Examination of Study Skills, Emotions, Engagement, and Academic Performance of Mechanical Engineering Students of CIT-University Taking Online Courses: Bases for Student and Faculty Development Program

Angelo A. Acenas, Shiela Marie B. Alia, Ronnel T. Lucero*
Department of Mechanical Engineering, Cebu Institute of Technology University, Cebu City, Philippines
*angeloacenas@gmail.com

ABSTRACT

Amidst the disruptive backdrop of the pandemic, faculty members are required to exhibit heightened awareness and adaptability in response to the challenges posed by the evolving academic landscape. Concurrently, students are tasked with cultivating resilience to effectively navigate their educational pursuits. To bolster the capacities of both faculty and students, a comprehensive exploration of various factors becomes imperative to grasp the intricacies of academic performance within the framework of online distance learning for undergraduate mechanical engineering courses. Scholarly literature suggests that academic performance is influenced by study skills, emotional well-being, and levels of engagement. By employing the revised Online Student Engagement Scale survey, data gathered from 243 students underwent meticulous analysis through Spearman rank-order correlation. This scrutiny unveiled a robust and affirmative correlation between students' study skills, emotional states, engagement levels, and academic accomplishments. Significantly, among these factors, student engagement emerged as the most influential predictor of elevated academic achievement. The research outcomes culminate in the formulation of a strategic intervention strategy. This strategy aims to augment the adeptness of both educators and learners in effectively navigating the realm of online learning. In conclusion, the upheaval caused by the pandemic underscores the urgency for faculty and students to adapt. Through an in-depth investigation, this study underscores the pivotal role of student engagement, alongside study skills and emotional well-being, in determining academic success. These insights guide the formulation of a targeted plan of action, poised to enhance the competence of both stakeholders in embracing the demands of online education.

Keywords: *Online class, student engagement, emotional well-being, academic performance, study skills*

Introduction

The COVID-19 pandemic has profoundly impacted various industries, including the higher education sector. In response to the "new normal," the higher education sector has undergone significant adaptations. The imperative to deliver quality outcomes-based education in an online format has compelled educators to explore innovative and effective methodologies for conducting virtual classes. Both educators and students have faced considerable challenges due to this transition to online higher education delivery.

Cebu Institute of Technology – University (CIT-University) is committed to upholding its commitment to delivering quality outcomes-based education despite the formidable challenges presented by the current circumstances. The university is determined to foster innovation and adjust to the new normal by introducing online services that maintain a high standard of service for administration, faculty, and students. In this context, the university has established the MADE4Learners framework to address the unique needs of students and instructors. To this end, CIT-University has adopted various approaches, including the online approach, online-blended approach, and distance-blended approach. Recognizing the importance of addressing students' emotional well-being, the university has initiated webinars and consultations through its guidance and counselling office. Moreover, to enhance students' study skills, the university has made the e-library and other online learning resources accessible. To encourage active participation in virtual classes, CIT-University has implemented a suite of tools, including the Moodle learning management system, video conferencing, and messaging tools such as MS Teams. However, despite these efforts, there remains a gap in understanding the impact of these interventions on students' academic performance.

Aligned with the University Research Agenda under Research and Development (R&D) for teaching and learning, faculty members have been encouraged to pursue research endeavours aimed at innovating and refining the online-distance learning setup to facilitate more effective and convenient learning experiences.

The overarching objective of the Department of Mechanical Engineering at CIT-University is to produce graduates who are not only skilled practitioners in their field but are also equipped for further graduate studies and research work. These graduates are expected to meet both local and global demands while upholding the ethical standards of their profession and fulfilling their responsibilities within the community. Given the unprecedented circumstances, the department is compelled to examine the factors influencing students' performance in online classes.

The outcomes of this investigation are intended to bolster the capabilities of both students and teachers in navigating the realm of online learning.

Considering the above, this study has developed a comprehensive faculty and student development program. The initial assessment phase of this program sought to address the following key inquiries:

1. What is the correlation between students' study skills and their academic performance?
2. To what extent does students' emotional well-being during online classes correlate with their academic performance?
3. What relationship exists between students' engagement levels in online classes and their academic performance?
4. Based on the findings, what actionable recommendations can be proposed to enhance the capacity of both students and teachers in the context of online learning?

Review of Related Literature

Online Class Study Skills and Performance

The online learning environment necessitates an exploration of the relationship between a learner's skills and their performance. Despite a general adjustment to the new normal, individual skill sets vary among students, as does the instructional approach of educators. These variations can yield differing outcomes compared to traditional face-to-face classes. Thurmond (2002) highlighted that student satisfaction with a university Web-based course was primarily influenced by the online classroom environment rather than the students' personalities.

Online Class Students' Emotion

Zembylas (2008) delved into the impact of learner emotions on performance within an online class. This study traced how emotions evolved throughout a year-long online-distance learning course. Novice adult learners displayed varying emotional responses to online learning, with openness and emotional expression becoming more evident as the course progressed. The study noted that emotions were influenced by factors such as gender roles, responsibilities, and the evolving demands of the online learning environment. Positive emotional responses included enthusiasm and excitement due to the flexibility of online learning, though fear and anxiety stemming from unfamiliarity with online methodologies were also reported. Feelings of alienation and a desire for connectedness were also prevalent, reflecting the students' recognition of their compatibility (or lack thereof) with the online setup. D'Errico et al. (2016) observed that students generally experienced higher levels of positive emotion compared to negative emotion during online classes, particularly synchronous sessions that allowed interaction with peers and instructors. The study also revealed that positive emotions during exam preparation were associated with better exam performance. Furthermore, Walton et al. (2020) established a strong association between social and emotional skills, learning management system (LMS) data, and grades.

Online Class Attendance and Participation

In the online context, a student's participation and attendance define their class performance. Despite the advantages and disadvantages of online learning, active participation remains a key expectation. Oser et al. (2008) highlighted distinct differences between online and offline class participation patterns, with stratification patterns varying due to factors such as income, age, gender, and socio-demographic variables. Caspi et al. (2006) underscored that gender differences also influence performance, with males tending to contribute more in face-to-face classes while females engaged more in online discussions. Khalili et al. (2018) proposed using online interaction or feedback platforms to enhance class participation, finding that adjusting instructional dynamics according to student needs and learning styles was essential. Furthermore, student engagement with the online instructor emerged as a critical factor for successful online learning, as noted by Fredericksen et al. (2000) and Jung et al. (2002) cited in Yeboah et al. (2016).

Methodology

The researchers employed the descriptive-correlational research method for the execution of this study, utilizing survey data collected from students. The survey was designed by adapting the Online Student Engagement Scale (Dixson, 2010) to suit the specific context of the investigation.

The study's participant pool comprised 243 students enrolled in the BS Mechanical Engineering program at Cebu Institute of Technology University during the 2020-2021 academic year. These students were specifically enrolled in online mechanical engineering major courses. The survey was administered using Microsoft Forms as the online survey platform. The gathered data was subsequently compiled, analyzed, and interpreted utilizing the Statistical Package for Social Sciences (SPSS).

Results and Discussion

The data collected from the online survey was organized to answer the following questions: What correlation exists between students’ study skills and class performance? What correlation exists between students’ online class emotional well-being and class performance? What correlation exists between students' online class engagement and class performance? With the findings, what plan of action may be proposed to enhance the capacity of both students and teachers in handling online learning?

The result of the demographic profiling of the respondents showed that there were 81% Male and 19% Female, 79% BSME Computational Science Track and 21% BSME Mechatronics Track, 6% fifth year, 38% fourth year, 33% third year, 20% second year, and 2% first-year students.

Table 1 provides an overview of the mean, standard deviation, description, and rank for each study skills-related statement. Statement A1 received the highest mean score, indicating a strong level of agreement among participants. On the other hand, statements A3, A5, and A4 obtained comparatively lower mean scores. This suggests that students are dedicated to allocating personal study time and actively participating in classes, yet there is room for improvement in terms of organizational skills and note-taking practices. Considering these findings, an instructional approach like flipped instruction could be adopted by educators. Flipped instruction involves reversing traditional notions of classroom activities and homework. Notably, the study conducted by Nouri (2016) unveiled that many students displayed a positive response to flipped instruction, manifesting in heightened motivation, increased engagement, and enhanced learning outcomes. This pedagogical approach may prove beneficial in further enhancing students' study skills and overall academic performance.

Table 1: Factors affecting academic performance related to study skills

Statements	Mean	Standard Deviation	Description	Rank
A1. I make sure to allocate personal study hours for ME major subjects on a regular basis.	3.93	0.73	Moderately true	1
A2. I am actively engaged with the reading materials of ME major subjects.	3.79	0.74	Moderately true	3
A3. I review ME major subject class notes before attending synchronous classes for better understanding of the study material.	3.75	0.84	Moderately true	4
A4. I am organized when it comes to ME major subjects.	3.79	0.74	Moderately true	3
A5. I take comprehensive notes during readings, PowerPoints, or video lectures of ME major subjects.	3.75	0.84	Moderately true	4
A6. I listen and read attentively during ME major classes.	3.82	0.81	Moderately true	2

The research results from Table 2 provide insights into the correlation between emotions and academic performance, shedding light on how emotional factors influence students' performance in their ME major subjects. The statements within the table represent various aspects of students' emotional involvement with the material and their desire to learn.

Table 2: Factors affecting academic performance related to emotions

Statements	Mean	Standard Deviation	Description	Rank
B1. I put forth effort in ME major subjects.	3.75	0.84	Moderately true	3
B2. I find ways to make ME major subject's study material relevant to my life.	3.82	0.81	Moderately true	1
B3. I apply ME major subject's study material to my life.	3.79	0.91	Moderately true	2
B4. I find ways to make the ME major subjects interesting to me.	3.82	0.81	Moderately true	1
B5. I really desire to learn the ME major subject study material.	3.79	0.91	Moderately true	2

Statements B1, B2, and B3 reflect students' effort, application, and relevance of the study material to their lives. Students moderately agreed that they put forth effort in their ME major subjects (B1), indicating a positive level of commitment. The fact that they find ways to make the study material relevant to their lives (B2) and apply it (B3) highlights their intention to connect their academic pursuits to practical applications. On the other hand, statements B4 and B5 delve into students' interest and desire to learn the subject material. Students indicated moderate agreement with finding ways to make the ME major subjects interesting (B4) and expressing a genuine desire to learn the study material (B5). This suggests that students actively seek ways to engage with the content and are motivated by personal interest.

Building upon the findings presented, it is worth noting the work of D'Errico et al. (2016), which highlights a strong correlation between positive emotions during exam preparation and students' motivation. This correlation directly supports the learning process and the resulting outcomes. To leverage these insights and enhance students' learning outcomes through targeted positive motivation and emotion, educators can implement strategies that align with the research findings.

Table 3 presents the result on the role of engagement in relation to academic performance. The results indicate the level of agreement with statements regarding different aspects of engagement within the online learning environment.

Table 3: Factors affecting academic performance related to engagement

Statements	Mean	Standard Deviation	Description	Rank
C1. I have enjoyable interactions in online chats, discussions, or emails with instructors or peers in ME major subjects.	3.98	0.75	Moderately true	2
C2. I actively participate in small-group discussion forums in ME major subjects.	3.79	0.91	Moderately true	3
C3. I assist fellow students in ME major subjects.	3.98	0.75	Moderately true	2
C4. I engage in online conversations (chat, discussions, email) related to ME major subjects.	4.19	0.68	Moderately true	1
C5. I regularly contribute to discussion forums about ME major subjects.	3.98	0.75	Moderately true	2
C6. I establish connections with other students in the ME major class.	4.19	0.68	Moderately true	1

In terms of student engagement, the data collected from BSME students at CIT University enrolled in ME major courses through online classes revealed a moderately positive response across all engagement-related statements. Notably, the two statements C4 and C6 garnered the highest mean scores, indicating a significant level of involvement and interaction within the larger class setting. Conversely, the statement C2 obtained the lowest mean score, suggesting a relatively lower engagement level in this specific activity. This finding highlights a potential gap in active participation within smaller group settings, which is crucial for fostering meaningful peer interactions and collaborative learning experiences.

Drawing insights from the works of Jung et al. (2002) as cited in Yeboah et al. (2016), it is evident that active cooperation among co-learners contributes to increased satisfaction, improved social interactions with instructors, and enhanced overall class learning. The emphasis on interactions with fellow students is underscored as a significant driver of effective online learning.

To address the observed gap in engagement within small-group discussion forums, several strategies can be employed. For instance, instructors can stimulate student engagement during synchronous classes by posing thought-provoking questions that encourage students to share their insights using the chat feature of video conferencing platforms. Additionally, the integration of focused group discussions and break-out rooms at the conclusion of synchronous sessions can provide opportunities for students to engage in in-depth, small-group interactions, enabling them to exchange takeaways from the lesson, ask questions, and enrich their understanding collaboratively.

Moreover, it is advisable for instructors to periodically assess students' experiences within small groups compared to larger class settings. This evaluation can offer valuable insights into the effectiveness of engagement strategies and provide a platform for making targeted improvements to enhance the overall learning experience.

The findings from Table 4 reveal how students perceive their academic performance within the context of ME major subjects. Statement D2 received the highest mean score of 4.19, indicating strong agreement among students. This suggests that students feel confident about their performance in assessments and quizzes within the ME major subjects. It is notable that this statement also holds the top rank, emphasizing its significance.

Table 4: Academic performance as perceived by the students

Statements	Mean	Standard Deviation	Description	Rank
D1. I am getting good grades in ME major subjects.	4.06	0.83	Moderately true	2
D2. I am doing well on the tests/quizzes of ME major subjects.	4.19	0.68	Moderately true	1

Statement D1 received a mean score of 4.06 and holds the second rank. While this mean score is slightly lower than that of D2, it still signifies a high level of agreement among students. This result underscores students' perception of achieving satisfactory grades in their ME major subjects. The relatively small standard deviations for both statements (0.83 and 0.68) suggest that there is a certain level of consistency among student responses, indicating that their perception of their academic performance is relatively uniform.

To create a more valid inference from the data above, statistical analysis was done using the Statistical Package for Social Sciences (SPSS). The result is presented in Table 5.

Table 5: Kolmogorov-Smirnov Normality Test using SPSS Statistic

Variables	p-value	Decision
Performance	< 0.001	Reject null hypothesis
Study Skills	< 0.001	Reject null hypothesis
Emotions	< 0.001	Reject null hypothesis
Engagement	< 0.001	Reject null hypothesis

Based on Table 5, the probability value is less than 0.05 for all the variables which is a valid basis for rejecting the null hypothesis that the data are normal. Hence, we accept the alternative hypothesis that the data are not normal. For not normally distributed Likert scale data, we shall use non-parametric method of data analysis such as ordinal, multinomial logistic regression analysis, and the Spearman rank correlation.

Using ordinal logistic regression test of parallel lines, Table 6 shows that the probability value is less than 0.05. This means that the assumption of proportional odds is violated. Thus, a traditional cumulative logistic regression needs to be used instead. A multinomial logistic regression is then used to determine the predictor of student performance among the three variables.

Table 6: Ordinal Logistic Regression Test of Parallel Lines using SPSS Statistic

Model	-2 Log Likelihood	Ch-square	df	p-value	Decision
Null hypothesis	669.9				
General	625.5	44.4	21	< 0.002	Reject null hypothesis

The "Final" row in Table 7 presents information on whether all the coefficients of the model are zero. Another way to consider this result is whether the variables you added statistically significantly improve the model compared to the intercept alone. Since the probability value ($p < 0.001$) is less than 0.05, then the full model statistically significantly predicts the dependent variable better than the intercept-only model alone.

Table 7: Multinomial Logistic Regression Fitting Information Using SPSS Statistic

Model	-2 Log Likelihood	Ch-square	df	p-value	Decision
Intercept only	808.2				
General	641.2	166.9	24	< 0.001	Reject null hypothesis

Table 8 shows which of the independent variables are statistically significant predictors of a student's academic performance. The emotional factor was not statistically significant ($p = 0.346$) while the study skill factor was statistically significant ($p = 0.008$) along with engagement ($p < 0.001$). These results contain the overall contribution of each independent variable to the model. Using the alpha = 0.05 threshold, we see that students' study skills and engagement are significant predictor of their academic performance.

Table 8: Multinomial Logistic Regression Likelihood Ratio Test Using SPSS

Effect	Chi-square	df	p-value	Decision
Intercept	96.776	8	< 0.001	Reject null hypothesis
Study Skills	20.555	8	< 0.008	Reject null hypothesis
Emotions	8.955	8	< 0.346	Accept null hypothesis
Engagement	54.539	8	< 0.001	Reject null hypothesis

Another method to determine the effects of each variable on student performance is the use of Generalized Linear Model. Table 9 shows the GLM's parameter estimates. The odd ratio indicates statistically significant result that the odds of being in a higher level on the student performance increases by a factor of 5.086 ($p < 0.001$) for each one unit increase on the student engagement and a factor of 2.357 ($p = 0.012$) for each one unit increase in study skills. Emotions on the other hand have no statistically significant result.

Table 9: Generalized Linear Model Parameter Estimates Using SPSS

Effect	Wald Chi-square	df	p-value	Odd ratio	Decision
Study Skills	6.455	1	0.012	2.357	Reject null hypothesis
Emotions	1.535	1	0.215	1.408	Accept null hypothesis
Engagement	43.053	1	< 0.001	5.086	Reject null hypothesis

Since the data are non-parametric, a Spearman's rank-order correlation was run to determine the relationship between 243 students' study skills, emotions, and engagement to student's academic performance as shown in Table 10. There was a strong, positive correlation between study skills and student's performance, which was statistically significant ($r = 0.493$, $p < 0.001$), between emotions and student's performance, which was statistically significant ($r = 0.441$, $p < 0.001$), and between engagement and student's performance, which was statistically significant ($r = 0.629$, $p < 0.001$). The strongest among the variables is student engagement.

Table 10: Spearman's Rank-Order Correlation using SPSS Statistics

Parameter	Spearman's rho	p-value	Decision
Study Skills	0.493	< 0.001	Reject null hypothesis
Emotions	0.441	< 0.001	Reject null hypothesis
Engagement	0.629	< 0.001	Reject null hypothesis

Conclusion

Based on the insights drawn from the analysis of 243 students enrolled in BS Mechanical Engineering major subjects within the online class setting at Cebu Institute of Technology University, a compelling connection emerges. The data unequivocally underscores a robust positive correlation between students' study skills, emotional disposition, engagement levels, and their subsequent academic performance. Notably, among these three critical facets, student engagement emerges as the most potent predictor, carrying the strongest influence over achieving commendable academic outcomes.

These findings hold significant implications for enhancing the academic journey of these students. To fortify academic performance, it is recommended that educators embark on a journey of self-improvement. This entails equipping teachers with targeted training sessions that encompass a spectrum of themes. These themes, while not confined to, encompass topics such as implementing flipped instruction techniques, harnessing experiential and active learning strategies, adeptly formulating attainable learning goals and outcomes, and cultivating an environment conducive to collaborative small group learning dynamics.

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.

Funding

This work received no specific grant from any funding agency.

Conflict of Interests

All authors declare that they have no conflicts of interest

Acknowledgment

We would like to thank our research advisory board for the assistance in making this research.

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Redesigning Outcomes-Based Mechanical Engineering Course Syllabus Using the Constructive Alignment Approach

Angelo A. Acenas, Edgardo Concepcion, Roberto P. Base, Jr.*
Department of Mechanical Engineering, Cebu Institute of Technology University, Cebu City, Philippines

*angeloacenas@gmail.com

ABSTRACT

The field of Mechanical Engineering is one of the earliest disciplines within the realm of engineering, having acquired a distinct identity during the nineteenth century. This study constitutes an ongoing endeavor aimed at enhancing the quality of Mechanical Engineering education. As the foundation for this revision, the authors have undertaken an evaluation of the existing syllabi for three major Mechanical Engineering courses, employing a constructive alignment approach. Pertinent data were collected through the analysis of existing documents, interviews, and consultations with the instructors of these ME major courses. Thematic analysis was employed to scrutinize the gathered data. The resultant insights were utilized to formulate a novel course syllabus that is attuned to the requisites and objectives of the university, while adhering to the Outcomes-Based Teaching and Learning Framework established by the Philippine Commission on Higher Education.

Keywords: *Education, Outcomes-Based, Engineering Education, Course Syllabus, Constructive Alignment.*

Introduction

There has been a global paradigm shift in higher education teaching, transitioning from a teacher-centered approach to a student-centered one. This shift is largely influenced by extensive research focusing on teaching and learning methods, particularly highlighting the efficacy of active-based learning. A prominent educational model aligned with this student-centered philosophy is Outcome-Based Teaching and Learning (OBTL), which centers on achieving learning outcomes through targeted educational activities. As a result, numerous educational institutions have begun to explore and integrate the outcomes-based approach into their academic frameworks.

In the Philippines, the Commission on Higher Education (CHED) has characterized the Bachelor of Science in Mechanical Engineering (BSME) program in its memorandum order (MO) 97 of 2017 as outcomes-based. The program's outcomes are aligned with the standards set by the US Accreditation Board for Engineering and Technology (ABET), with Higher Education Institutions (HEIs) mandated to adhere to the stipulated minimum requirements as per the CMO.

Notably, the Cebu Institute of Technology University (CIT University) has achieved Autonomous Status, the highest recognition bestowed by CHED upon academic institutions demonstrating commitment to excellence, sustainability, and advancement. Additionally, CIT University has displayed proactive endeavors in seeking accreditation from the Philippine Association of Colleges and Universities Commission on Accreditation (PACUCOA) in recent years. In fact, the university has earned distinction for holding the highest number of accredited programs within Region VII.

To ensure and uphold the quality of education, CIT University has established its Research and Development (R&D) initiative for Teaching and Learning. This initiative is dedicated to enhancing pedagogical approaches, delivery methods, quality assurance systems for teaching and learning processes, program assessment, curricular studies, student success, tracer studies, evaluation of graduate competencies, and the provision of academic and non-academic support services and systems.

This study contributes significantly to the pursuit of quality education by evaluating and proposing innovations within one of the university's flagship programs. The BSME program at CIT University aims to produce graduates who are not only competent in their profession but are also committed to lifelong learning, scientific exploration, and equipped to meet both local and international professional demands. These graduates are expected to demonstrate self-motivation, leadership capabilities, adherence to professional ethics, and responsible engagement within the community. While the university has implemented the BSME Curriculum 2017, a substantial portion of the course syllabus remains an adaptation of the 2008 Curriculum's syllabus. Moreover, there has been limited revision to align the syllabus design with the OBTL framework. Consequently, this study seeks to evaluate and innovate the existing course syllabus for two BSME courses, employing a constructive alignment approach to establish a model for other courses.

Specifically, the study aims to devise an inventive course syllabus for Engineering Thermodynamics and Combustion Engineering by evaluating the existing syllabus using a constructive alignment approach. The research endeavors to address the following key research questions:

1. To what extent do the contents of the existing course syllabus, including the course outline, intended learning outcomes, teaching, and learning activities, and assessments, align with the CHED MO program outcomes, course learning outcomes, course description, and CIT BSME program educational objectives?

2. What is the discernible level of cognitive processing and knowledge dimension evident within the existing course syllabus, particularly concerning performance indicators?

3. How do the existing course syllabus and the syllabus adopted by other local and international universities differ?

4. Based on the research findings, what actionable recommendations can be put forth to enhance the existing course syllabus?

In essence, this study aims to bridge the gap between theory and practice, enhancing the alignment of the BSME curriculum with contemporary educational paradigms and ensuring the production of competent, adaptable, and ethically conscious engineering professionals.

Literature Review

The motivation behind this literature review is to develop an innovative course syllabus for Engineering Thermodynamics and Combustion Engineering by assessing the existing syllabus using a constructive alignment approach. First, the author laid down the foundation of constructive alignment by citing pieces of literature focusing on the rationale behind it, the implementation of constructive alignment by different institutions, and the challenges encountered in doing so. Since constructive alignment has five major components namely: (a) course learning outcomes, (b) intended learning outcomes, (c) teaching and learning activities, (d) assessment tasks and content/resources; the author tried to look upon several pieces of literature to gather information on these different components to support to the development of the new and improved CIT University course syllabus for Engineering Thermodynamics and Combustion Engineering.

Constructive Alignment

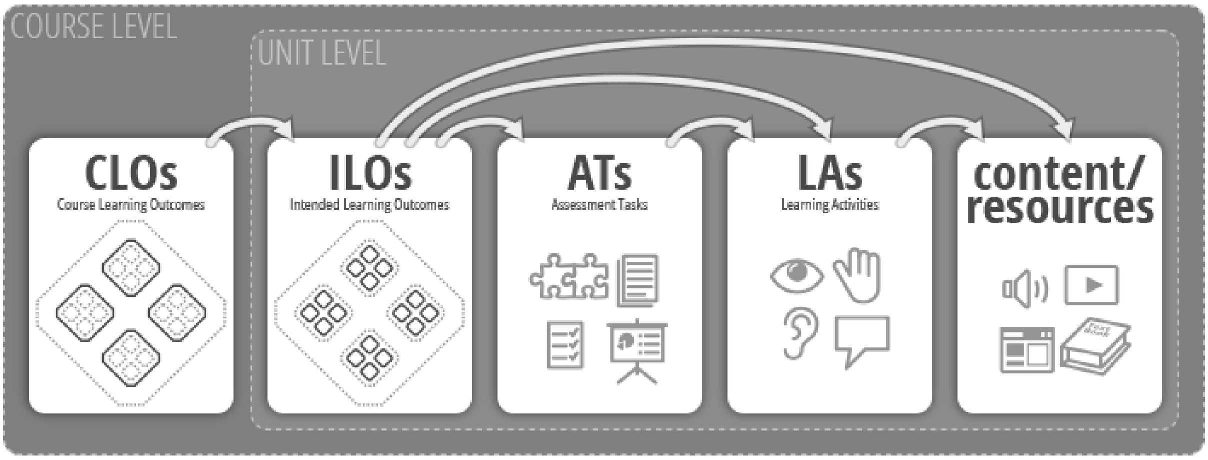

Figure 1: Constructive Alignment Diagram
Note: A visual representation of constructive alignment (Biggs, J. (2014). From Constructive alignment diagram, Beale Gurney & Nell Rundle, CC BY-SA

Constructive alignment is a methodical alignment of the “intended learning outcomes, teaching and learning activities and assessment tasks” which requires the students to participate in the learning activities to build their knowledge as constructed using “their own existing schemata” (Biggs, 2014; Biggs & Tang, 2011). According to Biggs (2014), it is a teaching method which is outcome-based while Morcke, Dorman, and Eika (2012) supported this by saying that the framework amplifies the development of outcome-based education by having a very good emphasis on learning and teaching process. According to Nightingale, Carew, and Fund (2007), there are two key elements of constructive alignment. The first one is that learning stems from the learners "as they gain meaning" through the activities and the second one is that teaching becomes effective when there is target learning outcome supported by relevant activities.

Biggs and Tang undertaken the first university-wide implementation of constructive alignment at the Polytechnic University of Hong Kong from 2002. The aim is to achieve improvement in student learning outcomes through "teaching quality and institutional support and systems" (Ruge, Tokede & Tivendale, 2019).

The benefit of constructive alignment was shown in the study of Cheung, Kwong, Su, Wang, and Wong (2013). They investigated whether the "adoption of constructive alignment has any effect on the students' learning approaches". Based on the result, the students who are exposed to a more aligned courses have higher chances of adopting deep learning method in their study of a course.

A study conducted by Ewe, Ng, and Thian (2018), capitalized on the constructive alignment framework and created "detailed and practical curriculum design model to aid the development of graduate student's capabilities". The authors emphasized the need for communicating strong reasons for change despite the challenges of implementing the framework due to the repetitive "process of alignment at level of program and module development".

There are only 34 from 245 syllabi analyzed by Chan (2021) from three Hongkong Universities included wide range of competencies in the intended outcomes. The outcomes are connected to both traditional and experiential pedagogies but were not assessed accordingly. The challenges in implementing constructive alignment are due to the "program leaders' conceptions of holistic competencies", the limited capabilities of instructor, and the issues on assessing competencies. They added the importance of training all levels of engineering instructors on different areas like holistic competency development, "industrial experiences, and expectations, developing top-down and bottom-up educational reforms to improve the engineering curricula", etc.

Koster, Schalekamp, and Meijerman (2017) gave six steps in implementing an outcomes-based education. First is to adopt a competency model that summarizes the competencies needed to be developed. Second is to define the learnings outcomes intended to be achieved. Third is the developmental of curriculum that integrates and shows the progression of competency. Fourth is the selection of appropriate assessment activities. Fifth is the design of educational environment like "the learning activities and experiences and teaching methods. Finally, the continuous review and improvement of the module and the curriculum".

Subject outlines from several Australian universities were analyzed by Nightingale, Carew, and Fund (2007) and found out that engineering professors are still very dependent on examinations the assessment of students. The examination uses different question types but still limited in accurately assessing other important competencies. Also, the "assessment tasks are not aligned to the learning objectives". Finally, the study showed that applying constructive alignment to the design of the subject assisted the academics to improve the assessment methods that actively engage the students with different learning experiences and achieve the desired learning outcomes better. The Revised Taxonomy (Anderson & Krathwohl, 2001) as shown in Table 1 was used to evaluate the subject outlines.

Table 1: Revised Bloom's Taxonomy (Anderson and Krathwohl, 2001)

The knowledge Dimensions	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
A) Factual Knowledge						
B) Conceptual Knowledge						
C) Procedural Knowledge						
D) Metacognitive Knowledge						

In the Revised Bloom's Taxonomy, the knowledge dimensions "encompassed four categories: factual knowledge includes the essential terminology, constants, symbols, and sources of information; conceptual knowledge includes the principles, classifications, models, theories, and structures; procedural knowledge which includes how to do something, algorithms, techniques, methods, and criteria used to select proper methods; and metacognitive knowledge which includes the awareness of educational strategies, strategies to improve learning, knowledge of one's own abilities and weaknesses, ability to recognize higher and lower-level thinking".

Outcomes-Based Education Initiatives

The City University of Hong Kong (n.d.) considered the outcome-based method to student learning as a student-centered approach. The method includes stating the expected learning outcomes and conducting assessment to know if the students have achieved the learning outcomes. The rationale behind this is that by clearly understanding and articulating the "intended learning outcomes, the design of effective curriculum, implementation of relevant and appropriate teaching, learning assessments tasks" can be facilitated.

In the Philippines, the initiative to establish an outcomes-based education in higher education is first promoted for engineering programs (CHED, 2012). Also, this was reinforced as CHED see the importance of making the Philippines Mechanical Engineering education updated with international trends (Belino, 2011). It issued a memorandum order (MO) last 2017 regulating the HEIs that offer BS Mechanical Engineering. The MO laid down the requirements of all colleges and universities offering BSME to make sure that graduates demonstrated the achievement of the program outcomes (PO) based on the Accreditation Board for Engineering and Technology (ABET) requirements. The PO includes the following: "(a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs within realistic constraints; (d) an ability to function on multi- disciplinary teams; (e) an ability to identify, formulate and solve engineering problems; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively in both Filipino and English languages; (h) an understanding of the impact of engineering solutions in a global and societal context; and (i) an ability to use techniques, skills, and modern engineering tools necessary for mechanical engineering practice." The CHED MO also provided the minimum required Course Learning Outcomes for the subjects Engineering Thermodynamics and Combustion Engineering as shown in Table 2.

Table 2: Course Learning Outcomes for Engineering Thermodynamics and Combustion Engineering

Engineering Thermodynamics 1	Engineering Thermodynamics 2	Combustion Engineering
a) Identify the different properties of pure substance, ideal gas, and real gas. b) Apply thermodynamics concepts and principles in analyzing and solving problems. c) Apply the laws of thermodynamic in analyzing problems. d) Evaluate the performance of thermodynamic gas cycles.	a) Apply the concepts of Thermodynamics in analyzing Power cycles. b) Determine the physical and thermodynamic properties of ideal gas mixtures, real gases, and mixtures of gases and vapor. c) Evaluate the performance of vapor power cycles and gas power plants and standard air-power cycles.	a) Explain basic combustion and stoichiometric process. b) Perform stoichiometric analysis of various gaseous, liquid, and solid fuels. c) Apply thermodynamic principles in analyzing the performance of internal combustion engines. d) Evaluate the principles, operations, maintenance, and design of internal combustion engines.

It is necessary to align the course learning outcomes to those required by CHED for the graduates of the BSME program to be able to compete with local and international standards. A study conducted by Belino (2011) cited different local and international accreditation agencies and their plan to change from input-based to outcomes-based accreditation.

The first one is the Philippines Technological Council (PTC). Through its arm, Accreditation and Certification Board for Engineering and Technology (ACBET), PTC accredits engineering programs through the policies, methods, and authorities as stated in its Certification and Accreditation System for Engineering Education (CASEE). The accreditation of the engineering program is recognized internationally through the Washington Accord (ptc.org.ph, n.d.). There is also private voluntary accreditation which aims to bring the standards of the educational institutions above the prescribed minimum requirements set by the government. Three agencies that accredits engineering schools are "Philippine Accrediting Association of Schools, College and Universities (PAASCU); the Philippine Association of Colleges and Universities- Commission on Accreditation (PACUCOA; and Accrediting Agency of Chartered Colleges and Universities (AACUP)". PAASCU and PACUCOA are on the way of going outcomes-based accreditation. An international accreditation, ABET, Inc., is recognized by the Council for Higher Education Accreditation and is one of the most prestigious accreditation organizations based in United States. "It accredits college and university programs such as computing, applied science, engineering, and technology" (abet.org, n.d.).

Student-Centered Teaching and Learning Activities

Halperin's study (as cited in Catalano, 1997) showed that majority of the classroom activities nowadays in higher education still reflect traditional style of teaching because students are passively receiving information from the instructors. To shift from this approach to a more student-centered one, Catalano (1997) identified several roles of a teacher in student-centered education. The first role is in exemplifying thinking and processing skills. The teacher can do this by verbally processing how the students think, do, hear, and make sense of the learning material and search for a solution to problems. The second role is in identifying where they want their students to be cognitively. In Bloom's taxonomy (Bloom, 1956), thinking begins "in the lower levels (knowledge and comprehension) to the highest levels (synthesis and evaluation)". Aschner and Gallagher (1965) divided thinking modes "into memory, convergent thinking, divergent thinking, and evaluation. The teacher should be aware of the level of thinking needed by the students" in doing the teaching, learning, and assessment activities and should explain this to the students. The third role is to make questions that encourages student exploration and growth. Instead of asking the common question "Are there any questions?", the instructor must ask questions that would compel the student(s) to show what is being learned. This can happen by allocating enough time so that the learners could leverage "of the quiet times to" create "own questions". Also, the teacher must take "periodic breaks in class asking students to summarize what had been" discussed. Lastly, learners must be encouraged to ask relevant questions and teachers role model such behavior. The fourth role is in utilizing visual tools to aid students in seeing how information can be interconnected and teaching them to use these tools. This idea stems from the fact that the right hemisphere of the human brain is visual. Mind mapping or graphic organizing are examples of visual tool that are very useful in a student-centered classroom. It is appropriate at different situations such as an overview of the course, review sessions before exams, end of the course, etc. It helps to organized information and to generate insights. Computers, audio, video playback systems, etc. can also be incorporated to the visual tools. The fifth role is in providing group-learning settings. Positive interdependence, "individual accountability, appropriateness of the assignment, teacher performs as facilitator, explicit attention to social skills, and emphasis on face-to-face problem solving" are the critical features of group learning (Cooper et al.,1992). Weimer (1996) added that group-learning situations should have many opportunities for inclusion (quantity), the more students engaged the better (extent) and deep rather than shallow student participation (depth). The sixth role is in using analogies and metaphors. An example of this is in teaching Thermodynamics where the instructor could explain the concepts of energy, availability of energy, and the second law in concepts that the students could relate like gross income, net income, and the passage of time. The objective is to help students in creating their own metaphors to explain new concepts that they have encountered. Finally, the seventh role is in providing a safe mechanism for indirect dialogue between teacher and student(s). The teacher can use for example a discovery sheet to hear students' opinions and facilitate open and honest communication. It can be given after exams, in new subject topics, or during a tough lesson, etc. This exchange of ideas, thoughts, and feelings can create a classroom environment free from indifference and with a sense of community.

In their book entitled "Teaching Engineering", Wankat and Oreovicz (2015) suggested several teaching and learning activities that can be implemented in an engineering class.

Problem solving

This method can be integrated in existing engineering courses without the need of having another course in problem solving. Illustrating the strategy is important when the teacher is solving problems in class and in the handouts provided to the students. The author added that the teacher must show that problem solving is not necessarily a neat process. This can be done by allowing the students to select the problem you will solve in front of the class or to solve problems you have not encountered before. The book offered many strategies in problem solving that the teacher can implement.

Lectures

There is still an argument whether the number of lectures should be increased or decreased in improving engineering education. If done properly, lecture can have many advantages such as having the audience as the focus, versatility and flexibility, easy updating, simple technology, acceptable and common, can integrate learning principles, can include assessment and rapid feedback, live contact, can include hands-on or demos, professor-efficient, time-efficient, instructor control, anyone can lecture, "potentially outstanding for motivation and for conveying information", stimulating, and student learning can be high. However, in most cases, becoming an excellent lecturer is hard and can lead to the following disadvantages: audience are ignored, inappropriate lecture style, stagnation, technical errors, student passivity, few learning principles may be satisfied, boredom, inadequate preparation or over preparation, lack of individualization, etc. In doing lectures, the following ideas can be utilized as a guide in selecting the lecture material: include key points and general concepts, lecture on topics that students find to be very interesting, include hard topics like topics that are not properly discussed in the textbooks, tackle important topics not covered in other learning materials, include a lot of examples, and select material that is suitable in terms of depth and simplicity. To sustain student engagement in lectures, it is also important to consider doing the following: ask questions, shift to a Socratic approach by asking them questions, let students summarize the very important points in the lecture on a piece of paper, give a short check-up quiz, or facilitate a group activity. The teacher can also take advantage of giving post lecture quiz, inviting guest lecturers, and feedback lectures. The lecture method is very effective when the objective "is to have students learn the three lowest levels of Bloom's taxonomy, but it is not the best approach for higher level cognitive objectives such analysis, evaluation, problem solving, and critical thinking".

Discussion

This is commonly utilized in social sciences education. Several scientific evidence shows that this approach is not an effective method for transferring facts and data in comparison to lectures. The good thing about discussion is that it can be better than lecture in inculcating "analysis, synthesis, evaluation, problem solving, and critical thinking". When the goal of the teacher is to work on higher-order thinking skills, engineering teachers can consider discussion as a teaching method. This includes activities such as brainstorming, small cooperative groups, engineering problem solving discussion, among others.

Cooperative Group Learning

Students can work cooperatively as a group to comprehend the learning material, do homework, accomplish projects, and review for examinations. Research says that this method is suitable in achieving higher-order cognitive objectives (Johnson et al., 1991; Smith, 1986, 1989). This method is common in engineering especially in doing laboratory works and design projects.

Panels

This method can be used to start a question-and-answer activity by having three or four experts on open ended questions. This method has been used in professional seminars on topics like how to do job hunting, what happens in job interviews, what the work in the industry is like, what industry looks from young engineers, how to obtain research funding, and how to achieve tenure. It can also be utilized for controversial engineering topics like "those where technology and policy interact".

Modified Debates

This method can be useful when a topic has two or more sides. Examples of debatable topic is competing designs or controversial engineering technology. It is a very good way to engage students in the learning material, improve communication skills, and exert collaborative effort.

Quiz shows

This can be done by using Trivial Pursuit, Jeopardy, or College Bowl where students can participate individually or as a group. Like in many competitive activities, this quiz shows works better if the participants are evenly matched. The teacher will serve as the quiz master.

Field trips and visits

This method is still not commonly utilized in majority of engineering subjects. It is essential for students to see real equipment or manufacturing operations. This experience can transform abstract concepts more real, and the field trip can be encouraging to a lot of students.

Tutored Videotape Instruction

This method was originally produced at Stanford University (Gibbons et al., 1977). Here a video is developed in the campus in a similar manner as that of the television.

Computer-Aided Instruction

A computer is utilized to teach the learning material to the learner. Simons (1989) "identifies three major modes for CAI". The first one is the drill-and-practice mode where is a learner is given question or problem, the student answers, and the computer gives feedback on the answer. The second one is the tutorial mode which contains learning material and can be a substitute for lecturing and textbooks. It contains sample problems and images, include questions and problems, and have abundant feedback compared to the first mode. The third mode is simulation using computer program.

Design

The activities that can be considered as design are those that (a) develops a system, process, or component to achieve a specific goal, (b) repetitive "process which uses decision making with economics and uses mathematical, scientific, and engineering principles", (c) involves goal setting, analysis, synthesis, evaluation, fabrication, testing, and reporting, (d) gives "student problems that are often open-ended", need use of design procedures and "creative problem solving", need creation "of the problem statement and an economic comparison" of different "solutions, and may need detailed system details" (ABET, 1989). Design projects can be implemented to teach design. Here, group of students are "given a design problem" and tasked to make the design. "Engineers learn design through designing" which makes this procedure appropriate. The problem needs to be open-ended to be considered design. Aside from design projects, case studies can be implemented since this is appropriate for design and non-design classes. Teacher may give case studies to students for reporting or for discussion (Henderson et al., 1983). There are many case studies which involves ethical questions and can serve as springboard for discussion. It can also aid in introducing the engineering profession which motivates some students. The relevance of the subject being studied can be inculcated to the students in introductory engineering classes.

Student-Centered Assessments

In his book entitled Teaching for Quality Learning at University, Biggs (2003) answered several questions that student-centered teachers may have in implementing assessments. Instead of asking many questions, he said that a crucial consideration that teacher should ask is "What are your objectives? He added that the best assessment method is the one that best achieves the intended learning outcomes.

Essay Examinations

This method is suitable to assess higher order thinking skills and for evaluating declarative knowledge. It is an open-ended exam where students can express thoughts and views with supporting details.

Assignments, term paper, and take-home

This method is appropriate to assess declarative knowledge. The advantage is that students are given ample time to construct ideas and do not have to depend in memory. Thus, it motivates deeper learning where learner may use several sources and synthesize information better. The problem is the issue of plagiarism which can be solve by providing shorter time for submission.

Multiple-choice tests

It is the most used objective test to assess declarative knowledge. This method can theoretically assess high-level cognitive skills but in actual practice is not. The disadvantage of MC is that it can encourage the use of game-playing strategies for students to answer the question. It is most convenient but can be more "useful as supplement to other assessment methods".

Ordered outcome items

It looks like MC but instead of choosing one correct choice from the options, the learner is required to answer all the sub-items (Masters, 1987). The sub-items are organized into increasing level of difficulty that shows progressive level of learning. The stem should give all the information needed to answer all the sub-items

Practicum

This can demonstrate the competence needed in actual situation like handling experiment in the laboratory, machining, and developing machines. It is more valid if the practicum is closer to the actual scenario in the field. The challenge with practicum is that it can distort reality since students behave differently when being assess from the way they would if they were not being assessed.

Presentation and Interviews

The students are "evaluated based on the content and the delivery of the content". The seminar for example if properly conducted can provide ample opportunities for formative discussion and peer assessment. The disadvantage is when teacher uses this method as a "poor substitute for teaching". "Student presentations" are highly suitable for assessing functional knowledge than "declarative knowledge". The "poster presentation follows the conference format" where a learner or groups display their output following the format provided by the teacher. This method gives outstanding "opportunities for peer-assessment", and for quick "feedback of results". The interview method is widely used in evaluating research papers. The student researchers make a thesis and defend in panel of experts.

Critical incidents

In this method, the learner reports critical incidents that make them think deeply on the topic. The student explain why they find this instance important, how it happen, and what can be done regarding it. Through this, the teacher can understand how students interpreted and use the lesson.

Project

It targets the "functioning knowledge". It can be a simple or complicated project and commonly done by "group of students". The instructor can assign the task of each member or give them the freedom to agree as a group. The challenge with this method is that "individual students too easily focus only on their own specific task, not really understanding other components, or how they contribute to the project".

Reflective journal

This method can be used in professional subjects. Students record any instances, thoughts or insights that are important to the topic. It is a valuable tool in evaluating the judgement of the students as to the relevance of the topic and their capacity to think upon their experience on the lesson.

Case study

In some fields, this is an ideal way of knowing how learners can put their "knowledge and professional skills into practice". It can be done with the supervision of an adviser or independently by the learner.

Portfolio assessment

The learner showcases best outputs "in relation to the intended learning outcomes". They can think and evaluate outputs and describe how it match the objectives.

In assessing large classes, the following methods can be useful:

Concept maps

This helps the teacher know the level of understanding of the students in a particular topic.

Venn diagrams

It is like concept maps but is simpler in expressing relationships between concepts.

Three-minute essay

It is a reflective activity by which teacher ask question such as "What is the main lesson I knew today?" This can help in assessing how students interprets the information for formative assessment or if students have right interpretation of the topic as summative assessment.

Short answer examinations

The learners respond in note form. The advantage of this method over MC is that it is less prone to game-playing strategies, it needs "active recall rather than just recognition" and it is easier to create though harder to score.

Gobbets

It includes important part of the lesson that learners should be familiar and must respond (Brown and Knight 1994). It can include items like photograph of a machine or an engine part. The learner must identify the gobbet, explain its context, its importance, what can they relate it to, etc.

Letter to a friend

The learner tells an imaginary or actual friend, who will be taking the course next year on their own experience of the lesson or activity (Trigwell and Prosser 1990).

Cloze tests

It is useful in evaluating student's reading comprehension. A passage is selected "that can only be understood if the topic under discussion is understood."

Table 3: Some Assessment Tasks and the Kinds of Learning Assessed

Assessment mode	Most likely kind of learning assessed
Extended prose, essay type	
Essay exam	Rote, equation spotting, speed structuring
Open book	as for exam, but less memory, coverage
Assignment, take home	read widely, interrelate, organize, apply, copy
Objective test	
Multiple choice	Recognition, strategy, comprehension, coverage
Ordered outcome	hierarchies of understanding
Performance assessment	
Practicum	Skills needed in real life
Seminar, presentation	Communication skills
Posters	Concentrating on relevance, application
Interviewing	Responding interactively
Critical incidents	Reflection, application, sense of relevance
Project	Application, research skills
Reflective journal	Reflection, application, sense of relevance
Case study, problems	Application, professional skills
Portfolio	Reflection, creativity, unintended outcomes
Rapid assessment (large classes)	
Concept maps	Coverage, relationships
Venn diagrams	Relationships
Three-minute essay	Level of importance, sense of relevance
Gobbets	Realizing the importance of significant detail
Short Answer	Recall units of information, coverage
Letter to a friend	Holistic understanding, application, reflection
Cloze	Comprehension of main ideas

Course Content

Wankat and Oreovicz (2015) mentioned that in required subjects the content must make the subject suit into the entire curriculum. Engineering departments generally create agreement on the content a learner needs to undergo prior to completing the degree. The content needs to appear somewhere in the curriculum. Since some courses are pre-requisite of the other courses, appropriate prerequisite content must be tackled. The following steps can be taken in selecting the course content: (a) align with other faculty, (b) know what is required for other courses, (c) communicate in detail what content are found in prerequisite courses and know what they are able to do after they taken the prerequisite courses, (d) communicate the outline with other teachers teaching the subject, (e) make sure that important material is not omitted when doing subject revisions or changing the textbook, (f) communicate with engineers in industry to know what content they utilize and do not, (g) make the content accessible in computers for easy updating. After outlining the course content, it is necessary to check the hierarchy of objectives the teacher want to include. The time allotted for every topic relies on the depth of coverage and objectives. The teacher must plan the level of delivery taking into consideration the learner's maturity and plan the important intended learning outcomes for each topic.

Methodology

This study employed a descriptive-evaluative design to review the existing course syllabus and determine doable revisions or suggestions based on criteria embodied in CHED documents and mandates and other relevant information from the literature reviewed in this study. Based on Table 4, there are five phases done to come up with the new course syllabus. The Assessment phase follows the constructive alignment approach. This paper emphasized the details of the first and second phases in the results and discussion. The third, fourth and final phases are in the conclusion and recommendation of this paper.

Table 4: Phases on Course Syllabus Revision

Key activities	Resources	Primary Participants
Phase 1. Assessment of existing course syllabus using constructive alignment: a) Reviewed CHED program outcomes (PO) to embed Program Educational Objectives (PEO) b) Mapped course learning outcomes (CLO) to PEO and PO c) Mapped topic intended learning outcomes (ILO) to CLO and Revised Bloom's Taxonomy d) Mapped course outline (CO) to ILO e) Mapped learning activities (LA) to ILO f) Mapped Assessment Tasks (AT) to ILO	CHED Memorandum Order Existing Course Syllabus	Department head ME Faculty Members
Phase 2. Benchmarking activities: a) Compare existing course syllabus course outline, course description and course learning outcomes to CHED MO b) Gather course outline from local and international universities c) Gather relevant topics to embed in proposed course syllabus	Existing Course Syllabus from local and international universities CHED Memorandum Order	Department head ME Faculty Members
Phase 3: Consultation with subject teachers		Department head ME Faculty Members

Phase 4. Course Syllabus Refinement activities: a) Refinement of CLO b) Refinement of CO c) Refinement of ILO d) Refinement of AT e) Refinement of LA	Department head ME Faculty Members
Phase 5: Final Assessment	Department head ME Faculty Members

Results and Discussion

To know whether the contents of the existing course syllabus conform to the CHED MO and CIT program educational objectives; the course syllabus were assessed using a constructive alignment approach based on the Outcomes-Based Teaching and Learning (OBTL) Framework.

Phase 1. Assessment of existing course syllabus

The first phase of the research is the assessment of the existing course syllabus. In Table 5, the program educational objectives were reviewed in alignment with CHED MO's required program outcomes. One hundred percent (100%) of the PO fell within the PEO set by the department. It means that the PEO is geared towards achieving the PO. Forty-two percent (42%) of the PO can be achieved through objective 1, 25% can be achieved through objective 2, and 33% can be achieved through objective 3. The PEO are general statements of what the program is preparing the student for in terms of career and professional development. According to CHED, it be reviewed on periodic basis for continuing improvement.

Table 5: Mapping of ME Program Educational Objectives and CHED Program Outcomes

Program Educational Objectives	Link to Program Outcomes
Objective 1: Competent to practice the profession and pursue graduate study and/or research work.	a) Apply knowledge of mathematics, engineering sciences, and physical/natural sciences to solve mechanical engineering problems. b) Design and/or conduct experiments, as well as to analyze and interpret data. e) Identify, formulate, and solve engineering problems. f) Recognize the need for and engage in life-long learning. k) Use appropriate techniques, skill, and modern engineering technology necessary for the practice of mechanical engineering.
Objective 2: Trained to meet the local and global demands of the professions.	c) Design a system, component, or process to meet desired needs within identified realistic constraints. h) Understand the importance of engineering solutions in a global, economic, environmental, and societal context. j) Aware of contemporary issues.
Objective 3: Self-motivated, able to lead others, and uphold the code of ethics of the profession as well as his responsibilities in the community.	d) Work effectively as a team in multi-disciplinary and multi-cultural teams. f) Recognize the professional, social, and ethical responsibility. g) Able to communicate effectively. l) Know the principles of engineering management, and able to manage projects in a multi-disciplinary environment.

In Table 6.1 to 6.3, the course learning outcomes of the three subjects were reviewed in alignment with the PEO and PO. From Table 6.1, one hundred percent (100%) of the CLO of Engineering Thermodynamics 1 is aligned to objective 1 of PEO, and 100% is aligned with PO "a" and "e" of CHED. This is a good indication since the subject is designed to be an introductory course to a program outcome and met the minimum requirement of CHED to achieve PO "a" and "e". However, the CLO can still be improved to meet objective 2 and objective 3 under PEO and meet more CHED PO. The same is true for Engineering Thermodynamics 2 (Table 6.2) and Combustion Engineering (Table 6.3).

Table 6.1: Mapping of Engineering Thermodynamics 1 Course Learning Outcomes to CIT ME Program Educational Objectives and CHED PO

Course Learning Outcomes	Program Educational Objectives	Program Outcomes
CLO1. Describe the terminology, concept, and principles of thermodynamic system, and define and compare the different forms of energy.	*Objective 1*	*a, e*
CLO2. Explain the laws of thermodynamics as applied to close and open systems.	*Objective 1*	*a, e*
CLO3. Evaluate thermodynamics systems involving ideal gas processes.	*Objective 1*	*a, e*
CLO4. Analyze and compute problems of a thermodynamic cycle involving ideal gas.	*Objective 1*	*a, e*
CLO5. Evaluate how much of available energy can be converted to useful work undergoing cyclic change.	*Objective 1*	*a, e*

Table 6.2: Mapping of Engineering Thermodynamics 2 Course Learning Outcomes link to CIT ME Program Educational Objectives and CHED PO

Course Learning Outcomes	Program Educational Objectives	Program Outcomes
CLO1. Demonstrate ability to use thermodynamic relations and the physical property tables and charts for the determination of properties of phase transformations of water, ideal gas mixtures, real gases, and mixtures of gases and vapor, evidenced by correct plotting of states in a thermodynamic diagram, and drawing of schematic diagram of cycle components.	*Objective 1*	*a, e*
CLO2. Apply the concepts of the Laws of Thermodynamics in analyzing mechanical equipment and components of power cycles.	*Objective 1*	*a, e*
CLO3. Evaluate the thermodynamic properties of gas and vapor mixtures in various air-conditioning processes.	*Objective 1*	*a, e*

Table 6.3: Mapping of Combustion Engineering Course Learning Outcomes to CIT ME Program Educational Objectives and CHED PO

Course Learning Outcomes	Program Educational Objectives	Program Outcomes
CLO1. Describe the different types of fuels, its properties, and composition.	*Objective 1*	*a, e*
CLO2. Compare theoretical combustion processes at different air requirement.	*Objective 1*	*a, e*
CLO3. Conduct combustion product composition analysis.	*Objective 1*	*a, e*
CLO4. Describe the classifications and operation of internal combustions engines.	*Objective 1*	*a, e*
CLO5. Apply thermodynamic principles in evaluating engine performance.	*Objective 1*	*a, e*

The primary focus of OBTL is the statement of regarding what learners can do after taking the topic also called the Intended Learning Outcomes (ILO). For constructive alignment, the ILO should help in achieving the CLO. It should also cover different levels of cognitive process and knowledge level dimensions of the revised Bloom's Taxonomy so that students are involved with various modes of learning attain the required learning outcomes (Nightingale, Carew, & Fund, 2007).

For Engineering Thermodynamics 1, Table 7.1 shows that 64% of the ILO is aligned to the CLO. In terms of the cognitive process dimension of revised Bloom's Taxonomy, 90% of the ILO are on the lower level (53% Remember, 17% Understand, 20% Apply) while the remaining 10% are on the higher level (7% Analyze, 3% Evaluate, and 0% Create). In terms of the knowledge level dimensions, 75% is in the lower level (25% Factual, 50% Conceptual) and the remaining 25% is in the higher level (25% procedural, 0% Metacognitive). There is clear evidence that the ILO can still be improved to align it with the CLO and cover higher levels of the cognitive process and knowledge level dimensions.

Table 7.1: Mapping of Engineering Thermodynamics 1 Intended Learning Outcomes to Course Learning Outcomes

Intended Learning Outcomes	Course Learning Outcomes	Cognitive Process Dimension	Knowledge Level Dimension
Identify the thermodynamic terminology.	CLO1	Remember	Factual
Describe concept of thermodynamics.	CLO1	Remember	Conceptual
Describe the properties of a thermodynamic system in a state of equilibrium as well as those undergoing a process or a cycle.	CLO1	Remember	Conceptual
Describe the relationship between mass and energy.	Not aligned	Remember	Conceptual
Describe the three state of matter and its property.	Not aligned	Remember	Conceptual
Use of property table and chart.	Not aligned	Apply	Procedural
Engineering system of units & SI units.	Not aligned	Apply	Procedural
Differentiate vapor from gas.	Not aligned	Understand	Factual
Describe the laws of Ideal Gas.	Not aligned	Remember	Conceptual
Solve problem involving processes involving Ideal Gas.	CLO3	Apply	Procedural
Identify & differentiate the different forms of energy.	CLO1	Remember, Understand	Factual
State and explain the first law of thermodynamics.	CLO2	Remember, Understand	Factual

Apply the first law of thermodynamics in a close and open systems.	CLO2	Apply	Procedural
Solve problem on each thermodynamic system.	CLO2	Apply	Procedural
Describe a thermodynamic system involving Ideal Gas undergoing a process.	CLO3	Remember	Conceptual
Describe the different gas laws and derive the equation of state of an ideal gas.	CLO3	Remember	Conceptual
Analyze and compute problems on ideal gas processes.	CLO3	Analyze	Procedural
Describe 2nd Law of Thermodynamics.	CLO2	Remember	Conceptual
Explain the difference between the Kelvin-Planck statement and the Clausius statement of the Second Law of thermodynamics.	CLO2	Understand	Factual
Understand the concept of irreversibility, availability, and entropy.	Not aligned	Understand	Factual
Describe the operation of a heat engine and a refrigerator/heat pump.	Not aligned	Remember	Conceptual
Define the conversion of efficiency of power and reversed cycle.	Not aligned	Remember	Factual
Describe the concept of entropy and irreversibility.	Not aligned	Remember	Conceptual
Solve problem on power and reversed thermodynamic cycle.	CLO5	Apply	Procedural
Describe the processes in a thermodynamic cycle.	CLO5	Remember	Conceptual
Describe the Carnot cycle and its performance.	CLO5	Remember	Conceptual
Compare the thermal efficiency of thermodynamic cycles.	CLO5	Evaluate	Conceptual
Analyze and compute problems of thermodynamic ideal gas cycles	CLO4	Analyze	Conceptual

For Engineering Thermodynamics 2, Table 7.2 shows that 88% of the ILO is aligned to the CLO. In terms of the cognitive process dimension of revised Bloom's Taxonomy, 53% of the ILO are on the lower level (12% Remember, 6% Understand, 35% Apply) while the remaining 47% are on the higher level (12% Analyze, 29% Evaluate, and 6% Create). In terms of the knowledge level dimensions, 59% is in the lower level (18% Factual, 41% Conceptual) and the remaining 41% is in the higher level (29% procedural, 12% Metacognitive). There is clear evidence that the ILO needs only little improvement to align it with the CLO. The ILO can cover an even distribution of the cognitive process and knowledge level dimensions.

Table 7.2: Mapping of Engineering Thermodynamics 2 Intended Learning Outcomes to Course Learning Outcomes

Intended Learning Outcomes	Course Learning Outcomes	Cognitive Process Dimension	Knowledge Level Dimension
Describe the Kelvin–Planck statement of the 2nd Law of Thermodynamics	CLO2	Remember	Conceptual
Apply the 1st and 2nd Laws of Thermodynamics to cycles.	CLO2	Apply	Procedural
Describe the processes involved in a Rankine cycle.	CLO2	Remember	Conceptual
Examine ways how to improve the efficiency of a basic Rankine vapor power cycle.	CLO2	Analyze	Metacognitive
Evaluate vapor cycle using the 1st and 2nd Laws of Thermodynamics.	CLO2	Evaluate	Conceptual
Estimate the effects of i) reheating steam before re-introduced to the steam engine, and of ii) regenerative heating on cycle thermal efficiency.	CLO2	Evaluate	Conceptual
Evaluate the effects on cycle thermal efficiency if these two modifications on the cycle are combined altogether.	CLO2	Evaluate	Procedural
Evaluate combined, binary and cogeneration cycles.	CLO2	Evaluate	Conceptual
Plot the states of different gas power cycles in a thermodynamic diagram.	CLO1	Apply	Metacognitive
Evaluate the performance of gas, and combined power cycles.	CLO2	Evaluate	Conceptual
Use the various principles involved in analyzing compressible flows through different mechanical devices.	Not aligned	Apply	Factual
Analyze the effect of back pressure on the operation of a converging–diverging nozzle on mass flow rate.	Not aligned	Analyze	Conceptual
Differentiate a real gas from an ideal gas.	CLO1	Understand	Factual
Develop a method of evaluating the h, u, and s of real gases using generalized enthalpy and entropy departure charts.	CLO1	Create	Factual
Calculate the thermodynamics parameters of atmospheric air.	CLO3	Apply	Procedural
Use the Psychrometric Chart as a tool to determine the properties of atmospheric air.	CLO3	Apply	Procedural
Apply the principles of the conservation of mass and energy to various air-conditioning processes.	CLO3	Apply	Procedural

For Combustion Engineering, Table 7.3 shows that 100% of the ILO is aligned to the CLO. However, none of the ILO is aligned with CLO1. In terms of the cognitive process dimension of revised Bloom's Taxonomy, 67% of the ILO are on the lower level (17% Remember, 17% Understand, 33% Apply) while the remaining 34% are on the higher level (17% Analyze, 17% Evaluate, and 0% Create). In terms of the knowledge level dimensions, 58% is in the lower level (25% Factual, 33% Conceptual) and the remaining 42% is in the higher level (42% procedural, 0% Metacognitive). There is clear evidence that the ILO can still be improved to link all the CLO and cover higher levels of the cognitive process (Create) and knowledge level (Metacognitive) dimensions.

Table 7.3: Mapping of Combustion Engineering Intended Learning Outcomes to Course Learning Outcomes

Intended Learning Outcomes	Course Learning Outcomes	Cognitive Process Dimension	Knowledge Level Dimension
Perform combustion reaction analysis.	CLO3	Apply	Procedural
Compare the Orsat analysis from the theoretical combustion gas analysis.	CLO3	Evaluate	Procedural
Evaluate and identify the product gas analysis from the type of fuel used.	CLO3	Evaluate	Conceptual
Relate the effect of hydrocarbon fuel to combustion gas composition and "green gas" emission control requirement.	CLO3	Analyze	Conceptual
Recall the thermodynamic operation Otto and Diesel cycles.	CLO2	Remember	Conceptual
Describe and relate the air-standard cycle to actual IC engines	CLO2	Remember	Conceptual
Analyze and compute the thermal efficiency of ideal IC engines.	CLO4	Analyze	Procedural
Differentiate IC engines according to its performance parameters.	CLO5	Understand	Factual
Perform energy distribution analysis of IC engines.	CLO5	Apply	Procedural
Determine and compute performance parameters of IC engines	CLO5	Apply	Procedural
Differentiate IC engines operation from other combustion engines	CLO4	Understand	Factual
Perform a comparative study of their advantages and disadvantages	CLO4	Apply	Factual

For constructive alignment, the Course Outline needs to be selected to achieve the ILO. Tables 8.1, 8.2, and 8.3 showed that majority of the content of the course is aligned with the intended learning outcomes. Some parts of the course outline need to be revised to align it with the ILO such as "Engineering System of Units & SI Units" which is not link to any of the course outline in the topic "Pure Substance". This ILO, however, can be transferred to the topic "System of Units". The same procedure can also be done with the other ILOs that are not aligned.

Table 8.1: Mapping of Engineering Thermodynamics 1 Course Outline to Intended Learning Outcomes

Course Outline	Intended Learning Outcomes	Alignment
Topic 1: Concept and Definitions 1) Thermodynamic Systems and Working Substance 2) Properties and State of a Substance 3) System of Units 4) Process and Cycle 5) Law of Conservation of Mass & Energy Concept	ILO1. Identify the thermodynamic terminology. ILO2. Describe concept of thermodynamics. ILO3. Describe the properties of a thermodynamic system in a state of equilibrium as well as those undergoing a process or a cycle. ILO4. Describe the relationship between mass and energy.	Aligned Aligned Aligned Aligned
Topic 2: Properties of Pure Substance 1) Phase Diagrams 2) Changes of Phase 3) Tables & Charts of Properties/Computerized Tables 4) Ideal-Gas Laws 5) Compressibility Factor	ILO1. Describe the three state of matter and its property. ILO2. Use of property table and chart. ILO3. Engineering system of units & SI units. ILO4. Differentiate vapor from gas. ILO5. Describe the laws of Ideal Gas. ILO6. Solve problem involving processes involving Ideal Gas.	Aligned Aligned Not aligned Aligned Aligned Aligned
Topic 3: First Law of Thermodynamics 1) Concepts of Energy & Conservation of Energy 2) Expression of 1st Law of Thermodynamics for a substance undergoing a change of state	ILO1. Identify & differentiate the different forms of energy. ILO2. State and explain the first law of thermodynamics. ILO3. Apply the first law of thermodynamics in a close and open systems. ILO4. Solve problem on each thermodynamic system.	Aligned Aligned Aligned Aligned
Topic 4: Processes of Ideal Gas 1) Closed System 2) Open Steady State Steady Flow Systems	ILO1. Describe a thermodynamic system involving Ideal Gas undergoing a process. ILO2. Describe the different gas laws and derive the	Aligned Aligned

	equation of state of an ideal gas. ILO3. Analyze and compute problems on ideal gas processes.	Aligned
Topic 5: Second Law of Thermodynamics & concept of Entropy 1) Heat Engine & Heat Pump 2) Statement of the 2nd Law of Thermodynamics 3) Reversible & Irreversible Processes 4) Thermal Efficiency & Coefficient of Performance 5) Machines and Perpetual Motion Machines 6) Inequality of Clausius 7) Entropy Generation 8) Exergy (Availability) and Irreversibility	ILO1. Describe 2nd Law of Thermodynamics. ILO2. Explain the difference between the Kelvin-Planck statement and the Clausius statement of the Second Law of thermodynamics. ILO3. Understand the concept of irreversibility, availability, and entropy. ILO4. Describe the operation of a heat engine and a refrigerator/heat pump. ILO5. Define the conversion of efficiency of power and reversed cycle. ILO6. Describe the concept of entropy and irreversibility. ILO7. Solve problem on power and reversed thermodynamic cycle.	Aligned Aligned Aligned Aligned Aligned Aligned Aligned
Topic 6: Gas Power Cycles 1) Three-Process Cycle 2) Carnot Cycle 3) Otto Cycle 4) Diesel Cycle 5) Ericsson Cycle 6) Sterling Cycle 7) Brayton Cycle	ILO1. Describe the processes in a thermodynamic cycle. ILO2. Describe the Carnot cycle and its performance. ILO3. Compare the thermal efficiency of thermodynamic cycles. ILO4. Analyze and compute problems of thermodynamic ideal gas cycles.	Aligned Aligned Aligned Aligned

Table 8.2: Mapping of Engineering Thermodynamics 2 Course Outline to Intended Learning Outcomes

Course Outline	Intended Learning Outcomes	Alignment
Topic 1: Course Orientation, & Review on the Thermodynamic Cycle a) 2nd Law of Thermodynamics b) Carnot Power Cycle	ILO1. Appreciate the significance of the course in relation to Mechanical Engineering practice. ILO2: Describe the Kelvin–Planck statement of the 2nd Law of Thermodynamics. ILO3. Apply the 1st and 2nd Laws of Thermodynamics to cycles.	Aligned Aligned Aligned
Topic 2: Steam Power Cycle Analysis a) Review on the Use of Tables & Chart, processes	ILO1. Describe the processes involved in a Rankine cycle. ILO2: Examine ways how to improve the efficiency of a	Aligned Aligned

b) Review on Processes of pure Substances c) Ideal Rankine Cycle d) Actual Rankine Cycle e) Improving Cycle Efficiency	basic Rankine vapor power cycle; and ILO3: Evaluate vapor cycle using the 1st and 2nd Laws of Thermodynamics.	Not aligned
Topic 3: Improved Steam Power Cycle a) Ideal and Actual Reheat Cycle b) Ideal and Actual Regenerative Cycle ✓ Open Feedwater Heater (OFWH) ✓ Closed Feedwater Heater (CFWH) c) Ideal and Actual Reheat-Regenerative Cycle d) Cogeneration Cycle e) Binary Vapor Cycle	ILO1: Estimate the effects of i) reheating steam before re-introduced to the steam engine, and of ii) regenerative heating on cycle thermal efficiency. ILO2: Evaluate the effects on cycle thermal efficiency if these two modifications on the cycle are combined altogether. ILO3: Evaluate combined, binary and cogeneration cycles.	Aligned Aligned Aligned
Topic 4: Air-Standard Gas Power Cycles a) Otto Cycle b) Diesel Cycle c) Stirling Cycle d) Ericsson Cycle e) Atkinson cycle f) Brayton Cycle g) Combined Gas–Vapor Power Cycle	ILO1: Plot the states of different gas power cycles in a thermodynamic diagram. ILO2: Evaluate the performance of gas, and combined power cycles.	Aligned Aligned
Topic 5: Gas Compression Analysis • Analyzing One-Dimensional Steady Flow in Nozzles and Diffusers • Flow in Nozzles and Diffusers of Ideal Gases with Constant Specific Heats • Effect of Back Pressure: Converging-Diverging Nozzle	ILO1: Use the various principles involved in analyzing compressible flows through different mechanical devices. ILO2: Analyze the effect of back pressure on the operation of a converging–diverging nozzle on mass flow rate.	Aligned Aligned
Topic 6: Real Gases • Compressibility factor • Evaluating Changes in Entropy, Internal Energy, and Enthalpy • p–v–T Relations for Gas Mixtures	ILO1: Differentiate a real gas from an ideal gas. ILO2: Develop a method of evaluating the h, u, and s of real gases using generalized enthalpy and entropy departure charts.	Aligned Aligned
Topic 7: Properties of Gas and Vapor Mixtures • Specific and Relative Humidity of Air • Dew-point Temperature, Adiabatic Saturation and Wet-bulb Temp. • The Psychrometric Chart • Air-Conditioning Processes	ILO1: Calculate the thermodynamics parameters of atmospheric air. ILO2: Use the Psychrometric Chart as a tool to determine the properties of atmospheric air. ILO3: Apply the principles of the conservation of mass and energy to various air-conditioning processes.	Aligned Aligned Aligned

Table 8.3: Mapping of Combustion Engineering Course Outline to Intended Learning Outcomes

Course Outline	Intended Learning Outcomes	Alignment
Topic 1: Fuels and Combustion 1. Thermochemistry a. Theoretical Combustion with 100% air b. Theoretical Combustion with excess air c. Theoretical Combustion with deficient air 2. Orsat Analysis of Combustion Product 3. Fuels & Types a. Fuel Self-Ignition Temperature b. Octane Number and Engine Knock c. Cetane Number d. Composition analysis Engine 4. Emissions and Air Pollution	ILO1. Perform combustion reaction analysis. ILO2. Compare the Orsat analysis from the theoretical combustion gas analysis. ILO3. Evaluate and identify the product gas analysis from the type of fuel used. ILO4. Relate the effect of hydrocarbon fuel to combustion gas composition and "green gas" emission control requirement.	Aligned Aligned Aligned Aligned
Topic 2: Air-Standard Internal Combustion Engine Cycle 1. Otto Cycle 2. Diesel Cycle	ILO1. Recall the thermodynamic operation Otto and Diesel cycles. ILO2. Describe and relate the air-standard cycle to actual IC engines. ILO3. Analyze and compute the thermal efficiency of ideal IC engines.	Aligned Aligned Not aligned
Topic 3: Internal Combustion Engine Classifications 1. Two-Stroke & Four –Stroke 2. Engine Operating Characteristics 1. Engine Parameters 2. Work, Torque & Power 3. Mean Effective Pressure 4. Air-Fuel Ratio 5. Engine Efficiencies 6. Emissions Index 3. Energy Distribution of IC Engines	ILO1. Differentiate IC engines according to its performance parameters. ILO2. Perform energy distribution analysis of IC engines. ILO3. Determine and compute performance parameters of IC engines.	Aligned Aligned Aligned
Topic 4: Combustion Engines a. External Combustion Engine b. Gas-Turbine	ILO1. Differentiate IC engines operation from other combustion engines. ILO2. Perform a comparative study of their advantages and disadvantages.	Aligned Aligned

Once the ILO has been established, the next step is to design the Teaching and Learning Activities (TLA). The TLA is any activity that stimulates, encourages, or facilitates the learning of one or more ILOs. The data gathered for Engineering Thermodynamics 1 as shown in Table 9.1 cannot specify whether the TLA is aligned with the ILO. The activities are too broad. The learning activities can be improved to make them more specific. It can also be observed that the teacher did not employ varied learnings activities. Halperin (as cited in Catalano, 1997) found out that many classroom activities today are still traditional where students passively receive wisdom from the professor. Aside from discussion and lecture, the teacher can engage the students in other learning activities that will help achieve the intended learning outcomes.

Table 9.1: Mapping of Engineering Thermodynamics 1 Intended Learning Outcomes to Learning Activities

Learning Activities	Intended Learning Outcomes	Alignment
Learning Activities 1: • Lecture using Multimedia • Interactive Discussion	ILO1. Identify the thermodynamic terminology. ILO2. Describe concept of thermodynamics. ILO3. Describe the properties of a thermodynamic system in a state of equilibrium as well as those undergoing a process or a cycle. ILO4. Describe the relationship between mass and energy.	Cannot be specified
Learning Activities 2: • Lecture using Multimedia • Interactive Discussion	ILO1. Describe the three state of matter and its property. ILO2. Use of property table and chart. ILO3. Engineering system of units & SI units. ILO4. Differentiate vapor from gas. ILO5. Describe the laws of Ideal Gas. ILO6. Solve problem involving processes involving Ideal Gas.	Cannot be specified
Learning Activities 3: • Lecture using Multimedia • Interactive Discussion	ILO1. Identify & differentiate the different forms of energy. ILO2. State and explain the first law of thermodynamics. ILO3. Apply the first law of thermodynamics in a close and open systems. ILO4. Solve problem on each thermodynamic system.	Cannot be specified
Learning Activities 4: • Lecture using Multimedia • Interactive Discussion	ILO1. Describe a thermodynamic system involving Ideal Gas undergoing a process. ILO2. Describe the different gas laws and derive the equation of state of an ideal gas.	Cannot be specified

	ILO3. Analyze and compute problems on ideal gas processes.	
Learning Activities 5: • Lecture using Multimedia • Interactive Discussion	ILO1. Describe 2nd Law of Thermodynamics. ILO2. Explain the difference between the Kelvin-Planck statement and the Clausius statement of the Second Law of thermodynamics. ILO3. Understand the concept of irreversibility, availability, and entropy. ILO4. Describe the operation of a heat engine and a refrigerator/heat pump. ILO5. Define the conversion of efficiency of power and reversed cycle. ILO6. Describe the concept of entropy and irreversibility. ILO7. Solve problem on power and reversed thermodynamic cycle.	Cannot be specified
Learning Activities 6: • Lecture using Multimedia • Interactive Discussion	ILO1. Describe the processes in a thermodynamic cycle. ILO2. Describe the Carnot cycle and its performance. ILO3. Compare the thermal efficiency of thermodynamic cycles. ILO4. Analyze and compute problems of thermodynamic ideal gas cycles.	Cannot be specified

The data gathered for Engineering Thermodynamics 2 as shown in Table 9.2 shows that majority of the TLA is aligned with the ILO. Unlike the first subject, the teacher employed more varied and specific learning activities that are more suitable to the ILO.

Table 9.2: Mapping of Engineering Thermodynamics 2 Intended Learning Outcomes to Learning Activities

Learning Activities	Intended Learning Outcomes	Alignment
Learning Activities 1: a) Student Profiling, LMS Orientation, and Setting of Expectations b) Discussions on ✓ Kelvin Plank Statement ✓ Heat Engine, both reversible	ILO1. Appreciate the significance of the course in relation to Mechanical Engineering practice. ILO2: Describe the Kelvin–Planck statement of the 2nd Law of Thermodynamics. ILO3. Apply the 1st and 2nd Laws of Thermodynamics to cycles.	Aligned Aligned Not Aligned

Learning Activities 2: a) Homework Reading b) Demonstrations on plotting of states and processes in a t-s diagram, and application of the 1st of Thermodynamics. c) Discussions, & Demonstrations in analyzing cycle performance	ILO1. Describe the processes involved in a Rankine cycle. ILO2: Examine ways how to improve the efficiency of a basic Rankine vapor power cycle; and ILO3: Evaluate vapor cycle using the 1st and 2nd Laws of Thermodynamics.	Aligned Aligned Not aligned
Learning Activities 3: a) Homework Reading b) Discussions, & Demonstrations in analyzing cycle performance	ILO1: Estimate the effects of i) reheating steam before re-introduced to the steam engine, and of ii) regenerative heating on cycle thermal efficiency. ILO2: Evaluate the effects on cycle thermal efficiency if these two modifications on the cycle are combined altogether. ILO3: Evaluate combined, binary and cogeneration cycles.	Aligned Aligned Aligned
Learning Activities 4: a) Homework Reading b) Discussions, & Demonstrations in analyzing cycle performance	ILO1: Plot the states of different gas power cycles in a thermodynamic diagram. ILO2: Evaluate the performance of gas, and combined power cycles.	Aligned Aligned
Learning Activities 5: a) Discussions, Demonstrations and Analyzes	ILO1: Use the various principles involved in analyzing compressible flows through different mechanical devices. ILO2: Analyze the effect of back pressure on the operation of a converging–diverging nozzle on mass flow rate.	Aligned Aligned
Learning Activities 6: a) Discussions, Demonstrations and Analyzes	ILO1: Differentiate a real gas from an ideal gas. ILO2: Develop a method of evaluating the h, u, and s of real gases using generalized enthalpy and entropy departure charts.	Aligned Aligned
Learning Activities 7: a) Discussions, Demonstrations and Analyzes	ILO1: Calculate the thermodynamics parameters of atmospheric air. ILO2: Use the Psychrometric Chart as a tool to determine the properties of atmospheric air. ILO3: Apply the principles of the conservation of mass and energy to various air-conditioning processes.	Aligned Aligned Aligned

The data gathered for Combustion Engineering as shown in Table 9.3 cannot specify whether the TLA is aligned with the ILO. The learnings activities can be improved to make them more specific. Aside from discussion and lecture, the teacher can engage the students in other learning activities found in the literature cited in this study that will help achieve the intended learning outcomes such as cooperative learning where students work together and develop higher-order cognitive skills (Johnson et al., 1991; Smith, 1986, 1989).

Table 9.3 Mapping of Combustion Engineering Intended Learning Outcomes to Learning Activities

Learning Activities	Intended Learning Outcomes	Alignment
Learning Activities 1: a) Lecture using OH Projector b) Interactive Discussion	ILO1. Perform combustion reaction analysis. ILO2. Compare the Orsat analysis from the theoretical combustion gas analysis. ILO3. Evaluate and identify the product gas analysis from the type of fuel used. ILO4. Relate the effect of hydrocarbon fuel to combustion gas composition and "green gas" emission control requirement.	Cannot be specified
Learning Activities 2: a) Lecture using OH Projector b) Interactive Discussion	ILO1. Recall the thermodynamic operation Otto and Diesel cycles. ILO2. Describe and relate the air-standard cycle to actual IC engines. ILO3. Analyze and compute the thermal efficiency of ideal IC engines.	Cannot be specified
Learning Activities 3: a) Lecture using OH Projector b) Interactive Discussion	ILO1. Differentiate IC engines according to its performance parameters. ILO2. Perform energy distribution analysis of IC engines. ILO3. Determine and compute performance parameters of IC engines.	Cannot be specified
Learning Activities 4: a) Lecture using OH Projector b) Interactive Discussion	ILO1. Differentiate IC engines operation from other combustion engines. ILO2. Perform a comparative study of their advantages and disadvantages.	Cannot be specified

The final OBTL component is the Assessment Tasks (AT) which quantifies how learners can apply their competencies in solving actual world problems, design, showcase creativity, and communicate effectively, among others. It can tell how the ILO has been met. As shown in Table 10.1 to 10.3, there is not enough evidence to specify the alignment of the assessment tasks with the ILO especially for Engineering Thermodynamics 1 and Combustion Engineering. It is also noticeable that the assessment tasks are the same in all the ILO for each of the subjects. Most of the assessment tasks are leaning towards an objective type of test. This is a good indication of a need to improve the existing methods of assessment. As a guide in doing this, the teacher can use Table 3 which shows the different modes of assessment and the corresponding kind of learning being assessed. Biggs (2003) mentioned that the best assessment is the one that best met the goals.

Table 10.1: Mapping of Engineering Thermodynamics 1 Assessment Tasks and Intended Learning Outcomes

Assessment Tasks	Intended Learning Outcomes	Alignment
Assessment Tasks 1: a) Seatwork b) Assignment/ Homework, & Research work c) Written Exam	ILO1. Identify the thermodynamic terminology. ILO2. Describe concept of thermodynamics. ILO3. Describe the properties of a thermodynamic system in a state of equilibrium as well as those undergoing a process or a cycle. ILO4. Describe the relationship between mass and energy.	Cannot be specified
Assessment Tasks 2: a) Seatwork b) Assignment/ Homework, & Research work c) Written Exam	ILO1. Describe the three state of matter and its property. ILO2. Use of property table and chart. ILO3. Engineering system of units & SI units. ILO4. Differentiate vapor from gas. ILO5. Describe the laws of Ideal Gas. ILO6. Solve problem involving processes involving Ideal Gas.	Cannot be specified
Assessment Tasks 3: a) Seatwork b) Assignment/ Homework, & Research work c) Written Exam	ILO1. Identify & differentiate the different forms of energy. ILO2. State and explain the first law of thermodynamics. ILO3. Apply the first law of thermodynamics in a close and open systems. ILO4. Solve problem on each thermodynamic system.	Cannot be specified

Assessment Tasks 4: a) Seatwork b) Assignment/ Homework, & Research work c) Written Exam	ILO1. Describe a thermodynamic system involving Ideal Gas undergoing a process. ILO2. Describe the different gas laws and derive the equation of state of an ideal gas. ILO3. Analyze and compute problems on ideal gas processes.	Cannot be specified
Assessment Tasks 5: a) Seatwork b) Assignment/ Homework, & Research work c) Written Exam	ILO1. Describe 2nd Law of Thermodynamics. ILO2. Explain the difference between the Kelvin-Planck statement and the Clausius statement of the Second Law of thermodynamics. ILO3. Understand the concept of irreversibility, availability, and entropy. ILO4. Describe the operation of a heat engine and a refrigerator/heat pump. ILO5. Define the conversion of efficiency of power and reversed cycle. ILO6. Describe the concept of entropy and irreversibility. ILO7. Solve problem on power and reversed thermodynamic cycle.	Cannot be specified
Assessment Tasks 6: a) Seatwork b) Assignment/ Homework, & Research work c) Written Exam	ILO1. Describe the processes in a thermodynamic cycle. ILO2. Describe the Carnot cycle and its performance. ILO3. Compare the thermal efficiency of thermodynamic cycles. ILO4. Analyze and compute problems of thermodynamic ideal gas cycles.	Cannot be specified

Table 10.2: Mapping of Engineering Thermodynamics 2 Assessment Tasks and Intended Learning Outcomes

Assessment Tasks	Intended Learning Outcomes	Alignment
Assessment Task 1: a) Problem Solving	ILO1. Appreciate the significance of the course in relation to Mechanical Engineering practice. ILO2: Describe the Kelvin–Planck statement of the 2nd Law of Thermodynamics. ILO3. Apply the 1st and 2nd Laws of Thermodynamics to cycles.	Not Aligned Not Aligned Cannot be specified

Assessment Task 2: a) Problem Solving	ILO1. Describe the processes involved in a Rankine cycle. ILO2: Examine ways how to improve the efficiency of a basic Rankine vapor power cycle; and ILO3: Evaluate vapor cycle using the 1st and 2nd Laws of Thermodynamics.	Not Aligned Not aligned Aligned
Assessment Task 3: a) Problem Solving	ILO1: Estimate the effects of i) reheating steam before re-introduced to the steam engine, and of ii) regenerative heating on cycle thermal efficiency. ILO2: Evaluate the effects on cycle thermal efficiency if these two modifications on the cycle are combined altogether. ILO3: Evaluate combined, binary and cogeneration cycles.	Aligned Aligned Aligned
Assessment Task 4: a) Problem Solving	ILO1: Plot the states of different gas power cycles in a thermodynamic diagram. ILO2: Evaluate the performance of gas, and combined power cycles.	Aligned Aligned
Assessment Task 5: a) Problem Solving	ILO1: Use the various principles involved in analyzing compressible flows through different mechanical devices. ILO2: Analyze the effect of back pressure on the operation of a converging–diverging nozzle on mass flow rate.	Aligned Aligned
Assessment Task 6: a) Problem Solving	ILO1: Differentiate a real gas from an ideal gas. ILO2: Develop a method of evaluating the h, u, and s of real gases using generalized enthalpy and entropy departure charts.	Not Aligned Aligned
Assessment Task 7: a) Problem Solving	ILO1: Calculate the thermodynamics parameters of atmospheric air. ILO2: Use the Psychrometric Chart as a tool to determine the properties of atmospheric air. ILO3: Apply the principles of the conservation of mass and energy to various air-conditioning processes.	Aligned Aligned Cannot be specified

Table 10.3: Mapping of Combustion Engineering Assessment Tasks and Intended Learning Outcomes

Assessment Tasks	Intended Learning Outcomes	Alignment
Assessment Tasks 1: a) Assignment/ Homework, and Research (library and/or internet) Work b) Written Exam	ILO1. Perform combustion reaction analysis. ILO2. Compare the Orsat analysis from the theoretical combustion gas analysis. ILO3. Evaluate and identify the product gas analysis from the type of fuel used. ILO4. Relate the effect of hydrocarbon fuel to combustion gas composition and "green gas" emission control requirement.	Cannot be specified
Assessment Tasks 2: a) Assignment/ Homework, and Research (library and/or internet) Work b) Written Exam	ILO1. Recall the thermodynamic operation Otto and Diesel cycles. ILO2. Describe and relate the air-standard cycle to actual IC engines. ILO3. Analyze and compute the thermal efficiency of ideal IC engines.	Cannot be specified
Assessment Tasks 3: a) Assignment/ Homework, and Research (library and/or internet) Work b) Written Exam	ILO1. Differentiate IC engines according to its performance parameters. ILO2. Perform energy distribution analysis of IC engines. ILO3. Determine and compute performance parameters of IC engines.	Cannot be specified
Assessment Tasks 4: a) Assignment/ Homework, and Research (library and/or internet) Work b) Written Exam	ILO1. Differentiate IC engines operation from other combustion engines. ILO2. Perform a comparative study of their advantages and disadvantages.	Cannot be specified

Phase 2. Benchmarking activities

The second phase of the study is the comparison of the existing course syllabus with the CHED MO and local and international course syllabus. It was agreed by the faculty members that the selection of topics should be consistent and satisfies the course description and course learning outcomes of CHED MO. The reasons behind this are to ensure that CIT University BSME graduates can compete with the graduates of other universities here in the Philippines, to give students more chances of being accepted to local and international schools should they choose to transfer or continue graduates studies, and to satisfy local and international accreditation requirements.

For Engineering Thermodynamics 1 as shown in Table 11.1, the existing course syllabus has been revised. In terms of the course description, most of the keywords in CHED MO such as "pure substance", "ideal and real gas", "laws of thermodynamics", "processes and cycles", and "vapor and gas cycles" is also reflected but enriched and specified in CIT syllabus. In terms of course learning outcomes, most of the CLO in the CIT syllabus is entirely different from the CHED MO. For the course outline, the only topic that is not included in the CIT syllabus is the CHED MO's "real gases". The topics have been rearranged and some are integrated into a single topic. Based on the above-mentioned results, there is a need to align the course learning outcomes and include the topic 'real gases" in the CIT syllabus.

Table 11.1: Comparison of Engineering Thermodynamics 1 CHED MO and Existing CIT Course Syllabus

CHED MO	CIT
Course Description: A course dealing with the thermodynamic properties of pure substance, ideal and real gases and the study and application of the laws of Thermodynamics in the analysis of processes and cycles. It includes introduction to vapor and gas cycles.	**Course Description:** The course deals with the relationships of different forms of energy. It emphasizes the application of thermodynamic laws applied to both close and open systems. The scope of the course covers thermodynamic properties of pure substance, ideal gas and real gas, energy concepts, laws of thermodynamics, and processes & cycles involving ideal gas. It presents the basic concepts on how heat can be transformed into work or vice-versa.
Course Learning Outcomes: CLO1. Identify the different properties of pure substance, ideal gas, and real gas. CLO2. Apply thermodynamics concepts and principles in analyzing and solving problems. CLO3. Apply the laws of thermodynamic in analyzing problems. CLO4. Evaluate the performance of thermodynamic gas cycles.	**Course Learning Outcomes:** CLO1. Describe the terminology, concept, and principles of thermodynamic system, and define and compare the different forms of energy. CLO2. Explain the laws of thermodynamics as applied to close and open systems. CLO3. Evaluate thermodynamics systems involving ideal gas processes. CLO4. Analyze and compute problems of a thermodynamic cycle involving ideal gas. CLO5. Evaluate how much of available energy can be converted to useful work undergoing cyclic change.
Course Outline: 1. Introduction	**Course Outline:** 1. Course Orientation
2. Basic principles, concepts, and definition.	2. Concepts and Definition
3. First law of thermodynamics.	3. Properties of Pure Substance
4. Ideal gases and ideal gas laws.	4. First Law of Thermodynamics
5. Processes of ideal gases	5. Processes of Ideal Gas
6. Properties of pure substance	6. Second Law of Thermodynamic and Concept of Entropy
7. Processes of pure substance	7. Gas Power Analysis
8. Second law of thermodynamics	
9. Introduction to gas and vapor cycles.	
10. Real Gases	

For Engineering Thermodynamics 2 as shown in Table 11.2, the existing course syllabus has been revised. In terms of the course description, the teacher adapted the CHED MO in the CIT syllabus. In terms of course learning outcomes, the first and the last CLO from CHED MO have been modified and specified. The last statement in the CIT syllabus is not aligned with the course description since the topic “air-conditioning processes” is not yet introduced in Thermodynamics 2. For the course outline, the teacher included all the required topics but in a more condensed form. Based on the above-mentioned results, there is a need to align the course learning outcomes in the CIT syllabus.

Table 11.2: Comparison of Engineering Thermodynamics 2 CHED MO and Existing CIT Course Syllabus

CHED MO	CIT
Course Description: This course is aimed to further enhance the student's knowledge regarding the principles of Thermodynamics by using these principles in practical application specifically in the field of power generation. This includes the study of real gases, properties of gas and vapor mixtures and introduction to reactive systems.	**Course Description:** This course is aimed to further enhance the students' knowledge regarding the principles of Thermodynamics by using these principles in practical application specifically in the field of power generation. This includes study of real gases, properties of gas and vapor mixtures and introduction to reactive systems. .
Course Learning Outcomes: CLO1. Apply the concepts of Thermodynamics in analyzing Power cycles. CLO2. Determine the physical and thermodynamic properties of ideal gas mixtures, real gases, and mixtures of gases and vapor. CLO3. Evaluate the performance of vapor power cycles and gas power plants and standard air-power cycles.	**Course Learning Outcomes:** CLO1. Demonstrate ability to use thermodynamic relations and the physical property tables and charts for the determination of properties of phase transformations of water, ideal gas mixtures, real gases, and mixtures of gases and vapor, evidenced by correct plotting of states in a thermodynamic diagram, and drawing of schematic diagram of cycle components. CLO2. Apply the concepts of the Laws of Thermodynamics in analyzing mechanical equipment and components of power cycles. CLO3. Evaluate the thermodynamic properties of gas and vapor mixtures in various air-conditioning processes.
Course Outline: 1. Review the Thermodynamic Cycle	**Course Outline:** 1. Course Orientation, & Review on the Thermodynamic Cycle
2. Simple Rankine Cycle	2. Steam Power Cycle Analysis
3. Improving Rankine Cycle Efficiency	3. Improved Steam Power Cycle Analysis
4. Actual Rankine Cycle	4. Air-Standard Gas Power Cycles
5. Ideal and Actual Reheat Cycle	5. Gas Compression
6. Ideal and Actual Regenerative Cycle	6. Real Gases
7. Ideal and Actual Reheat-Regenerative Cycle	7. Properties of gas and vapor mixtures
8. Binary Cycles (Combined Power Cycle)	
9. Topping or Superposing Cycles	
10. Incomplete Expansion Engine	
11. Other Gas Power Cycles	
12. Gas compression Analysis	
13. Real Gases	
14. Properties of gas and vapor mixtures	

For Combustion Engineering as shown in Table 11.3, the existing course syllabus has been revised. In terms of the course description, several topics have been included in the CIT syllabus but the required topics such as "compression and combustion charts", "engine components", "engine design" have been omitted. In terms of course learning outcomes, the required CLO's 1, 2, and 4 are not reflected in the CIT syllabus. For the course outline, the teacher did not reflect required topics such as "principles of Thermodynamics, "mixture of gases", "engine testing and performance", and "engine design". There is a need to align the course description, course learning outcomes, and course outline.

Table 11.3: Comparison of Combustion Engineering CHED MO and Existing CIT Course Syllabus

CHED MO	CIT
Course Description: The course deals with principles involved in combustion, carburetion, and fuel injection; fundamentals and basic principles of combustion processes, compression and combustion charts, fuels, (manifolds) engine components, engine performance and combustion engine design.	**Course Description:** It is a study of combustion process which covers fuel and its properties, chemical reaction in combustion, combustion analysis and combustion gases composition analysis. The course deals also with the principles of internal combustion engines, carburetion, fuel injection, combustion engine performance parameters and its operation with due consideration of its effect to the environment.
Course Learning Outcomes: CLO1. Explain basic combustion and stoichiometric process. CLO2. Perform stoichiometric analysis of various gaseous, liquid, and solid fuels. CLO3. Apply thermodynamic principles in analyzing the performance of internal combustion engines. CLO4. Evaluate the principles, operations, maintenance, and design of internal combustion engines	**Course Learning Outcomes:** CLO1. Describe the different types of fuels, its properties, and composition. CLO2. Compare theoretical combustion processes at different air requirement. CLO3. Conduct combustion product composition analysis. CLO4. Describe the classifications and operation of internal combustions engines. CLO5. Apply thermodynamic principles in evaluating engine performance.
Course Outline: 1. Principle of Thermodynamics	**Course Outline:** 1. Fuels and Combustion
2. Mixture of Gases	2. Air-Standard Internal Combustion
3. Handling of Gaseous Fuels Handling of Volatile Liquid Fuels Handling of Fuel Oils	3. Internal Combustion Engine Classifications
4. Combustion of Fuels	4. External Combustion Engines
5. Theoretical Cycles	
6. Engine Testing and Performance	
7. Engine Design	
8. External Combustion Engine	

Conclusion and Recommendation

It is imperative to maintain an ongoing assessment of the BSME program to ensure alignment with the stipulations of the Philippine Commission on Higher Education (CHED) and to contribute effectively to the goals of Cebu Institute of Technology University (CIT). The analysis of the current course syllabus reveals a lack of full conformity to the CHED Memorandum Order (MO) and CIT BSME program's educational objectives in terms of course learning outcomes, course descriptions, and course outlines. Furthermore, the existing course syllabus demonstrates a cognitive process and knowledge dimension that predominantly falls within the lower levels of the revised Bloom's taxonomy, whereas engineering courses inherently necessitate the cultivation of higher-order cognitive skills and knowledge dimensions. Developing crucial engineering competencies like creativity, critical thinking, and innovative problem-solving mandates engaging students in activities that transcend these higher cognitive levels (Goel & Sharda, 2004). Comparing the course syllabus with those of local and international universities unveils a similarity between the existing syllabi and those of local institutions, yet significant discrepancies exist when compared to international counterparts. In light of the study's findings and the insights garnered from consultations with subject teachers, the following recommendations are proposed: (a) Revise and enhance the obligatory course description, course learning outcomes, and course outline as outlined in the CHED Memorandum Order, and (b) Foster elevated cognitive processes and heightened knowledge dimensions among students by incorporating these aspects into the intended learning outcomes, diversifying pedagogical approaches, and aligning assessments with the intended learning objectives.

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.

Funding

This work received no specific grant from any funding agency.

Conflict of Interests

All authors declare that they have no conflicts of interest

Acknowledgment

The authors thank the project advisory board for helpful guidance and suggestions.

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Evaluation of Undergraduate Research Course Using Stufflebeam's Context, Input, Process, Product Model

*Angelo A. Acenas**
Department of Mechanical Engineering, Cebu Institute of Technology University, Cebu City, Philippines

*angeloacenas@gmail.com

ABSTRACT

An undergraduate research course is often considered the pinnacle of a student's college experience, as it allows them to apply both the soft and hard skills acquired during their academic journey. In order to ensure students gain relevant experiences that align with desired learning outcomes, the evaluation of such courses is essential. This study explores the perceptions of graduating research students regarding their experiences in undergraduate research courses. Using a descriptive survey, data was collected from 60 students to investigate their views. The assessment of their evaluation of the course was based on their level of agreement with statements related to context, input, process, and outcomes of their Undergraduate Research Experience (URE). The majority of students indicated strong agreement with most statements. However, their agreement was only moderate concerning the availability and usefulness of library and laboratory resources, the financial support available for research, and the accessibility of research advisors. In conclusion, the students' perceptions suggest that the undergraduate research course aligns well with the intended outcomes. Nevertheless, the findings highlight the necessity to evaluate and enhance laboratory and library resources to better support engineering research. Moreover, implementing financial support mechanisms to alleviate financial barriers in conducting studies and optimizing the support provided by research advisors is recommended.

Keywords: *research, evaluation, CIPP, undergraduate research*

Introduction

Research plays a pivotal role in our daily lives, boasting a range of practical applications such as uncovering medical breakthroughs, propelling technological advancements, and dissecting and resolving issues in education, business, the economy, and society. It serves as a foundational framework for subsequent investigations and project planning, thus enhancing the quality of life by streamlining convenience and comfort. Moreover, research delves into historical understanding to offer remedies for contemporary societal challenges, while simultaneously challenging individuals to evolve by assimilating novel ideas, perspectives, and skills (Avilla, 2016).

In developing nations like the Philippines, universities have traditionally excelled in teaching but lagged in research endeavors. To address this, the Philippine Commission on Higher Education (CHED) has implemented policies and directives aimed at fostering enhanced research productivity. CHED ardently advocates for heightened research orientation within Higher Education Institutions (Clemeña & Acosta, 2007) and underscores the importance of research skills by integrating research courses and activities into nearly all higher education curricula (Arrelano, Morano & Nepomuceno, 2012).

The significance of Research and Development (R&D) finds resonance across diverse sectors including agriculture, manufacturing, education, and healthcare. Within this context, the Cebu Institute of Technology University, as a Higher Education Institution, is tasked by CHED with producing graduates actively engaged in generating novel knowledge and contributing to research and development initiatives. Responding to this mandate, the university has established the Innovation and Technology Support Office (ITSO) and Research and Development Coordinating Office (RDCO). Additionally, the Department of Mechanical Engineering strives to equip graduates with the competence to excel in professional practice and pursue graduate studies or research endeavors. The integration of the ME Project Study in the BSME Curriculum, employed as an undergraduate research course, serves as a means to achieve this objective. However, it is worth noting that no prior assessment has been conducted to gauge the efficacy of the undergraduate research course.

This study endeavors to evaluate the undergraduate research course, encompassing all stages from project ideation and inception to execution and implementation. By employing a comprehensive evaluation approach—assessing context, input, process, and product—this investigation aims to furnish an analytical and reasoned foundation for decision-making regarding course enhancement.

Literature Review

In an article entitled "Understanding Research" from Education and Training Unit, research is defined as "the organized and systematic method of finding answers to questions. It is systematic because it is a process broken up into clear steps that lead to conclusions." Additionally, "research is organized because there is a planned structure or method used to reach the conclusion". Research is said to be successful only if "we find answers, whether we like these answers or not." Research is important because the decisions that government, business, institutions, labor, organizations and society in general needs to be based on valid and reliable information and thorough analysis.

In an article published by The National Academies Press (NAP) (1995), engineering research is concerned with "the discovery and systematic conceptual structuring of knowledge." Additionally, "engineers develop, design, produce or construct, and operate devices, structures, machines, and systems of economic and societal value." Also, "almost all university research in both science and engineering is performed as a component of the advanced education of students. For most engineering students, the goal of a career in industry motivates their pursuit of advanced study" and "engineering students' outlook on research tends to be predisposed toward the application in engineering practice." Undergraduate research is the exploration of a specific topic within a field by an undergraduate student that makes an original contribution to the discipline. According to Zupanc (2012) as cited in NAP (2017), "undergraduate research is sometimes thought to be a relatively recent development in higher education. However, faculty-mentored, apprentice-based undergraduate research has a long and rich history, dating back more than 200 years to Wilhelm von Humboldt." From the same article, it is mentioned that "undergraduate research has intensified among various national and regional groups across campuses, in response to the need to better prepare an increasingly diverse student population to face 21st century challenges."

Challenges in undergraduate research

Sharma and Mantri (2019) cited the lack of group participation (Knutson, Smith, Wallert & Provost, 2010 and Leeder & Shah, 2016) poor writing skills (Jaafar, Boumlik, & Alberts, 2018, and Wang & Correnti, 2016) and plagiarism (Šprajc, Urh, Jerebic, Trivan & Jereb, 2017) as some of the major challenges faced by industry/research organization in hiring graduates. The results of the study conducted by Jin, Li and Xu (2014) showed that the undergraduate research students writing level is generally poor, theoretical innovation and practical significance is lacked. In another study by Arellano, et al. (2012), conducted among 963 graduating students in a state-funded university in the Philippines, result showed that "students are able to identify factors when choosing research problem, formulate conclusions, from research findings, apply sampling techniques, correctly choose data gathering instrument and identify variables." However, "less than half are able to state hypothesis, choose appropriate scale of qualitative variables, identify appropriate statistical test, identify research design, and state elements of the introduction of a research proposal." Lastly, "students performed poorly in outlining general steps and procedures for carrying out a research project" and "majority of the students is not proficient in the lower order research competencies." In a study of Campillan (2019), "results revealed that students had difficulties in formulating their research problem, writing their review of related literature, sampling of their respondents, developing the research instruments, transcribing interviews, video production delays are among others. They also had problems in coordination, plagiarism processing, and other difficulties such as time constraints, absence of research partners, personal issues, and other conflicts." Mapolisa and Mafa (2012) (as cited in Bass, Washuta, Howison, Gonzales, & Maier, 2018), "identified three main categories of challenges that effect how successful a student's research experience is; mentor-student, student-related, and institution-related. The mentor-student challenge comprised the level of engagement between the advisor and student, advisor availability, and student interest in the topic. The students-student challenge identified personal issues in the student's lives that could affect their level of research, such as financial issues, motivation/commitment, and lack of knowledge. Lastly, the institution-related challenges stemmed from overcoming hurdles like lack of research materials and workshops to help foster a student's computer literacy."

"Time is another challenge to overcome with getting the students up to speed and conducting experiments. They have to maintain good academic standing, so they have to exercise effective time management. Time is also a consideration for the research advisor. As mentioned, initial training of the students takes a considerable amount of time. The students need to stay on track, stay productive, and stay excited about the research" (Bass, et al., 2018). The study concluded the challenges that arise includes "overcoming knowledge gaps, time management and pacing of topic delivery."

Benefits in undergraduate research course

Knutson, Smith, Wallert and Provost's study (as cited in Sharma et al., 2019) said that undergraduate research experience (URE) and scientific investigations performed by students result in their cognitive skills enhancement which not only benefit them in the interview protocols and other phases of recruitment process but also in their long term careers. They also cited important studies reported by Kardash (2000) and Zydney et al. (2013) in the past reveal the fact that engaging students in scientific investigations foster their ability to think critically and develop cognitive & personal skills. Sharma and Mantri (2019) cited another study by Wang and Correnti (2016) & Leeder and Shah (2016) that reveals that URE not only improves cognitive skills but also boosts critical thinking and problem-solving skills of students, which helps in cultivation and development of habits to have deeper insights and understanding of the topics. Descriptions of student-identified benefits of undergraduate research experiences are drawn from analysis of 76 first-round student interviews. As part of the interview protocol, students commented on a checklist of possible benefits derived from the literature. Students were overwhelmingly positive: 91% of all statements referenced gains from their experiences. The benefits described were of seven different kinds. Expressed as percentages of all reported gains, they were personal/professional gains (28%); "thinking and working like a scientist" (28%); gains in various skills (19%); clarification/confirmation of career plans (including graduate school) (12%); enhanced career/graduate school preparation (9%); shifts in attitudes to learning and working as a researcher (4%); and other benefits (1%) (Seymour, Hunter, Laursen & DeAntoni, 2004). According to Petrella and Jung (2008), the research process impacts valuable learning objectives that have lasting influence as undergraduates prepare for professional service. Faculty members at teaching intensive institutions can enhance learning experiences for students while benefiting from a productive research agenda. The university in turn benefits from presentations and publications that serve to increase visibility in the scientific community. Whether projects are derived through student-generated or mentor-generated means, students benefit from completion of exposure to the hypothesis-driven scientific method. When it comes to the opportunity in enhancing research experiences, Jin et al. (2014) recommended ways in improving the quality the quality of undergraduate theses. These are: (a) promoting field research and maintaining academic integrity, (b) improving management and monitoring system, (c) emphasis on ethics and enhancing responsible awareness, (d) enhancing daily training and establishing writing courses.

Context, Input, Process and Product (CIPP) evaluation Model

According to an article from Yale Poorvu Center for Teaching and Learning, "the CIPP model was created in the 1960s by Daniel Stufflebeam and is considered a decision-oriented model that systematically collects information about a program to identify strengths and limitations in content or delivery, to improve program effectiveness or plan for the future of a program. Users of this model are often focused on management-oriented evaluation, as this Model combines four stages of evaluation. The focus is on continuous improvement by concentrating on four areas of a program: the overall goals or mission Context Evaluation); the plans and resources (Input Evaluation); the activities or components (Process Evaluation); and the outcomes or objectives (Product Evaluation)." Also, "the CIPP model provides a comprehensive Model for conducting both formative and summative evaluations of programs, projects, personnel, products, and organizations by focusing on context, input, process, and product" (Frey, 2018).

Methodology

This study employed a descriptive research design. A total of 60 undergraduate research students participated in the study. These participants were requested to express their level of agreement with various statements using a researcher-developed Likert Scale instrument. The survey was conducted using Google Forms. The degree of agreement indicated by the participants served as a measure to assess their perception of different aspects related to their undergraduate research experience.

To evaluate the students' perceptions of their undergraduate research experience, the researchers utilized the levels of agreement as indicators. The analysis of the gathered data involved comparing the weighted means and standard deviations for each statement in the Likert Scale.

In addition to rating their agreement with the provided statements, the students were also prompted to encapsulate their undergraduate research experience in a single word. These responses were subjected to thematic analysis, complementing the quantitative findings and providing a qualitative dimension to the study's results.

Results

The study sought to evaluate the undergraduate research course in terms of the context, input, process, and product variable. The interpretation of the level of agreement is based on the table below.

Table 1. The extent of agreement of the students to the context variable

Weighted Mean	Level of agreement
1.0 - 1.7	Very weak
1.8 – 2.5	Low

2.6 – 3.3	Average
3.4 – 4.1	High
4.2 – 5.0	Very high

Context Variable

The context variable revolves around the objectives, mission, and goal statements presented in the Program Educational Objectives (PEO) and Program Outcomes (PO) of the BSME program, as outlined in the course syllabus. The findings indicate that ninety-two percent of the statements received a 'very high' level of agreement, while eight percent garnered a 'high' level of agreement. The aspects that gained the highest level of acceptance encompass utilizing research to design systems, components, or processes in order to fulfill specific needs within identified realistic constraints, conducting research to identify, formulate, and resolve engineering problems, and employing research to apply appropriate techniques, skills, and modern engineering technology.

Conversely, the statements that achieved the lowest weighted mean scores are those related to utilizing research to develop effective communication, leveraging research to work efficiently within a team, and employing research to cultivate an awareness of contemporary issues. The presence of varying standard deviations across different statements suggests a diversity in the levels of agreement and attitudes towards specific objectives.

Table 2: Extent of agreement of the students to the context variable

Statements	WM	STD	Interpretation
I took research to apply knowledge of mathematics, engineering sciences and physical/natural sciences to solve mechanical engineering problems.	4.33	0.57	Very high
I took research to design or conduct experiments as well as analyze and interpret data.	4.27	0.66	Very High
I took research to design a system, component or process to meet desired needs within identified realistic constraints.	4.37	0.66	Very high
I took research to develop working effectively as a team.	4.20	0.71	Very High
I took research to identify, formulate and solve engineering problems.	4.37	0.61	Very high
I took research to develop communicating effectively.	4.07	0.80	High
I took research to recognize professional, social, and ethical responsibility.	4.23	0.70	Very High
I took research to understand the importance of engineering solutions in a global, economic, environmental, and societal context.	4.30	0.72	Very high
I took research to recognize the need for and engage in life-long learning.	4.28	0.69	Very High
I took research to be aware of contemporary issues.	4.20	0.71	Very High
I took research to use appropriate techniques, skills, and modern engineering technology.	4.37	0.58	Very high
I took research to know the principles of engineering management.	4.22	0.69	Very High

Input Variable

The input variables were assessed in terms of resources, infrastructures, and curriculum content associated with the undergraduate research course, and they can be categorized as student-related, teacher-related, and institution-related factors. All statements received a 'high' level of agreement from one hundred percent of the students. Among the input variables, those related to teachers garnered the highest level of agreement from the students, while the ones related to the institution received the lowest level of agreement.

The statements with the lowest level of acceptance pertain to students' confidence in their financial capacity to support their studies, the availability of university laboratory facilities for their area of interest, and the accessibility of university library resources. On the other hand, the statements that garnered the highest levels of confidence were related to students' motivation and commitment, the research instructor's proficiency in conducting research, and their engagement with the chosen topic.

The varying standard deviations across different statements indicate a diverse range of agreement levels, reflecting differing attitudes towards specific inputs.

Table 3: Extent of agreement of the students to the input variable

Statements	Mean	STD	Interpretation
Teacher-related input variables			
I am confident of the knowledge of my instructor in teaching research.	4.00	0.78	High
I am confident of the knowledge of my instructor in doing research.	4.05	0.79	High
I am confident of the availability of a research adviser for my topic of interest.	3.93	0.88	High
I am confident of the ability of my adviser in directing our research study.	3.92	0.89	High
Average	**3.98**		**High**
Student-related input variables			
I have interest in my research topic.	4.05	0.79	High
I am motivated, committed in doing research.	4.15	0.71	High
I am confident with my writing level in doing research.	3.87	0.81	High
I am confident in my theoretical knowledge in mechanical engineering for my research.	3.82	0.70	High
I am confident in my knowledge of mechanical design in doing research.	3.83	0.72	High
I am confident in my knowledge of doing computer-aided drawings/drafting.	3.90	0.68	High
I am confident of my financial capacity to support my research study.	3.42	1.06	High
Average	**3.86**		**High**
Institution-related input variables			
I find the subject description accurately reflected the content of the course.	3.88	0.85	High
I find that expectations were clearly outlined in the syllabus.	3.97	0.80	High
I find the university laboratory facilities available for my topic of interest.	3.50	1.08	High
I find the university library resources available for my topic of interest.	3.67	0.93	High
Average	**3.76**		**High**

Process Variable

The research course's teaching-learning process was evaluated through various process variables, encompassing project initiation, proposal preparation and approval, design, fabrication, data analysis, and final paper preparation. The results indicated that 94 percent of the statements received a 'high' level of agreement from the students, while 6 percent achieved an 'average' level of agreement.

Among the aspects evaluated, students exhibited the least confidence in the process of selecting a research adviser, the perceived utility of university laboratory equipment, and the effectiveness of library resources. Conversely, students expressed high levels of confidence in collaborating within their research groups, conducting data measurement and collection, and receiving input from their adviser or instructor.

It is noteworthy that the standard deviation observed in this variable is notably higher compared to the other variables assessed using the CIPP framework. This suggests a range of agreement levels and, consequently, varying attitudes towards specific processes.

Table 4. Extent of agreement of the students to the process variable

Statements	Mean	STD	Interpretation
I find the process of finding a research adviser relatively easy.	3.38	1.03	Average
I find the input from my adviser/instructor helpful in doing my research.	3.88	0.94	High
I find the instructor/adviser engaged in the process of doing my research.	3.83	0.99	High
I find the teaching method of the research teacher effective.	3.90	0.99	High
I am confident of the process of identifying the research topic and title defense.	3.72	0.96	High
I am confident of the process of proposal paper preparation.	3.73	0.95	High

I am confident of the process of defending our project proposal.	3.80	0.88	High
I am confident of the process of doing literature review.	3.75	0.84	High
I am confident of the process of designing the instrument/machine.	3.80	0.82	High
I am confident of the process of fabricating the machine.	3.83	0.92	High
I am confident of the process of data measurement and collection.	3.93	0.80	High
I am confident of the process of data analysis and interpretation.	3.82	0.77	High
I am confident of the process of preparing the final research paper.	3.73	0.88	High
I am confident of the process of defending the final research paper.	3.75	0.89	High
I am confident in selecting my research group.	3.82	1.03	High
I am confident in working with my research group.	3.95	1.03	High
I find laboratory equipment in the university useful in the research process.	3.43	0.98	High
I find the library resources in the university useful in the research process.	3.58	0.91	High

Product Variable

The product variable assessed the skills, values, attitudes, and outcomes of the undergraduate research course, as perceived by the students. These outcomes align with the Program Educational Objectives (PEOs) of the BSME program. All statements garnered a high level of agreement from the participants, totaling one hundred percent. However, there were variations in the students' confidence levels across different areas. While the students displayed lower confidence in pursuing graduate studies, achieving the study's objectives, and developing research skills, they exhibited higher confidence in the practical applicability of their research to end-users, the contribution of their work to the advancement of knowledge in mechanical engineering, and the pursuit of careers in research. Analysis of the standard deviations across various statements indicates a diverse range of attitudes towards the evaluated products.

Table 5: Extent of agreement of the students to the product variable

Statements	Mean	STD	Interpretation
I am confident that we are able to achieve the objective of our study.	3.75	0.68	High
I am confident that our research contributed to advancement of knowledge in mechanical engineering.	3.82	0.72	High
I am confident that the result of our research is useful to the end user.	4.15	0.71	High
After doing my research study, I am confident of my research skill.	3.77	0.67	High
After doing my research study, I am confident in pursuing work related to doing research.	3.82	0.77	High
After doing my research study, I am confident in pursuing work related to doing research.	3.78	0.80	High
After doing my research study, I am confident in pursuing graduate study (master’s and doctorate).	3.60	0.92	High

Discussion

Combining the four variables of CIPP, the findings demonstrate the students' perception of their undergraduate research experience (URE). The results indicate a high level of satisfaction among students with their URE.

Regarding the context variable, respondents strongly agree on the significance of the undergraduate research course for achieving the Program Educational Objectives (PEO) and Program Outcomes (PO) of the BSME Program. Statements with notably high agreement levels suggest that students anticipate research will aid them in designing systems, components, or processes to meet practical needs within identified constraints, identifying and solving engineering problems, and utilizing modern engineering technology. Petrella and Jung (2008) note that the research process impacts valuable learning objectives that have lasting influence as undergraduates prepare for professional service. The results also suggest that students prioritize the development of communication, effective teamwork, and contemporary issue awareness less. This could be attributed to the engineering research focus on preparing students for tasks such as designing, constructing, and operating devices and systems with economic and societal value (NAP, 1995). However, skills like communication, collaboration, and awareness of contemporary issues are essential for success in the 21st century information age. Thus, there is an opportunity for research instructors to continually integrate these skills into the course's teaching-learning process.

In relation to the input variable, results indicate that students perceive the resources, infrastructure, curriculum, and content of the research course as valuable for their research experience. Nevertheless, the fact that not all statements reached a 'very high' rating implies areas needing improvement. Enhancements could involve establishing financial support or research funds for student-conducted studies, as noted by Petrella and Jung (2008), where monetary constraints often limit established undergraduate research curricula. Attention is also needed for establishing laboratory and library resources aligned with students' research interests, as evidenced by students outsourcing fabrication and testing due to limited facilities. Given that practical work in labs involves hypothesis forming, experimental design, methodology, and result evaluation (Edward, 2016), aligning these processes with research activities becomes crucial. The evaluation of library resources might stem from underutilization, possibly due to students' lack of awareness or underestimation of their importance for studies (Gunasekera, 2010). Comprehensive information literacy programs should thus be conducted to raise awareness among students about available resources for their research. Among the input variables, students value their motivation, commitment, instructor knowledge, and research topic interest. Mapolisa and Mafa's study (2012), cited in Bass et al. (2018), highlights factors like engagement between advisors and students, advisor availability, student interest, and motivation/commitment influencing students' evaluation of their URE. Consequently, emphasis should be placed on institution-related input variables when planning for improvements.

Concerning the process variable, gathered data demonstrates high agreement among students, indicating their confidence in research processes. However, the majority of ratings falling short of 'very high' suggests areas for improvement. The evaluation of research adviser selection and the utility of lab and library resources in the research process appear as areas requiring more attention than other process variables. This aligns with the input variable results emphasizing the importance of research adviser engagement, lab equipment, and library resources. Conversely, students express satisfaction with group collaboration, data collection, and input from advisors/instructors during research.

Lastly, the product variable garners high agreement among students. Similar to the other variables, there's room for improvement in achieving a 'very high' level of agreement regarding the outcomes of students' research experiences. Based on the study's results, confidence in pursuing graduate study, confidence in achieving research objectives, and research skill development require improvement compared to other areas. This aligns with the fact that only a small number of BSME graduates pursue further studies. Enhancing research skills would benefit students in graduate study, as Ruchina et al. (2015) emphasize the role of research work in master's student training. Improved research skills would bolster students' confidence in pursuing advanced studies. While students might not be highly confident about achieving research objectives, they express high confidence in their research results' usefulness to end users. This aligns with their perception of the contribution of their research to mechanical engineering knowledge and their confidence in research-related careers. These results suggest a positive outcome for undergraduate study in supporting the ME department's mission to produce graduates competent in practicing the profession, pursuing graduate study, and engaging in research work.

Conclusion and Recommendation

Based on the findings of the study, it can be concluded that the undergraduate research experience for students aligns with the overarching objectives of a research-oriented course and the educational goals set forth by the department. However, there exists a challenge in enhancing the student researchers' experience by providing essential facilities and support. These include, but are not limited to, access to well-equipped laboratories, comprehensive library resources, financial backing, and effective communication with research advisors.

Furthermore, the research course should expand its scope to offer increased opportunities for nurturing not only research skills but also skills in communication, collaboration, and social awareness. This multifaceted approach will instill greater confidence in researchers when pursuing advanced studies and striving to attain their research aspirations.

Conversely, for the research course to maintain its high standards, it must continually foster students' motivation and dedication. This involves ensuring a knowledgeable instructor is available to offer valuable insights, sustaining students' interest in relevant topics, enabling them to identify, formulate, design, and solve engineering problems. This collective effort contributes to the overall progression of knowledge within the field and bolsters students' confidence in pursuing research-related careers.

Based on the shortcomings highlighted through the CIPP evaluation, the following recommendations are put forth by the researcher:

a) Conduct an assessment of students' laboratory facility requirements and establish well-equipped laboratories that support activities such as hypothesis formulation, experimental design, methodology execution, and result evaluation.

b) Launch an information campaign to heighten students' awareness regarding the accessibility and utility of library resources for their research endeavors. This entails updating library resources to cater to diverse research interests.
c) Institute funding initiatives aimed at supporting undergraduate research students, thereby removing financial barriers that hinder the pursuit of novel, innovative, and high-impact research projects.
d) Incorporate soft skill development, including effective communication, collaboration, and an understanding of contemporary issues, into the teaching-learning process.
e) Implement the aforementioned recommendations through action research and subsequent re-evaluation within the department.

By implementing these measures, the department can actively address the highlighted areas of improvement and enhance the overall quality of the undergraduate research experience. This approach not only aligns with the goals of the research course but also ensures continuous progress and refinement in preparing students for successful careers in research and related fields.

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.

Funding

This work received no specific grant from any funding agency.

Conflict of Interests

All authors declare that they have no conflicts of interest

Acknowledgment

The authors thank the project advisory board for helpful guidance and suggestions.

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

*Angelo A. Acenas**
Department of Mechanical Engineering, Cebu Institute of Technology University, Cebu City, Philippines

Edsel P. Inocian, Michelle Mae J. Olvido
College of Teacher Education Graduate School, Cebu Normal University, Cebu City, Philippines

*angeloacenas@gmail.com

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.

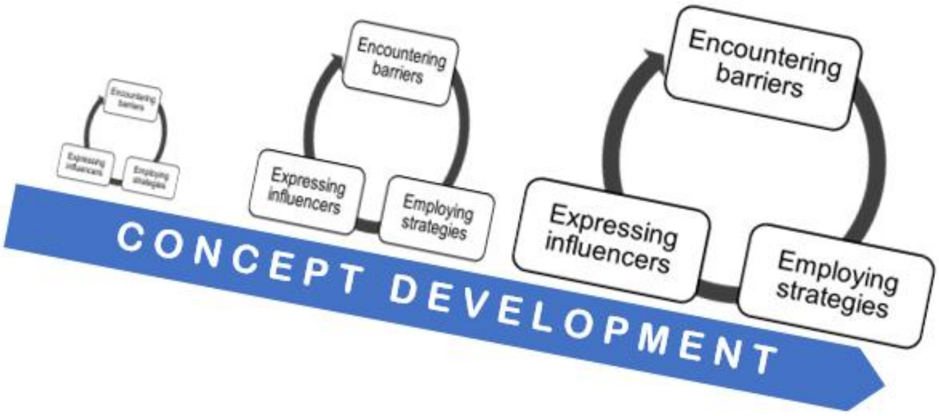

Figure 1: Conceptual model for research conceptualization in mechanical engineering

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.

Funding

This work received no specific grant from any funding agency.

Conflict of Interests

All authors declare that they have no conflicts of interest

Acknowledgment

The authors thank the project advisory board for helpful guidance and suggestions.

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Development of a Device for Brazing Copper Pipes in HVAC Installations

*Sydney Olandria, John Vincent Cabesas, Dominic Geganto, Brent Kenneth Olivar, Gerald Osa, Angelo A. Acenas**

Department of Mechanical Engineering, Cebu Institute of Technology University, Cebu City, Philippines

*angeloacenas@gmail.com

ABSTRACT

The brazing process plays a crucial role in HVAC installations, particularly in joining copper pipes. However, current brazing methods are often unsafe, time-consuming, laborious, and prone to inconsistencies. Interviews with construction workers involved in the process have highlighted the hazards associated with brazing in construction areas where conventional groundworks lack suitable devices. To address these challenges, this study developed a new device specifically designed for brazing copper pipes in HVAC installations. During the design phase, simulation techniques were employed to carefully consider factors such as thermal stress, heat distribution, and deformations caused by applied heat. This approach ensured that the final design would optimize performance and minimize risks. Subsequently, an actual prototype of the device was developed and has demonstrated significant potential in improving soldering in terms of safety and efficiency. The effectiveness of the device was evaluated through comprehensive testing, revealing noteworthy enhancements in production and accuracy rates. To fully realize its potential, it is strongly recommended to provide operators with thorough safety training. Clear guidelines on handling and positioning the device and the MAPP gas should also be provided to ensure safe and proper usage.

Keywords: *Brazing, Soldering, Copper pipes, HVAC installation*

Introduction

The installation of heating, ventilation, and split-type air conditioning (HVAC) systems in residential, commercial, and industrial settings often requires the precise joining of copper pipes. These pipes serve as crucial conduits for refrigerant flow, ensuring efficient cooling and heating performance [1]. One common method for joining copper pipes in HVAC installation is brazing. Brazing involves applying heat and adding a filler metal to join two pieces of metal. The filler metal, which has a lower melting point than the metals being joined, is either pre-placed or fed into the joint as the parts are heated [2, 3].

However, current brazing techniques often result in braze joints that leak and require rework or, in some cases, scrapping of the entire component. The costs associated with poor internal braze quality can be significant, depending on the equipment size, number of joints requiring rework, labour costs, and component scrap costs [4]. Interviews with workers involved in the brazing process from an HVAC company have revealed that the existing practice is challenging and time-consuming, requiring skilled personnel and meticulous attention to detail. Inefficient soldering techniques have led to subpar connections, resulting in leaks, reduced system efficiency, and potential system failures. Additionally, the traditional or manual soldering method for preparing materials often leads to issues such as burning hazards. Hazards like burns, eye damage, electrical shock, cuts, and crushed toes and fingers are all potential risks associated with soldering copper pipes [5]. Improper handling of the welding torch, which is used to melt the welding rod and solder the connected copper pipes, can cause burns. Welding torches typically use oxygen and acetylene, producing flames with temperatures ranging from 2760 degrees Celsius to 3316 degrees Celsius [6].

Various inventions related to brazing can be found in patent databases, including a small-diameter pipe extrusion and soldering sealing device [7], an automatic solder spraying machine for pipe fitting [8], a welding device for air conditioner refrigeration copper pipes [9], a copper pipe joint with preset solder [10], and a welding apparatus for copper pipes [11]. However, these existing inventions suffer from two main drawbacks: a lack of portability and a complex design, making it difficult for unskilled workers to utilize the devices effectively.

To address these challenges, this research focuses on the development of a device for brazing copper pipes in HVAC installation. The primary goal is to overcome accidents and health hazards associated with the manual brazing process by providing a stable and secure platform for holding the copper pipes in precise positions. The development of this device involved careful consideration of factors such as tube alignment, heat distribution, soldering flux application, and joint quality control. The effective utilization of this device can help prevent injuries and enhance the overall working conditions for individuals in the industry. Moreover, this device has the potential to significantly improve both the operation time and accuracy of the brazing process, resulting in cost savings and increased productivity.

Methodology

The purpose of this study was to create a device that would enhance the brazing of copper pipes, thereby lowering or eliminating harmful working conditions and increasing efficiency. First, surveys that were given to employees of an HVAC installation firm, who acted as the target users, were used to gather qualitative data. These surveys seek to learn more about respondents' opinions and issues with the existing brazing procedure. The preferences of the intended users were then taken into consideration when the qualitative findings were examined to determine potential areas for process improvement. A conceptual design was then developed using the principles of machine design and heat transfer. The design was modelled in SolidWorks to acquire important insights into thermal stresses, heat distribution, and part deformation brought on by applied heat. After the simulation phase, the device was fabricated and put through a series of actual testing.

Design conceptualization

Since the goal is to address the issues faced by workers during HVAC installation, the results of the conducted survey, along with the insights gained from the value proposition canvas and cause-and-effect diagram, were used to develop the user preferences for product design. These preferences are presented in Table 1.

Table 1: User preferences for product design

Preferred Feature	Description
Ease of use	The device is user-friendly, especially for novice workers.
Labor reduction	The device simplifies and accelerates brazing work, requiring less manual labor.

Based on the table, two key themes emerged from the conducted survey: Ease of use and labor reduction. This indicates that workers prefer a device that is user-friendly, even for novice workers. Additionally, they desire a device that simplifies the brazing process, accelerates the work, and minimizes the need for manual labor.

Design and material selection

Using knowledge of machine design, the device was constructed as shown in Figure 1.

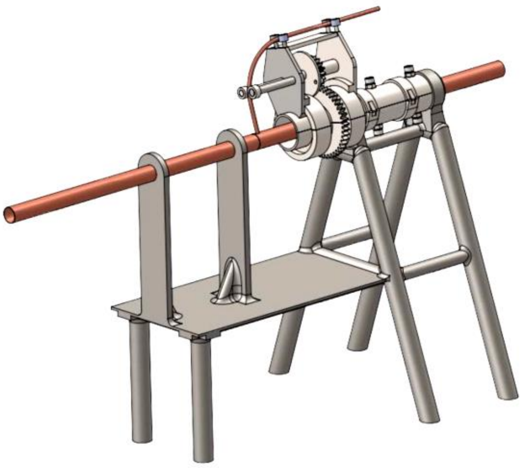

Figure 1: Ground assembly of the device

The selected materials for the device include alloy steel, engineering plastic, and aluminum alloy. Alloy steel is used for the body components such as gears, housing, shafts, and feeder. Engineering plastic is utilized for the soldering filler holder, while aluminum alloy is used for the clamps. The choice of these materials was based on their availability and suitability in terms of their physical and mechanical properties [12,13]. Alloy steel was chosen for its desirable density, hardness, toughness, thermal conductivity, and coefficient of thermal expansion. Similarly, aluminum alloy and engineering plastic were selected for their toughness, hardness, thermal conductivity, and corrosion resistance. The material selection is summarized in Table 2.

Table 2: Material selection

Parts	Material selected
Pinion, Ratchet, Gear, Feeder, Rotating housing, Ratchet pin plate, Ratchet pin, Pinion shaft, Gear tube housing	Alloy steel
Clamp	Stainless steel
Filler holder	Nylon 101

Analysis

Prior to fabrication, extensive calculations and simulations were conducted to ensure that the device meets the desired performance requirements [14,15]. The detailed results of these calculations and simulations are presented in the following sub-sections.

Design consideration

The following factors were considered during the design process and fabrication of the device:

a. The device must be capable of securely holding copper pipes of three different sizes: ½, ¼, and 3/8 inches in diameter.
b. The device must be able to handle the heat released by the MAPP gas.
c. The device must prioritize safety in both operation and maintenance.
d. The device should be cost-effective to manufacture and operate.
e. The device should be compact and user-friendly.
f. The device must facilitate a clean and precise soldering process.

Heat transfers

The heat generated by the copper tube will radiate and impact the adjacent components of the device, leading to an increase in temperature. To determine the final temperatures of the surrounding parts of the device, SolidWorks Flow Simulation was utilized. The results, depicted in Figure 2, provide insights into the temperature distribution.

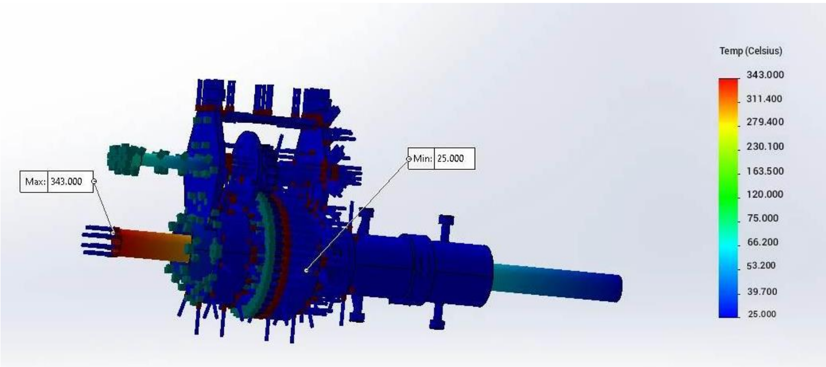

Figure 2: Temperature gradient across all parts of the device

Upon simulating the area affected by the heat radiated from the copper tube, it was observed that the feeders were impacted, as shown in Figure 3.

These results were further verified through manual calculations using Equation (1) which resulted in a temperature of 71 degrees Celsius for the feeders.

$$Q = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{r_1}{r_2} + \frac{1-\varepsilon_2}{\varepsilon_2}} \tag{1}$$

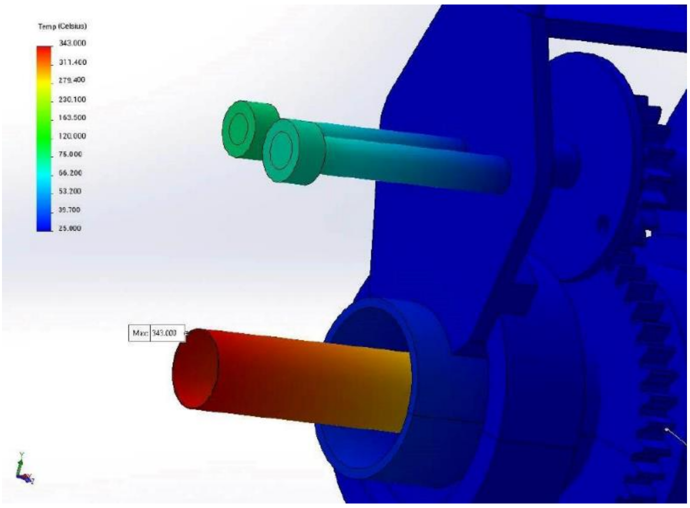

Figure 3: Temperature gradient for the feeder and shaft

Thermal stress

The heat radiation imposes stress on the device as the heated copper tube causes nearby parts to increase in temperature. Figure 2 illustrates the temperature gradient across all parts of the device, while Figure 3 specifically displays the temperature gradient for the feeder and shaft, ranging from 66.2°C to 75°C. To ensure safety, it is important to consider the maximum temperature. To calculate the thermal stress, Equation (2) was utilized which resulted in a calculated stress of 125 MPa which is less than the yield stress of 620 MPa. Therefore, the design is safe from thermal stress.

$$\sigma_T = E\alpha\Delta T \tag{2}$$

Deformation due to applied heat

Since the feeder and shaft are not constrained in a single direction, they are anticipated to expand in all directions. As a result, their deformation per unit length can be expressed using Equation (3). The expansion was calculated as 0.000468 per mm which is negligible.

$$\frac{\delta_T}{L} = \alpha\Delta T \tag{3}$$

Fabrication

The fabrication process of the device involves a series of steps which included the following steps:

a. Prepare the materials: The materials for the device consist of alloy steel plates for gears, housing, and stand, stainless steel for clamps, nylon 101 for the soldering filler holder, and bolts and nuts. These materials need to be cut and shaped to fit the device design.

b. Fabricate the gear housing and rotating housing: The gear housing, which serves as the main body of the device, holds all the parts except for the stand used in ground assembly. It is constructed from alloy steel pipes and plates. The fabrication process involves cutting and welding the pipes and plates to achieve the desired shape.

c. Fabricate gears, ratchets, shafts, pins, and ratchet plate: Gears can be fabricated using a gear hobbing machine or a CNC wire cut machine. Other components are fabricated through cutting, welding, and machine operations.

d. Assemble the parts in the rotating housing: This step involves assembling the pinion, shaft, ratchet, ratchet plate, and pin within the rotating housing. The shafts are connected to the pinion and/or ratchet using press fitting, while other connections are secured with screws. Some assemblies may require calibration to ensure proper functioning.

e. Assemble the gear to the gear housing: Prior to attaching the gear to the gear housing, both components are cut in half. The gear is then welded in place, and clamps are attached using set screws. Nuts are also welded onto the housing concentric to the existing holes.

f. Assemble the rotating housing to the gear housing: Since both the gear housing and the gear are cut in half, the rotating housing is slide-fitted into the channels allotted in the gear housing. It can also be secured in place with a set screw.

Performance evaluation

In line with the objectives of the study, the following parameters were used to evaluate the machine's performance:

a. Heat distribution and thermal stress
b. Production rate
c. Accuracy

Results and Discussion

Heat distribution and thermal stress

The heat distribution in both simulation and actual testing is presented in Table 3. The difference in the result can be attributed to several factors. One specific factor is the positioning of the MAPP gas. The direction in which the flame of the MAPP gas is pointing can cause temperature variations in different parts of the tool. The testing was conducted with the flame directed perpendicular to the copper tube, resulting in the heat being directed away from the tube. However, during actual heating, the flame covers half of the circumference of the copper tube facing the flame, causing the heat to disperse in the direction of the tool. On the other hand, in the simulation, the heat was only directed towards the end face of the copper tube and was confined to the end face cross-section, leading to an increase in temperature at the feeder.

Table 3: Actual and simulation results of heat distribution

Parts	Actual	Simulation
Feeder	75 °C	61 °C
Rotating housing	30 °C	39 °C
Gear tube housing	30 °C	35 °C

The thermal stress experienced by the device is within acceptable value (<620 MPa). On the other hand, the thermal expansion is negligible. The results are summarized in Table 4. Previous studies have also examined the importance of thermal stress and thermal expansion in the design of soldering or brazing operations [16, 17, 18]. These studies have shed light on the significance of these parameters in the overall design process.

Table 4: Actual and simulation results of thermal stress and expansion

Parameter	Actual	Simulation
Thermal stress	125 MPa	98 MPa
Thermal expansion	5.95E-4 mm/mm	4.68E-4 mm/mm

Production rate

The device's actual performance is tested by measuring the average production rate for three specified diameters of copper pipes: ½, ¼, and 3/8 inch. The production rate is calculated based on the number of workpieces completed per minute. Figure 4 depicts the comparison of the results with and without using the device. The results demonstrate a significant increase in the overall production rate due to the implementation of the device. This finding aligns with previous studies that have also highlighted the positive impact of technology adoption on improving productivity in the HVAC industry [19, 20].

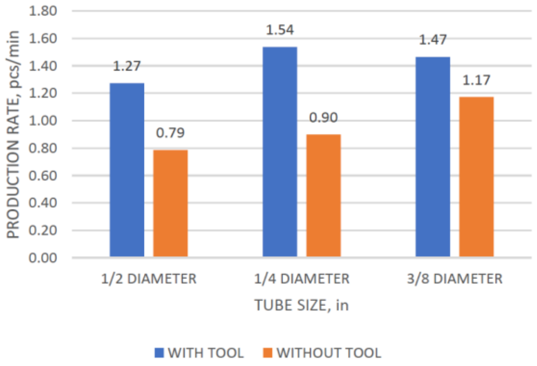

Figure 4: Average production rate with and without the device

Accuracy

Figure 5 depicts the actual performance results of the device, specifically focusing on accuracy, as tested with copper pipes of three specific diameters: ½, ¼, and 3/8 inch. Accuracy is determined by calculating the ratio of accurately produced workpieces to the total number of completed workpieces. There was an overall improvement in accuracy because of the intervention of the device. This result further reinforces the significance of accuracy in the brazing operation, building upon previous findings [21,22].

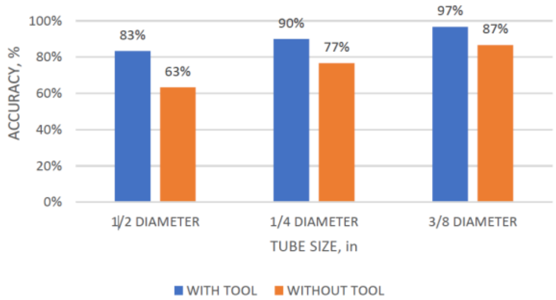

Figure 5: Average accuracy with and without the device

In lieu of the findings above, to effectively implement the designed and fabricated device for brazing copper pipes in construction sites, consideration should be given to the specified diameters and the tool's versatility for both overhead and ground operations. Proper training and instruction are crucial to maximize the tool's benefits and ensure safety. Continuous monitoring of the tool's performance, usability, and safety through user feedback and periodic assessments is recommended, allowing for necessary improvements. Future research should focus on investigating the device’s long-term durability, exploring its adaptability for other materials and joint configurations, and addressing ergonomic design considerations to enhance user comfort and reduce fatigue.

Conclusion

The study developed a device for brazing copper pipes in HVAC installation which has effectively addressed concerns regarding the work environment and workplace safety and the need for multiple personnel. The device demonstrates the potential to enhance the brazing process in terms of safety and efficiency. The simulation provided valuable insights into heat distribution, thermal stress, and thermal expansion encountered by the device. Actual testing demonstrated higher production rates and improved accuracy when using the device compared to the existing practice.

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.

Funding

No funding from others.

Conflict of Interests

All authors declare that they have no conflicts of interest

Acknowledgment

The authors would like to thank the research advisory committee.

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