Assessing the Effectiveness of 'Research Design' as a Pedagogical Tool for Promoting the skill of 'Decision-making' Towards Developing Leadership in Engineering Students

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Abstract

The engineering fraternity is required to make critical decisions and demonstrate leadership in the process of developing technological innovations. However, during a typical undergraduate engineering program the students are not taught about effective decision-making or leadership, as these are considered to be management modules and outside the core engineering curriculum. This research paper, based on a case study from Plaksha University, a new engineering university in India presents a pedagogical innovation that centers research design as an effective pedagogical tool to teach decision-making and leadership skills to engineering students. To test this, we collected data on three major questions: student perception of the importance of decision-making and leadership, actual student performance in the course, and student perception of the effectivity of research design as a pedagogical tool in making engineering students learn better decision-making and leadership skills.

Data was collected from 78 second-year undergraduate engineering students enrolled at Plaksha university in India who participated in the course “research design and decision-making”. Both quantitative and qualitative data along with student course performance data were analyzed to answer the research questions. The findings of this research showed that there was a significantly high perceived importance for skills like critical thinking, decision-making and leadership among participants. Furthermore, student performances in the course were significantly higher than expected, showing higher retention of the skills taught. Additionally, students rated the effectiveness of research pedagogy in teaching the skills of critical thinking and decision-making significantly higher than expected. The study results prove that decision-making and leadership skills can be organically brought into engineering when research design is used as a pedagogical tool for teaching about decision-making explicitly.

Introduction

Engineering education in the 21st century needs to consider the future of work, which takes into account the aspects of the Fourth Industrial Revolution, and the role of automation [1]. Educators need to keep in mind the rapid technological changes that are happening in our world today to align the engineering curriculum to real-world requirements. Learning in classrooms needs to incorporate solutions that offer customized and flexible ways that facilitate innovation. Decision-making is an integral part of innovation, yet it is not traditionally included in engineering education [2]. Therefore, engineering education cannot be simply based on training in technical knowledge, but also must incorporate an ability to learn and imagine solutions to problems, leading to innovation. Hence, decision-making as a tool for leadership, traditionally part of management education, now needs to become an inherent part of engineering education. [1]. This is particularly significant for contemporary engineering education, which needs to incorporate innovative solutions, as the ground of mechanized solutions gives way to connectivity, and a merging of physical, digital and biological ways that is unprecedented [2].

The specific pedagogical innovation that forms part of this case study is in teaching research design as a tool for decision making, leading to problem solving and innovation. This case study from Plaksha University in India will present a pedagogical innovation that centers decision making for problem-solving, a key engineering concept, as the centerpiece of the "Research Communication and Decision-making" course for second year engineering students. The course and its outcomes are analyzed and presented in this paper as an example of incorporating the research design tools to arrive at leadership decisions in any work context. While this may not be unusual in management education, incorporating research design and decision-making in undergraduate engineering education was meant to prepare students for leadership much earlier in their careers. This pedagogical intervention, and its quantitative as well as qualitative outcomes offer space for further examination of the efficacy of this approach in other spaces. This pedagogical intervention, along with its quantitative as well as qualitative outcomes offer space for further examination of the efficacy of this approach in other spaces.

Literature Review

Innovation and solution building, since the beginning of engineering education have been considered synonymous with the engineering field [3]. According to the National Academies Press [4]: engineering is more than just applied science, despite popular belief to the contrary. Engineering makes use of the knowledge that science provides along with insights from the real world to move towards innovation, which remains the primary driving force [5]. Similarly, according to Nair [6], engineering is the application of mathematics and natural sciences to innovate and come up with solutions to practical issues that are "useful to people."

So, to fulfil the aforementioned requirement for engineers, modern curricula are primarily geared towards innovation and creating technical solutions [3]. Even 21st century employers and governments are looking at technological innovations not only to solve niche problems, rather they are looking at them as a solution towards bigger world problems like economic growth, environmental challenges, public health etc. [5].

Since innovation is one of the primary goals of engineering education, it becomes important to look at the strategies being used by educators to make students innovate. According to framework provided by Dekoninck [7], there are 5 skills needed for innovation namely: tenacity, creativity, independence, decision-making (risk analysis, intuition) and leadership. Similarly, other scholars have also identified competencies like creativity, decision-making collaboration, reflection and technological expertise as the primary requirements for innovation [8],[9].

However, according to Palomera-García [10] there is a glaring flaw in engineering education regarding the absence of decision-making as one of the teaching competencies. This is despite the fact that almost all modern engineering jobs require critical decision-making skills on an everyday basis [7]. The importance of decision-making for engineering students in getting jobs is also evidenced by the National Employability Survey (India) of 2016 and 2019 [11] and research by Deming [12] on the growing importance of decision-making skills for the majority of jobs including the ones in the engineering field.

This is where we find a gap in current engineering education where the majority of the curricula do not take decision-making into account. This is due to various reasons including:

- Lack of perceived need for teaching skills such as decision-making: Many engineering students think that their engineering knowledge would be sufficient for their careers, but many also don't take soft skills like decision-making seriously because they don't know what employers are looking for [13].
- Class size and curriculum overload: Studies also show that instructors find it difficult to include assignments that incorporate such soft skills in their already very content-heavy courses. Additionally, most lectures have an average class size of 100 students, which dramatically reduces how well they learn such skills [14].

However, courses on decision-making and leadership are major modules in management studies which does not overlap with engineering education currently. So, it becomes important to take insights from management studies, a discipline which has decision-making as an integral component.

Decision-making in Management Studies

"Making decisions is like speaking prose- people do it all the time, knowingly or unknowingly" [15] and because of this, even though engineering students might avert it or fear it, having a thorough understanding of the decision-making processes could aid in both deterring and promoting wise judgments.

In management studies, various models are used to teach decision-making including but not limited to the rationality model, incrementalist model, garbage-can model and naturalistic decision-making to name a few [16].

Research design as pedagogy for teaching decision-making

The heart of innovation however is research design. Therefore, we find various studies demonstrate the importance of teaching research design to engineering students [17],[18]. The rationality model is one of the most well-known decision-making models. Therefore, it becomes necessary to look at it in-depth to understand it better. Below are the four components of the rationality model of decision-making:

a. *Intelligence:* when to make a decision
b. *Design:* analysing earlier actions, making possible plans
c. *Choice:* choosing the best possible plan based on merit
d. *Review:* assessing past choices

It is interesting to note that this model is very similar to the four-part structure of 'research design' which, being central to innovation, is already a part of the engineering curriculum. The four-part research design structure is (a) identifying a relevant problem to solve around a theme in a field of interest (b) surveying past solutions to the problem (c) staking a claim and collecting evidence in support and (d) articulating one's argument persuasively and offering a consideration of counterarguments. Thus, we can see that the research design model already implicitly has a teaching on decision-making within its structure.

Therefore, through this paper, we argue that decision-making can be taught to engineering students by using a research design pedagogy. This is possible as the majority of engineering

institutes already have integrated research as a part of the undergraduate engineering curriculum [20],[21]. Therefore, by explicating the decision-making process while teaching research design, we can organically teach decision-making to engineering students.

Through this study, we attempt to test our argument by delivering a course on research design with an emphasis on teaching decision-making as one of the major course outcomes. By analyzing the data from both a survey and class assessments, we hope to gauge both student interest and learning of decision-making skills through this course.

Research Questions:

RQ 1: What is the perceived importance of decision-making for engineering students?

RQ 2: What is the actual student performance in the course "research design and decision-making"?

RQ 3: How effective is research design as a pedagogical tool in making engineering students learn better decision-making?

Methods

Participants

The participants for this study are 78 second-year undergraduate engineering students enrolled in a research communication course at a university in India. The data was de-identified prior to the analysis.

Context

The course covered the foundational skills that are central to a research communication course, these skills are also of critical value for any engineer or technology enthusiast. The Research Communication course had two major components: the discussion component and the lab/ tutorial component. Table 1 represents the description of each module.

Table 1: Course Modules and Description

Module Number	**Module Title**	**Description**
1	Decision-making	In this first module, students will be introduced to the course and the central theme of decision-making. This module will revolve around the goal of helping students understand the critical importance of decisions and what it takes to make them. The premise of this course is that the research process offers an excellent pathway for making decisions on any subject in any area of life. Each student is introduced to critical thinking and communication skills as well as a practical skill-based experiential approach to research and decision-making.

2	Towards Self Knowledge	This module will explore different psychological theories such as Abraham Maslow's Hierarchy of Needs, Julian B. Rotter's Locus of Control, and Carol Dweck's Mindset. Through this module, students will be able to understand their deficiency of needs as well as what they need in their growth towards their higher education, personal growth or to attain the level of self-actualization.
3	Fields of Decision-Making and Research	In this module, the students will be allowed to identify their own research interests, or decision-making arenas which align with their future goals. Some of these could be making decisions regarding: Corporate jobs, Startups and entrepreneurship, public service (Grand Challenges), Higher studies (India or overseas) and Research and/or teaching career etc.
4	Raising a Critical Research Question	Once the field of research and the theme/problem for decision-making have been identified, the important task of raising a viable research question that will give a SMART goal to be pursued for decision-making. The student will learn to do project-based research inquiry. Identifying problems and questions for research.
5	Surveying Past Solutions and Staking a Claim	A good decision-making process takes time to review past solutions that have been provided for the problem one has identified to resolve. There are academic theoretical solutions as well as practical and corporate solutions. At this point, we will not make a distinction between these solutions. The goal is to look for the latest contemporary solutions provided by both the academy as well as the world. Once these have been identified, our aim is to critique both solutions with a view to finding their limitations. It is in this quest that one is able to find out the gap in the literature, which is the real problem – the problem behind the visible problem, that needs to be resolved through the taking of appropriate decisions.
6	Decision-Making as Argumentation	Once a hypothesis has been built, one needs to establish it by finding evidence and proper reasoning. This requires a basic research strategy of data collection and analysis. Data can be qualitative or quantitative. It can come from past data sets or freshly collected. The key is that the data must be relevant and must speak directly to the question raised and the decision that needs to be made. Once there is an alignment between one's hypothesis, which is a claim, and the evidence gathered through data analysis, then one is able to form an argument with sound reasoning. This is precisely where research practice and decision-making come together.

7	Self-Critique and Present Counterarguments	In this final module, the student will be taught to critique one's own argument and present counterarguments. When decisions are made, often the decision-maker feels that his decisions are universally valid and can therefore become either haughty arrogant, or stubborn with one's decision and position. However, the deep insight we want to teach in this course is that all decisions, and even those decisions informed by sound research have their limitations as they are historically situated and will not be relevant to situations and contexts that are different. Therefore, the ability to look at the limitations of one's argument and decision is of utmost value.
8	Writing out your Research Paper	In this module, the students will learn how to write out their newly made decisions or their research findings into a coherent written script which captures the entirety of the argument. This script need not be purely academic, or research writing. One also has the choice to write it up as a journalistic piece or a corporate document.

The Lab/ Tutorial component had two parts: projects and a final exam. The major assignment and output was to write a research script of 1200 words, which could be either an academic research paper or a journalistic piece or even a business proposal. The Lab/ Tutorial component was conducted in six sessions of three hours each over a period of six weeks.

Data Collection and Analysis

The data was collected from two sources: an online survey and class assignment scores. The survey was conducted at the end of the semester. This survey was primarily designed to gauge the learning outcomes and understanding of the decision-making skills of students taking part in the research communication course. The survey had both subjective and objective questions. This evaluation focused on two critical questions: What is the perceived importance of decision-making for engineering students? and how effective is research design as a pedagogical tool in making engineering students learn better decision-making? The class assignment scores also provided data on actual student performance in the course.

The data was analysed using descriptive statistics and thematic analysis. Descriptive statistics were used to understand student perceptions about the importance of decision-making, and in understanding course effectiveness in teaching those skills. Qualitative data was thematically analysed for a more comprehensive understanding of student learning outcomes regarding decision-making skills.

Results

Quantitative data analysis

Perceived importance of the skills

Preliminary descriptive analysis was done to explore student perception of the importance of skills like critical thinking, decision-making and leadership in being an engineer. From table 2 below, we can interpret that all 3 are viewed as extremely important by the students.

As Fig. 1 depicts, a single sample T-test was done for the perceived importance rating of critical thinking skills shows that the students reported a higher rating (M= 4.17, SD= 0.796) than the expected mean rating, t (78) = 18.5, p < .001. A single sample T-test was done for the perceived importance rating of decision-making shows that the students reported a higher rating (M= 3.88, SD= 0.360) than the expected mean rating, t (78) = 34.0, p < .001. A single sample T-test was done for the perceived importance rating of leadership skills for an engineer shows that the students reported a higher rating (M = 3.79, SD= 0.466) than the expected mean rating, t (78) = 24.5, p < .001.

Table 2: Descriptives of student perception on the importance of decision-making, critical thinking and leadership.

One Sample T-Test

		Statistic	df	p	Mean difference
"Importance of Critical Thinking	Student's t	18.5	77.0	< .001	1.67
"Importance of Decision Making Skills	Student's t	34.0	77.0	< .001	1.38
"Importance of leadership skills as an engineer."	Student's t	24.5	77.0	< .001	1.29

Note. H_a $\mu \neq 2.5$

Descriptives

	N	Mean	Median	SD	SE
"Importance of Critical Thinking	78	4.17	4.00	0.796	0.0902
"Importance of Decision Making Skills	78	3.88	4.00	0.360	0.0407
"Importance of leadership skills as an engineer."	78	3.79	4.00	0.466	0.0528

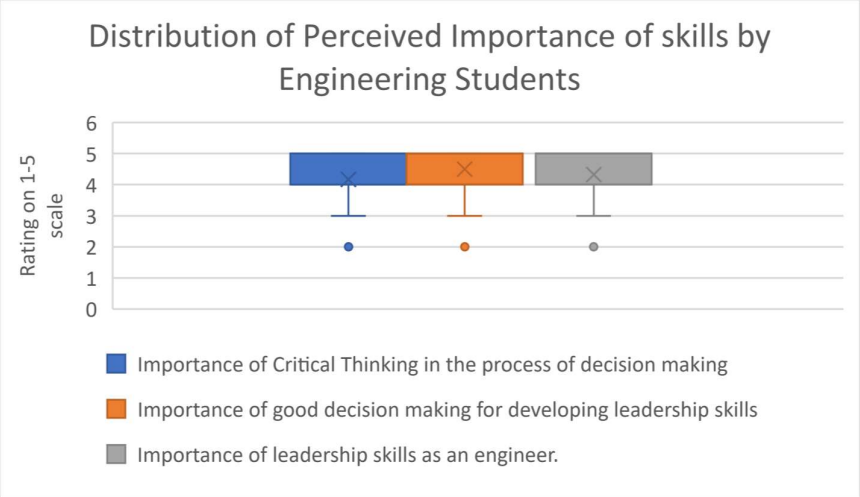

Figure 1: Perceived importance of critical thinking, decision-making and leadership for engineering students

Actual student performance in the course "research design and decision-making"

Preliminary descriptive analysis was done to understand actual student performance in the course. As the table below and Fig. 2 depict, a single sample T-test was done for actual

student performance in the course. The data shows that the students have a higher score (M= 78.8, SD= 7.41) than expected mean score of 70, t (78) = 10.5, p < .001.

Table 3: Descriptives for actual student performance

One Sample T-Test

		Statistic	df	p	Mean difference
Student scores	Student's t	10.5	77.0	< .001	8.85

Note. H_a $\mu \neq 70$

Descriptives

	N	Mean	Median	SD	SE
Student scores	78	78.8	80.4	7.41	0.839

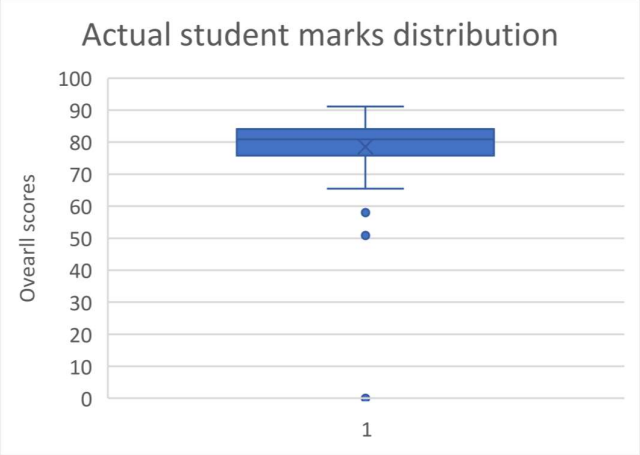

Figure 2: Actual student performance in the course

Course effectiveness in teaching Critical thinking, Decision-making and leadership skills

Preliminary analysis of responses (Figure 3) looked at student response distribution upon the course's effectiveness in delivering its set of goals.

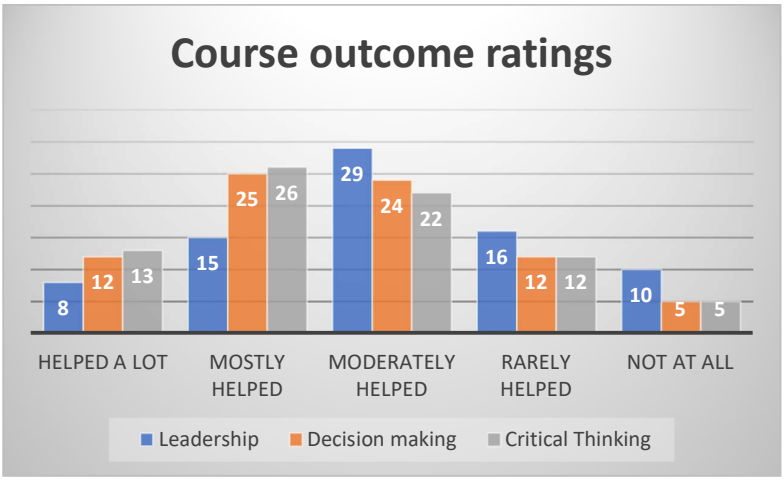

Figure 3: Student perception of course effectiveness in delivering skills of decision-making and leadership.

A descriptive analysis of course effectiveness was done by converting course helpfulness ratings into descriptive form using table 4.

Table 4: Conversion of responses to ratings

Rating given	**Numeric Rating**
Helped a Lot	5
Mostly Helped	4
Moderately helped	3
Rarely helped	2
Not at all	1

Analysis of the course effectiveness ratings (table 5 and figure 3) reveals that the course "Mostly-Moderately helped" students in developing skills like good decision-making and critical thinking. However, the course "rarely-moderately helped" them in developing leadership skills.

A single sample T-test was done for measuring course effectiveness ratings of teaching decision-making skills to the students. The data shows that the students reported a statistically higher rating ($M= 3.35$, $SD= 1.11$) than the expected mean rating, $t(78) = 6.70$, $p < 0.05$. A single sample T-test was done for measuring course effectiveness ratings of teaching critical thinking skills to the students. Data shows that the students reported a statistically higher rating ($M= 3.38$, $SD= 1.13$) than the expected mean rating, $t(78) = 6.91$, $p < 0.05$. A single sample T-test was done for measuring course effectiveness ratings of teaching leadership skills to the students. Data shows that the students reported a lower rating ($M= 2.94$, $SD= 1.15$) than the expected mean rating, $t(78) = -0.490$, $p = .625$.

Table 5: Descriptives for student perception on effectivity of course in delivering decision-making and leadership skills.

One Sample T-Test

		Statistic	df	p	Mean difference
Decision Making	Student's t	2.743	77.0	0.008	0.3462
Critical Thinking	Student's t	3.004	77.0	0.004	0.3846
Leadership	Student's t	−0.490	77.0	0.625	−0.0641

Note. H_a $\mu \neq 3$

Descriptives

	N	Mean	Median	SD	SE
Decision Making	78	3.35	3.00	1.11	0.126
Critical Thinking	78	3.38	3.50	1.13	0.128
Leadership	78	2.94	3.00	1.15	0.131

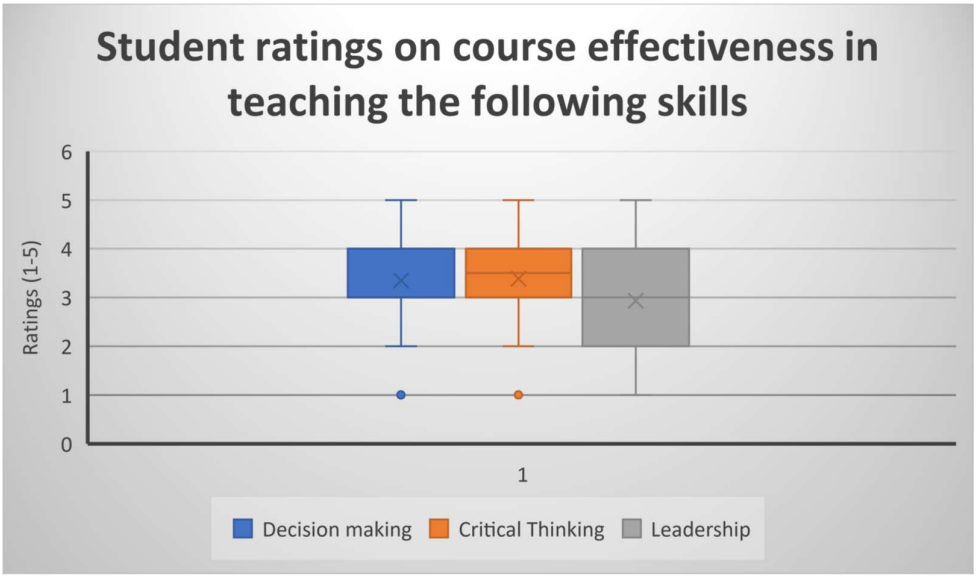

Figure 4: Student perception of the effectiveness of the course in teaching decision-making, critical thinking and leadership.

Qualitative data analysis

To gather a more comprehensive understanding, a thematic analysis of the qualitative data was also done to understand student learning throughout the course. The quotes presented below were not picked up verbatim, rather they were put into categories which had similar responses. Below are the four major questions that we looked at and their responses:

1. ***Point out an insight that you got from this course for problem-solving.***

The majority of students (34 students) highlighted 2 insights: '*Breaking down complex problems into smaller, more manageable parts'* and '*The importance of considering multiple perspectives when approaching a problem'.* While other students also wrote about '*inductive and deductive reasoning'*, and *'collaborative skills.* 6 students also pointed out that they gained no particular insights on problem-solving through this course.

2. ***Describe one aspect of the research process that helped you in learning how to make a decision.***

For this question, the majority of students (31 students) responded with: '*Identifying credible sources', 'knowledge of existing solutions and evidence to support decision-making'*. Other students also highlighted aspects like *'specifying research question'* and *'research paper structure' to be useful aspects.* 8 students also specified that this particular research process did not help them with decision-making.

3. ***How did the research process help you in arriving at a particular decision in the course?***

For this question, the majority of students (27 students) responded with: '*The research process provided me with a thorough understanding of different aspects of a problem, enabling me to make an informed decision in choosing my research problem'*. Other students also highlighted aspects like *'helped in finding form of output', 'challenging my initial assumptions',* and *'reinforcing my assumptions'.* 10 students could not identify the places where the research process helped them in arriving at a decision.

4. ***What was the role of counterargument and self-critique in your decision-making?***

For this question, an overwhelming majority (50 students) mentioned '*being aware of the limitations of one's argument'* as the role of counterargument. Other students also highlighted aspects like *'clarity over one's own argument'* and *'making your writing more persuasive' to be useful aspects.* 5 students also specified that counterarguments and self-critique did not help them in decision-making.

Discussion

Perceived importance of the skills

Quantitative data analysis through a single sample t-test shows that students rated the perceived importance of the skills higher than what the literature predicted [13],[14]. Therefore, the course was successful in creating a perceived importance of skills like critical thinking, decision-making and leadership through the course.

Student performance in the course "Research Design and Decision-making"

A single sample t-test analysis demonstrates that student performances in the course "research design and decision-making" were significantly higher than an expected average grade of 70. This proves the course was successful in terms of teaching both research design as well as decision-making skills.

Course effectiveness in teaching critical thinking, decision-making and leadership skills

Quantitative data analysis using a single-sample t-test reveals that students rated the effectiveness of research pedagogy in teaching the skills significantly higher than expected for Critical thinking and Decision-making.

However, effectiveness of teaching leadership skills was rated below par when compared to expected average ratings. This could be due to the fact that leadership as a skill wasn't mentioned explicitly in the course, due to which students did not make the connection of linking decision-making skills to leadership.

Thematic analysis of qualitative data shows that the majority of students responded to the questions in line with the course material and expectations. Students also raised other aspects of decision-making like 'challenging one's own assumptions' to be insights which were implicit in the course and yet were deciphered by the students successfully. This also indicates that the course was successful in teaching students decision-making process while teaching research design.

The limitation of this study is that it takes participants only from one university which influences the generalizability of the findings of this study. The findings also rely on student self-report for gauging the efficacy of course in teaching decision-making and leadership skills. Additionally, the research design framework used in this study is specific to the university and might change with different universities. Therefore, same study could be applied to different frameworks of research design in the future.

Conclusion

Students' responses and their quantitative and qualitative analysis emphatically demonstrate that incorporating research design as a pedagogical intervention offered rich dividends, particularly in learning about decision-making. It was also evident that the perception of incorporating research design and critical thinking expanded the student's imagination of the significance of such skills in engineering education. However, more research needs to take place on how leadership skills can be developed even as decision-making and critical thinking are taught. There needs to be further inquiry into what counts as leadership amongst engineers, and how these skills can be included through further pedagogical interventions within engineering education.

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