Integrating Research Methodology into Capstone Projects: Best Practices and Strategies

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***Abstract*—Using research methodology in capstone projects is important for encouraging critical thinking, improving academic quality, and making sure the results are relevant and accurate. This paper looks at the best ways to include research methodology in capstone projects in different fields of Electrical Engineering. It covers key points like making sure research questions match the project goals, framing the objective, controllable variables, research environment, choosing the right research methods, how to collect and analyze data, and the importance of keeping ethical standards throughout the process. The paper also highlights the role of teacher support and response in improving the quality of capstone projects. By offering practical strategies, this study aims to help students and instructors create thorough, high-quality capstone projects that are valuable both for academic research and real-world use.**

***Keywords*—Academic research, Capstone projects, Data analysis, Data collection, Ethical standards, Research methods.**

***ICTIEE* Track—Innovative Pedagogies and Active Learning**

ICTIEE Sub-Track—Project-Based and Problem-Based Learning (PBL)

I. INTRODUCTION

The capstone project course is a key student-focused activity that gives undergraduate students a chance to solve real-world problems by using the technical and soft skills they have learned. One of its main goals is to apply engineering practices to meet customer needs. The challenges and best practices learned during the development and execution of the open-ended capstone project, aiming to improve the quality and learning results [1]. In the context of engineering education, research methodology serves as a foundational skill that enables students to conduct experiments, analyze data, and derive conclusions. Traditionally, research methodology has been taught as a theoretical subject, often detached from the practical applications students will eventually encounter in their professional careers [2]. This detachment can lead to disengagement, with students struggling to see the relevance of research techniques to their projects and future work.

Capstone projects, on the other hand, are designed to bridge the gap between theory and practice by providing students with the opportunity to apply their learning in real-world scenarios and it is also a project-based learning [3]. By integrating research methodology with capstone project experience, educators can create an engaging, context-rich learning environment where students learn by doing. This paper outlines an innovative approach to teaching research methodology to third-year B.Tech. students by using their capstone projects as a real-time platform for learning and applying research methodology.

Research methodology plays a crucial role in developing critical thinking, ensuring academic rigor, and validating the outcomes of the capstone project with unique solutions. By examining the best practices and strategies, it provides valuable insights into aligning research questions with project goals, selecting suitable research designs, and maintaining ethical standards. The goal of this paper is to offer actionable strategies to help both students and instructors create capstone projects that contribute meaningfully to academic knowledge and practical application.

II. ROLE OF RESEARCH METHODOLOGY IN CAPSTONE PROJECT

Fig. 1. Research Methodology Algorithm.

Fig. 1 shows the research methodology algorithm developed to apply the formulation of capstone project group problem and make it decision making, the terms used in this algorithm illustrates the research methodology key points for a capstone project.

1. *Individual/Organization (I)*

Represents the entity responsible for addressing the problem.

2. *Environment (N)*

The context or setting in which the entity operates. This environment is influenced by uncontrolled variables (Y_j), such as external factors that cannot be controlled by the researcher.

3. Courses of Action (C_1, C_2)

These are the possible strategies or actions that can be taken. Each course of action is defined by specific controlled variables, which are factors that can be adjusted or manipulated.

4. Outcomes (O_1, O_2)

The possible results of each course of action. One of these outcomes is preferable to the other, meaning one is more aligned with the researcher's goal or objective.

5. Probabilities (P (O_1|I, C_1, N) and P (O_1|I, C_2, N))

These represent the likelihood of each outcome occurring based on the chosen course of action. The probabilities must be different for each course of action, as this difference is what drives the decision-making process.

T.Y. B.Tech. Electrical Engineering, Sem-VI have both the research methodology and Capstone Projects in the curriculum. In a capstone project course, the listed terms of research methodology algorithm play an important role in guiding the process of defining the capstone project topic and solving a problem. The first step is identifying the person, group, or organization called 'I', that is responsible for tackling the issue. This person or entity operates within a certain environment, 'N', which is affected by several factors or variables referred to as 'Y_j' that cannot be controlled.

Next, the research methodology requires exploring at least two possible actions or strategies, C_1 and C_2, each defined by specific controlled factors. These strategies lead to different outcomes, O_1 and O_2, and one of them must be more favorable than the other. This establishes a clear goal for the research: finding the best possible result.

The courses of action must offer different chances of achieving the desired outcome. If both strategies gave the same chance of success, there would be no need to choose between them. For example, the likelihood of reaching outcome O_1 by choosing strategy C_1 in environment N must be different from the probability of achieving the same outcome by choosing strategy C_2 in the same environment. This difference in the effectiveness of each option helps the capstone project students to decide which approach to pursue in order to achieve the best possible result.

The above-mentioned model is given to the 20 capstone project groups of T.Y. B. Tech. Electrical Engineering, Sem-VI students as ISE component and to finalize their capstone project title and the research methodology terms according to it. Also, all the Capstone groups are informed to prepare and present a report which is a part of ISE-II.

III. Methodology

By considering design of an energy-efficient electrical motor as one of the topics of capstone project group we look methodology of the research methodology algorithm. The goal of this project would be to design an electric motor that minimizes energy consumption while still providing the necessary power and performance for the application. You could consider two different designs for the motor and choose the most energy-efficient one based on some expected outcomes from the research methodology algorithm.

Problem Description for Capstone Project

Capstone project group decided to design an energy-efficient electrical motor. In this project, T.Y. B. Tech. capstone project group (the individual/organization I) is trying to decide between two different motor designs (the courses of action C_1 and C_2). The environment is the operating conditions, such as voltage and load (the uncontrolled variables Y_j). The outcomes will be based on how well each motor design performs in terms of energy efficiency and power output (the outcomes O_1 and O_2). The goal is to choose the motor design that provides the most energy-efficient performance while still delivering the required output.

The goal is to choose between various designs or technologies (courses of action) that could lead to the most energy-efficient motor with desirable performance outcomes.

I, Individual or Organization The capstone project group or engineer working on motor design.

N, Environment Factors that impact motor efficiency, such as power supply characteristics, operating conditions, load demands, etc.

*Y_j, Uncontrolled variable*s Load

C_1, C_2, Courses of Action Different motor designs or configurations, such as:

C_1 Design with Permanent Magnet Motor (PMM).

C_2 Design with Induction Motor (IM).

C_3: Design with Brushless DC Motor (BLDC).

O_1, O_2, O_3, Outcomes Possible outcomes associated with each motor design:

O_1 High energy efficiency (desired outcome).

O_2 Moderate energy efficiency.

O_3 Low energy efficiency (undesirable).

Objective Maximize energy efficiency while meeting performance requirements.

Now, we will apply the decision-making algorithm to this scenario, if each motor design has a probability of achieving the desired energy efficiency based on certain environmental conditions (N).

IV. Step-by-Step Research Methodology Algorithm for Energy-Efficient Motor Design

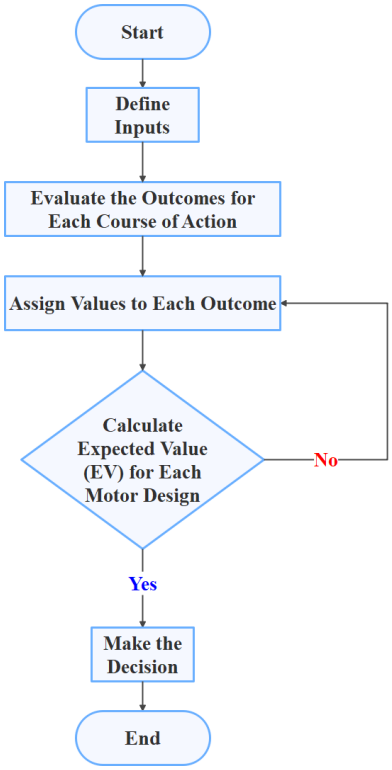

Fig. 2. Flowchart of Research Methodology Algorithm for Energy Efficient Motor

Fig. 2 represents the flowchart of research methodology algorithm for the decision making for an energy efficient motor used by the T.Y. B. Tech. capstone project group. The following are the steps involved in the algorithm.

1. Define Inputs

I: Research team.

N: Environmental factors like power supply, operating temperature, etc.

Y_j**:** Load

C_1, C_2, C_3: Available motor designs (PMM, IM, BLDC).

O_1, O_2, O_3: Energy efficiency outcomes (High, Moderate, Low).

$P(O_j \mid I, C_j, N)$: Probability of obtaining outcome o_j for each motor design under environmental factors.

2. Evaluate the Outcomes for Each Course of Action

For each motor design, calculate the probability of achieving high, moderate, or low efficiency.

Example probabilities (these could be experimentally derived or simulated):

A. For PMM (C_1)

1. $P(O_1 \mid I, C_1, N) = 0.7$ (70% chance of high efficiency)
2. $P(O_2 \mid I, C_1, N) = 0.2$ (20% chance of moderate efficiency)
3. $P(O_3 \mid I, C_1, N) = 0.1$ (10% chance of low efficiency)

B. For Induction Motor (C_2)

1. $P(O_1 \mid I, C_2, N) = 0.5$ (50% chance of high efficiency)
2. $P(O_2 \mid I, C_2, N) = 0.3$ (30% chance of moderate efficiency)
3. $P(O_3 \mid I, C_2, N) = 0.2$ (20% chance of low efficiency)

C. For BLDC Motor (C3):

1. $P(O_1 \mid I, C_3, N) = 0.8$ (80% chance of high efficiency)
2. $P(O_2 \mid I, C_3, N) = 0.1$ (10% chance of moderate efficiency)
3. $P(O_3 \mid I, C_3, N) = 0.1$ (10% chance of low efficiency)

3. Assign Values to Each Outcome

We need to assign a value to each outcome based on how desirable it is:

1. $\text{Value}(O_1) = 1$ (High efficiency is the most desirable).
2. $\text{Value}(O_2) = 0.5$ (Moderate efficiency is acceptable).
3. $\text{Value}(O_3) = 0$ (Low efficiency is undesirable).

4. Calculate Expected Value (EV) for Each Motor Design

Now we calculate the expected value for each design, which gives us a quantitative measure of how effective each design is in terms of achieving energy efficiency.

1. For PMM (C_1)

$EV(C1)=P(O_1|I,C_1,N)\times\text{Value}(O_1)+P(O_2|I,C_1,N)\times\text{Value}(O_2)+P(O_3|I,C_1,N)\times\text{Value}(O_3)$

$EV(C_1)=(0.7\times1)+(0.2\times0.5)+(0.1\times0)$

$EV(C_1) = 0.7 + 0.1 + 0 = 0.8$

2. For Induction Motor (C2)

$EV(C2)=(0.5\times1)+(0.3\times0.5)+(0.2\times0)$

$EV(C2)=0.5+0.15+0=0.65$

3. For BLDC Motor (C3)

$EV(C3)=(0.8\times1)+(0.1\times0.5)+(0.1\times0)$

$EV(C3)=0.8+0.05+0=0.85$

5. Make the Decision

The motor design with the highest expected value (EV) will be chosen. In this case:

1. $EV(C_1) = 0.8$
2. $EV(C_2) = 0.65$
3. $EV(C_3) = 0.85$

Since C_3 (the BLDC motor) has the highest expected value, the decision is to proceed with the BLDC motor design, as it has the highest likelihood of achieving the desired outcome of high energy efficiency.

The assessment of the implementation of research methodology for the Capstone project course involves a comprehensive evaluation process conducted through In Semester Evaluation of T.Y. B. Tech. Electrical students.

V. Result of Implementation of Research Methodology into Capstone Project

From the above algorithm, capstone project group students can gain several key insights related to decision-making and the application of probability and expected value in real-world scenarios. Below are the general observations regarding their understanding,

1. *Understanding the Decision-Making Process*

Clear Structure: Students will see that designing an energy-efficient motor isn't just about picking one motor design randomly. Instead, it's about systematically comparing different designs (courses of action) based on how likely they are to achieve the desired outcome (high energy efficiency).

Importance of Comparison: The algorithm helps students understand that each motor design has its own chance of achieving high efficiency. They will learn how to evaluate each design against specific criteria and choose the one with the best chance of success.

2. *Application of Probabilities*

Managing Uncertainty: Students will recognize that in the real world, not every motor design will guarantee the best efficiency. The use of probabilities shows that there's always a chance of variation, and students will understand how to incorporate these uncertainties into their decisions.

Real-World Relevance: The concept of assigning probabilities to different outcomes (e.g., achieving high, moderate, or low efficiency) helps students connect theoretical ideas to real-world scenarios like motor design, where outcomes aren't always predictable.

3. *Expected Value and Decision Making*

Weighing Outcomes Based on Importance: Students will learn that expected value allows them to make decisions by considering both the likelihood and the value of different outcomes. By assigning values (such as 1 for high efficiency, 0.5 for moderate, and 0 for low), they will see how to prioritize which outcome is most desirable.

Choosing the Best Design: The expected value calculation demonstrates how students can choose the design that offers the highest probability of reaching the goal of energy efficiency. They will realize that even if a design has a high probability of moderate efficiency, another design might have a better overall expected value.

4. *Optimizing for the Desired Outcome:*

Maximizing Efficiency: By applying this algorithm, students will understand that the goal in designing an energy-efficient motor is not just to make a working motor but to maximize energy efficiency in real operating conditions.

Trade-offs and Decisions: The algorithm also teaches students about trade-offs. For example, while a design like the BLDC motor might have a higher chance of high efficiency, other designs might offer different advantages, like cost or ease of manufacturing. Students will understand that optimization is about balancing all these factors.

5. *Critical Thinking in Engineering*

Evaluating Different Design Options: Through this algorithm, students will realize the importance of evaluating various design options based on objective data and probabilities. They will understand that making decisions in engineering requires analysing all available information carefully to make the best possible choice.

Understanding Engineering Complexity: The task of designing an energy-efficient motor involves considering multiple factors (e.g., cost, performance, energy efficiency, material constraints), and students will see that engineers need to balance all these factors when making decisions.

6. *Integration of Mathematics in Engineering*

Realizing the Role of Math in Engineering: Students will connect the mathematical concepts of probabilities and expected value to real-world engineering problems. They will understand that math is not just an abstract concept, but a tool used in practical situations to make better decisions.

Simulation and Data Analysis: Students will recognize that to apply such algorithms in real-world engineering, they would often use simulations or gather data to estimate the probabilities of different outcomes (e.g., motor efficiency). This shows them how theoretical decision-making can be supported by data-driven methods.

VI. Understanding of the Research Methodology Algorithm With Implementation in a Capstone Project:

A. Understanding of the Research Methodology Algorithm Without Implementation

1. *Conceptual Understanding*
   Without implementation, the algorithm serves as a conceptual framework that explains how to approach decision-making in an engineering project. Students will understand the theoretical steps involved, such as defining the courses of action (motor designs), evaluating outcomes (efficiency levels), assigning probabilities, and calculating expected value.
2. *General Learning*
   In this case, students learn about the structure of decision-making and the importance of using tools like probabilities and expected values to assess various alternatives. The focus is on grasping the key concepts in decision theory and the decision-making process.
3. *Practical Application*
   While the algorithm provides a structured method for decision-making, students may find it difficult to relate to real-world complexities like data collection, environmental variables, and practical constraints without actual implementation. They might not experience the nuances of applying theoretical knowledge in a dynamic environment (e.g., gathering data, adjusting probabilities based on changing conditions, or handling uncertainties).
4. *Outcome*

The outcome of studying the algorithm without implementation is knowledge-based learning. Students may grasp the mathematical concepts and theoretical underpinnings but lack the experience of applying them in real-world situations.

B. *Understanding of the Research Methodology Algorithm with Implementation in a Capstone Project*

1. *Conceptual and Practical Understanding*
   When implemented in a capstone project, the algorithm goes beyond just theory and becomes a practical tool for solving a real-world engineering problem. Students not only understand the theoretical steps but also experience the challenges of gathering data, interpreting it, and making decisions based on those real inputs.

2. *Real-World Experience*
   In a capstone project, students apply the algorithm to actual motor designs and real-world conditions (e.g., performance requirements, environmental factors, budget constraints). This helps them **bridge the gap** between theory and practice. They might have to gather data from different motor designs, evaluate actual probabilities (based on testing or simulations), and then adjust their calculations based on real-world feedback.

3. *Data Collection and Validation*
   The students are likely to face challenges like data collection, simulation modelling, and validating their assumptions. They may need to experiment with different motor designs, run simulations, and adjust the probabilities based on real data. They could also factor in other variables, like cost and material efficiency, which may not have been considered in the theoretical framework.

4. *Problem-Solving and Iteration*
   A real-world capstone project typically involves iteration and refinement. Students might find that their initial expected values or probability estimates are off, leading them to reassess their design choices. This iterative process teaches them the importance of adaptability and the need for continuous learning and optimization in engineering projects.

5. *Outcome*
   With implementation, the outcome is a hands-on learning experience, where students test and apply the algorithm to real data, gaining insights that theoretical learning alone cannot provide. They learn not just to follow the steps of the algorithm, but to adjust based on real-world constraints, data, and outcomes.

VII. Impact of Research Methodology in Attainment of Course Outcome (CO) and Program Specific Outcomes (PSO):

The following are the CO statements of research methodology as well as capstone project course and PSO of Electrical Engineering program.

TABLE I
Research Methodology Implementation Comparison Summary

Aspect	Without Implementation	With Implementation
Focus	Theoretical understanding of decision-making steps.	Practical application of decision-making steps to solve a real-world problem.
Conceptual Learning	Students learn about the structure of decision-making and the use of expected value and probabilities.	Students learn to apply these concepts while facing real-world challenges like data collection and handling uncertainty.
Application	Limited to understanding the algorithm in abstract terms.	Full application, including data collection, simulation, and design iteration.
Skills Developed	Basic understanding of decision theory, probabilities, and expected value.	Enhanced skills in data analysis, simulation, optimization, and real-time problem-solving in engineering.
Learning Outcome	Knowledge-based learning and understanding of decision-making theory.	Hands-on learning with a focus on problem-solving, adaptability, and real-world application.

CO of Research Methodology Course

1. Describe the research process and the principle activities, skills and ethics associated with the research process.
2. Formulate a research problem.
3. Assess and critique a published journal article.
4. Identify the components of a literature review process
5. Construct an effective research article or proposal by following research ethics

CO of Capstone Project Course

1. Carry out literature surveys and identify as well as select a problem.
2. Comprehend and analyze engineering problems and report findings to provide an appropriate solution.
3. Design an experimental setup or develop an analytical model to analyze the system under consideration.
4. Communicate problems, methodology and outcomes systematically and effectively in the form of a technical report.
5. Work as a member and a team leader in engineering teams / multidisciplinary teams.
6. Demonstrate an ability to use different tools and techniques to solve the given problem.

PSO of Electrical Engineering

1. Apply knowledge of power systems, power electronics, electrical machines and control systems for the industrial applications.

2. Operate and control renewable energy sources and electric vehicle systems.

The Capstone Project course for T.Y. B. Tech Electrical Engineering (Semester VI) helps students achieve both Course Outcomes (COs) and Program Specific Outcomes (PSOs), especially when using research methodology. The 20 groups apply research methodology algorithm to define their project topic idea decision making and solve real-world electrical engineering problems. This helps them meet CO1, CO3 and CO6 (Problem Identification and Solution Design) by using methods like surveys, experiments, and data analysis to find solutions. CO2, CO4 and CO5 (Research and Data Analysis) are achieved as students gather and analyze data using proper research methods to ensure their results are reliable.

TABLE II
RESEARCH METHODOLOGY IMPACT OF CO AND PSO ATTAINMENT.

Impact Area	Course Attainments (CO)	Program Specific Attainments (PSO)
Evidence-based Problem Solving	Demonstrates ability to apply research to solve problems	Ensures data-driven decision-making aligns with program goals
Application of Concepts	Shows mastery of course methodologies (qualitative, quantitative)	Demonstrates integration of interdisciplinary knowledge
Communication of Results	Ensures clear and logical presentation of research	Aligns with program's emphasis on effective communication
Practical Application	Applies theoretical knowledge to real-world problems	Reflects the program's focus on real-world impact
Innovation and Contribution	Enables original, data-driven insights	Aligns with program goals of contributing to the field
Building Research Competence	Demonstrates research skills like data analysis, report writing	Develops independent research skills for professional use
Critical Thinking and Analysis	Encourages critical analysis and interpretation of data	Promotes thoughtful evaluation and problem-solving in complex scenarios
Ethical Standards in Research	Ensures ethical handling of data and subjects	Reflects program's emphasis on ethical responsibility in research

Students also meet CO3 (Effective Communication of Results ang preparing the reports on it) by presenting their research findings clearly, with strong supporting data. At the program level, research methodology helps students meet PSO1 by designing and developing electrical systems based on data, by using modern tools in their projects which focuses on the sector power systems, power electronics, electrical machines and control systems, and PSO2 by considering the environmental impact of their solutions in the era of renewable energy sources and electric vehicle systems. Through this research-focused approach, students achieve both course and program goals, preparing them for careers in electrical engineering.

Twenty capstone project groups of T.Y. B. Tech. class are finalized their topics using this algorithm.

Course exit survey considering different questions related to the understanding of the research methodology taken through the moodlle. The Fig. 3 shows the sample questions, 68 students responded to this question.

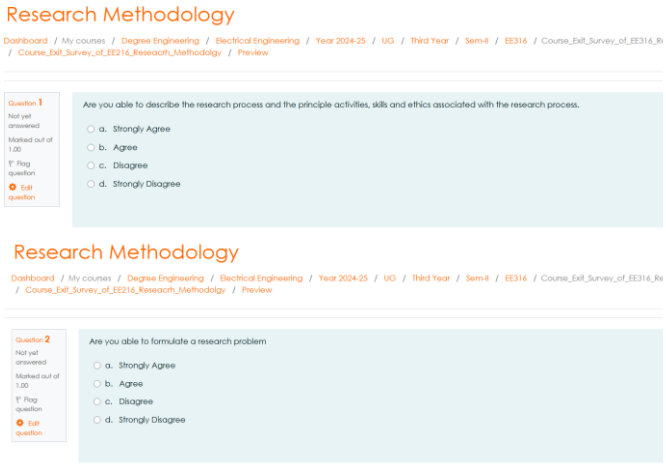

Fig. 3. Course Exit Survey

Finally, students capstone project presentations were carried out at the end of the semester, and an evaluation process was done through the external examiners. Fig. 4 shows the moment of the presentation.

Fig. 4. Evaluation of students through presentation.

This algorithm helps to make an interdisciplinary project that can bridge the gap between problem identification

CONCLUSION

Using research methodology in capstone projects is important for achieving strong results and clear conclusions and decision making. By following best practices like defining clear research questions, choosing the right research methods, and collecting and analyzing data carefully, students can improve the quality of their projects. Strategies such as getting regular feedback, reviewing progress often, and working with mentors or peers can also help improve the research process. In the end, a well-planned research approach makes the project stronger and provides students with useful skills for their future careers and studies.

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