close to my heart is something that can help the handicapped and the like." His personal interests in agriculture and assisting individuals with disabilities influenced his choice of research topics, highlighting the importance of aligning one's passion with their academic pursuits. Apart from personal interests, Ana emphasized the role of prior experience as an internal influencer. She mentioned, "During SHS, we also did research, so I already have experience and ideas about research." Drawing from her past research experience, Ana was able to leverage her knowledge and ideas to shape her current research endeavor. This showcases how previous experience can provide valuable insights and inform research directions. Karen also highlighted her prior interest in a related student project about wind power generation, stating, "It is in line with my project now, which is developing power." Her past interest in renewable energy served as an internal influencer, guiding her toward her current project and fueling her motivation to explore alternative sources of electricity. The researcher's motivation was identified as another internal influencer impacting research conceptualization. Greg mentioned, "Another influence is seeing electricity bills of people increase because I learned that producing this electricity requires expensive raw materials. So it also inspires me to look for ways to provide alternative sources of electricity." This indicates that his motivation stemmed from a desire to address the increasing cost and environmental impact of electricity production. Marco found motivation through direct interaction with individuals experiencing a specific problem. He explained, "One of our motivations is that we really had the chance to talk to the person who has the problem. Because we know the person and that we were able to talk and hear from this person his challenges, so with our ideas in mind, we become hopeful that our idea can help the person." This highlights how personal interactions and empathy can inspire researchers to develop solutions that directly benefit people in need. In summary, internal influences such as personal interests, prior experience, and individual motivation significantly impact research conceptualization. These internal influencers played a crucial role in guiding the researchers' research directions and fueling their commitment to their projects.

Subcategory 2: External Influencers

External influences, such as guidance from supervisors and feedback from peers, play a crucial role in shaping research decisions and actions. Alex highlighted the impact of feedback from their research committee, stating, "Initially, we intentionally proposed a general objective so that we would have more freedom once we fabricated it, but the panel challenged us to make it specific." This demonstrates how the guidance from the research committee influenced the researchers to refine and specify their objectives. Mark further emphasized the role of the panel's feedback, stating, "At first, we set the objective, but since it was not as specific as per the panel, we made it clear..." The external influence of the panel's feedback prompted the researchers to modify and clarify their objectives to meet the panel's expectations. Karen provided additional insights into how external influences can shape research decisions. She mentioned, "Our top one was that it is simple and budget friendly. But as the panel introduced some changes, where they required two products, those criteria got disregarded. We just pushed through versus not being able to present ideas." This suggests that the researchers were willing to adapt their criteria and make necessary changes based on the feedback and requirements set by the panel. The external influence of the panel's suggestions led to adjustments in their approach. In addition to the panel, peers also played a significant role in influencing research decisions. Ana acknowledged this influence, stating, "One influence is the peers that I chose because they can help boost your research experience." The input and support from peers can provide valuable insights, diverse perspectives, and knowledge-sharing opportunities, contributing to the overall research experience. In summary, external influences such as guidance from supervisors and feedback from peers play a vital role in shaping research decisions and actions.

Core Category: Concept Development

The conceptual model of research conceptualization proposes that engineering students continuously cycle through the stages of encountering barriers, expressing influencers, and employing strategies. Encountering barriers triggers the need to employ strategies. Strategies, in turn, are influenced by both barriers and influencers as researchers seek ways to overcome barriers while expressing influencers. Influencers play a significant role in shaping and modifying the strategies established by the researchers. Students iterate through the research conceptualization process. Each sub-cycle informs and shapes the subsequent cycle, leading to the ongoing refinement of the research concept. Through this iterative process, students gradually develop a comprehensive and well-conceptualized research project.

Discussion

The different yet interrelated concepts that appear in the conceptual model resulting from this study are encountering barriers, expressing influencers, and employing strategies during research conceptualization. Our findings connect to previous literature but suggest new research avenues.

During their research conceptualization, the students encountered various challenges that hindered their progress in developing comprehensive and well-informed research concepts. These challenges can be broadly categorized into three types: personal challenges, technical challenges, and research management challenges. Understanding and addressing these challenges is crucial to overcome the barriers that impede the research conceptualization process. For instance, one of the personal challenges faced by the students was the pressure of time constraints. In their attempt to meet deadlines, they sometimes resorted to proposing research titles without considering their innovativeness. This compromised the quality of their conceptualization output, as expressed by Greg who stated, "We just want to make things fast." This finding aligns with a study conducted by Fareed et al. (2022), which highlighted the numerous problems students encounter during research conceptualization. These problems encompass both internal factors such as capacity and competency levels, as well as external factors like interpersonal dynamics, institutional support, and financial constraints. Our findings resonate with this research, as the challenges faced by the students can be classified within these broader problem areas. Moreover, previous studies by Rumsey (2008), Conradie (2000), and Afzal (2017) cited in Fareed et al. (2022) have demonstrated that the difficulties and problems experienced during the initial stages of research tend to magnify as the research progresses, resulting in inadequate outcomes. Our findings reinforce this observation, as these challenges act as barriers to the development of appropriate research concepts. However, our research contributes to the existing body of knowledge by specifically identifying challenges that are unique to the field of engineering, particularly in relation to machine concept development. Mechanical engineering, being one of the broadest engineering disciplines, presents technical challenges such as calculation, drawing, integrating novelty, machine design, simulation, and more. By recognizing and addressing these barriers, researchers, and practitioners in the field of mechanical engineering can devise strategies to enhance research conceptualization. This comprehensive understanding of the challenges will help pave the way for more effective and well-informed research endeavors, ultimately contributing to the advancement of the field.

The challenges encountered by engineering research students necessitate the implementation of effective strategies to overcome these obstacles. For instance, Ana emphasized the usefulness of employing strategies in facilitating the identification of research topics and determining their feasibility. By utilizing these strategies as a foundation, students were able to assess whether a particular topic was suitable for their research. As previously discussed, students adopted a variety of strategies to aid their research process. These strategies encompassed establishing decision-making criteria, identifying and validating the research problem, seeking guidance from mentors and experts, effectively managing tasks, modifying existing technologies, strategically developing concepts and designs, conducting thorough literature reviews, and leveraging technological tools.

These findings align with the work of Dubicki (2015), who discovered that students sought assistance from professors and librarians while conducting their research. This correlation is particularly evident in the strategies categorized as "consulting people" and "conducting a literature review." Moreover, several students mentioned their approach of "managing tasks" through the systematic scaffolding of research assignments. This approach allowed them to progressively enhance their research skills over the course of the semester. Dubicki's study also highlighted that student initiated their research process by brainstorming potential paper topics, drawing upon their textbooks, syllabi, and previous coursework. Many students emphasized the importance of selecting an "interesting" and "passionate" idea for their research, which aligns with the subcategory of "strategic development of concept and design."

However, it is worth noting that Dubicki's study solely focused on students' experiences related to the utilization of library resources. Consequently, the current research endeavor contributes to a more comprehensive understanding of the strategies employed by mechanical engineering students. By exploring various avenues and employing diverse strategies, students in this field were able to address the unique challenges they encountered during their research journey.

Additionally, the research findings indicate that the conceptualization of students' research is influenced by both internal and external factors. Internal influencers refer to personal factors such as motivation, interest, prior knowledge, and experience, while external influencers encompass peers, research committees, and available resources. These influencers play a significant role in the development of the students' research concepts. For instance, Karen, one of the participants, highlighted the importance of simplicity and affordability as top priorities for her research. However, when the research panel introduced changes that required the inclusion of two products, these criteria were disregarded. This illustrates how external influences can shape and modify the students' research concepts.

The findings of this study are consistent with earlier research conducted on college seniors, including studies by Anderson and Sexstone (2013), Picard and Logan (2013), and Strong et al. (2013) as cited in Dubicki (2015). These studies emphasized that students draw upon their previous research experiences to expand their knowledge base when encountering challenges in their research. The current study's findings contribute to this body of knowledge by further identifying various factors that can influence the process of research conceptualization. The factors that may impact research conceptualization include the researcher's motivations, personal and professional interests, goals, values,

abilities, experiences, and proficiency in information and communication technology, as well as psychological, socio-cultural, linguistic, and cognitive factors. Additionally, the influence of supervisors and problem-solving skills has been recognized as significant in shaping the research conceptualization process. These factors have been investigated in previous studies conducted by Pennanen and Vakkari (2003), Widiastuti (2010), Mohamed and Nordin (2013), D'Couto and Rosenhan (2015), Mosyjowski, Daly, and Peters (2017), Fila and Purzer (2017), Noguez and Neri (2019), Suyadi, Husnaini, and Elvina (2020), Housseine (2021), and Ashipala and Livingi (2021).

Limitations

This study, like all qualitative research, had limitations that must be addressed. Because of their nature, qualitative results may have limited relevance to many contexts and circumstances. In the case of this study, it is critical to understand that the researchers' results and conceptual model are most relevant and practical within the context of a single Philippine university, with a sample size of eight participants. It is important to emphasize that the applicability of this conceptual model to various situations, such as other student demographics, other engineering disciplines, or new academic subjects, would necessitate more research. As a result, more research is required to investigate and assess the generalizability of the findings outside the current study's unique environment. Future studies concentrating on students' research conceptualization in mechanical engineering will be beneficial in gaining a more thorough grasp of the limits and potential expansions of this conceptual model. Such research efforts might push the boundaries of the present model and find additional categories that could improve its application in various circumstances. Finally, it is critical to recognize that the field of mechanical engineering is an evolving one. Mechanical engineering is undergoing changes because of technological breakthroughs, shifting industry needs, and emergent research fields. As a result, the conceptual model developed in this study is also adaptive and able to evolve over time.

Conclusions

This study aimed at providing a comprehensive and detailed understanding of the processes involved in students' research conceptualization in undergraduate mechanical engineering, highlighting how their research concepts are developed throughout their research journey. To achieve this, the researchers have developed a conceptual model that describes the process of research conceptualization among engineering students. The conceptual model of research conceptualization presented in this study offers valuable insights into the research process specifically within the context of mechanical engineering students. It emphasizes the interplay between various factors such as barriers, influencers, and strategies, underscoring their impact on the success of students' research conceptualization. Although further research is needed to explore the limitations and generalizability of this model, it serves as a foundation for future studies examining how these factors shape the development of research concepts. The identified categories and subcategories within the model can be further examined to determine their positive or negative effects on research conceptualization. This analysis would provide a deeper understanding of the specific influences that contribute to or hinder students' research conceptualization process. In addition to focusing on students, future research could also investigate the research conceptualization experiences of practicing research engineers, comparing their processes with those observed in academic settings. Such investigations would contribute to bridging the gap between mechanical engineering practice and research, enabling researchers and practitioners to collaborate more effectively in developing original and impactful research topics with immediate real-world applications. This study's findings hold significant implications for the discipline of mechanical engineering. By shedding light on the procedures and challenges associated with conducting research in this field, the study enhances the research culture within mechanical engineering. It provides valuable insights into the barriers, influencers, and strategies that mechanical engineering students encounter during the conceptualization phase of their research. This knowledge can ultimately facilitate the integration of research and practice in the field. Moreover, this study makes a substantial contribution to grounded theory as a research methodology. By employing grounded theory as the foundation for the research technique, the author demonstrates the value of data and the bottom-up construction of theory. This approach enhances the credibility and validity of the findings, further strengthening their practical applications. The implications of this study extend beyond the academic realm. The findings can be leveraged to develop guidelines and best practices for conducting research in the field of mechanical engineering. By gaining insights into the research conceptualization process, researchers and practitioners can collaborate more effectively, leading to the development of original and impactful research endeavours with immediate applicability.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest

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