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A Cause-and-Effect Approach to Empowering Engineering Students

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Abstract

This paper explores how engineering students, particularly those in their first year, can utilize self-assessment to identify academic and personal challenges. Using the cause-and-effect diagram (Ishikawa or fishbone diagram) as a problem-solving tool, students are encouraged to reflect on the root causes of their difficulties and develop practical solutions. While the study primarily focuses on first-year students, the results offer insights applicable to a broader student population, demonstrating the tool's versatility in fostering critical thinking and problem-solving skills across different academic contexts.

Keywords

First-Year Engineering Students, Problem-Solving, Cause-and-Effect Diagram, Self-Assessment, Academic Challenges.

Introduction

Engineering students often face unique academic and personal challenges, especially in their first year. As they navigate new environments, demanding coursework, and evolving personal responsibilities, these students benefit from developing self-assessment and problem-solving skills early in their academic journey. Empowering students to identify and address their own challenges can play a significant role in their academic success and personal growth. This study explores how engineering students can utilize the cause-and-effect diagram, commonly known as the fishbone or Ishikawa diagram, supported by the 5-Why method, to analyze and resolve the obstacles they encounter. By employing the 5-Why approach alongside the fishbone diagram, students can explore deeper root causes, enhancing their problem-solving capabilities and fostering more effective solutions.

Originally developed for quality control in manufacturing, the cause-and-effect diagram is a staple of Lean Systems and engineering management practices, which emphasize process improvement, waste reduction, and efficiency. Engineering management tools like Lean, Six Sigma, and Kaizen have shown success beyond industry applications, proving effective for systematic problem-solving in academic settings. Applying these methods to education empowers students to analyze and address issues with the same structured approaches used in businesses and industries. By guiding students through categorizing and visualizing their challenges, these tools encourage critical thinking, enabling students to better understand and resolve academic and personal barriers.

In this study, first-year engineering students are introduced to the cause-and-effect diagram, supplemented by the 5-Why method, as a tool for self-assessment and problem-solving, helping them explore root causes of their struggles and develop actionable solutions. Although this study centers on freshmen, the findings suggest broader applicability, underscoring the potential of Lean and engineering practices to support students in building resilience and problem-solving skills across various academic disciplines. Integrating these methods in academia not only empowers students but also fosters a culture of continuous improvement within educational settings, bridging the gap between industry practices and academic success.

Literature Review

Lean tools like value stream mapping and the A3 process aid continuous improvement in education by visually structuring communication and problem-solving approaches [1]. Adapting these practices from manufacturing is challenging, but Lean's focus on iterative improvement and empowering participants makes it well-suited for tackling educational challenges. Ihsan and Khalifa [2] highlight the critical role of Continuous Quality Improvement (CQI) in engineering education to address the dynamic demands of the job market and technological progress. They discuss CQI's role in refining educational processes through innovation, evidence-based practices, and systematic evaluations. Their paper outlines a model for assessing student learning outcomes and merging CQI with outcomes-based approaches to ensure engineering programs remain relevant and of high quality.

Six Sigma, Lean, Kaizen, and DMAIC are powerful tools for enhancing efficiency and streamlining operations in service sectors like higher education. Six Sigma's main philosophy centers on examining, analyzing, and reducing process variations. By emphasizing variation reduction and leveraging statistical metrics to improve performance, this approach is highly adaptable across different industries [3]. According to Hoerl and Snee [4], Six Sigma is a data-driven methodology focused on improving processes by cutting waste and reducing costs from poor quality, ultimately increasing process effectiveness and overall efficiency.

Lean Six Sigma principles applied in the service sector, including education, are equally relevant to other engineering management practices like 5S and Kaizen. These methods emphasize simplicity and align well with natural human behaviors, prioritizing engagement, commitment, and leadership backing rather than simply accelerating work. When implemented successfully, they enhance organization, efficiency, and workplace atmosphere, fostering teamwork, morale, and job satisfaction through gradual, low-cost improvements [5]. To implement Kaizen successfully in education, it should be integrated with the institution's strategic goals, aiming to deliver value to students by emphasizing simplicity, quality, speed, and cost-effectiveness. Establishing a culture of excellence grounded in Kaizen principles can drive sustained improvement, with strong leadership and an emphasis on reducing resistance to change helping to address previous setbacks in educational reform [6].

Antony et al. [7] demonstrated that management strategies from engineering, particularly those enhancing production efficiency, are adaptable to educational improvement across various levels. In their kindergarten-focused study, they applied Lean and Six Sigma techniques—such as the

5S method, A3 reporting, and the fishbone diagram—to restructure daily operations. This intervention minimized unnecessary movement, transportation, and excess supplies, resulting in a significant saving of prep time. Their work illustrates both the advantages and challenges of integrating these engineering and production management tools within educational environments, as well as the potential for broader application in future educational settings.

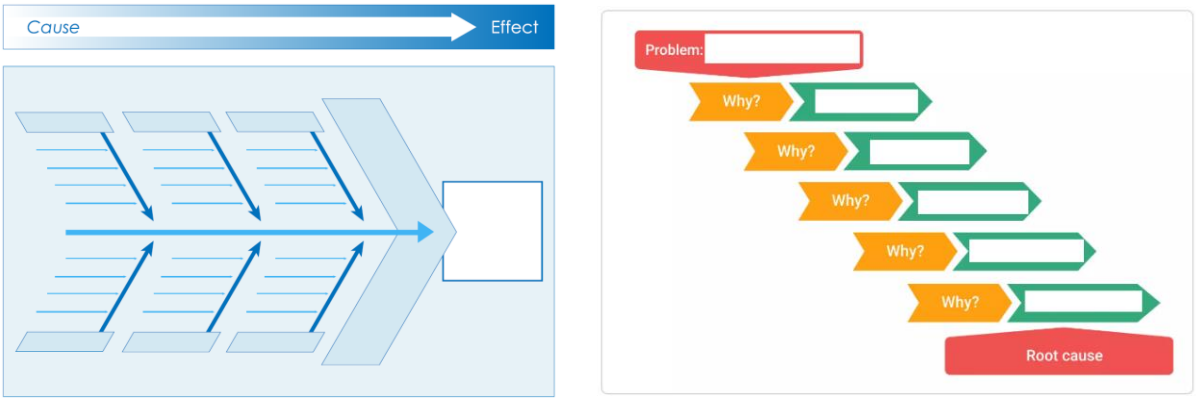
The PDCA (Plan-Do-Check-Act) model has been shown to positively influence various levels of education, including secondary school. It serves as an effective engineering tool for driving continuous improvement, as demonstrated in a study at Northwestern Polytechnical University where it was applied to optimize processes in industrial engineering education [8]. This involved evaluating core and elective courses from the 2013 undergraduate curriculum to identify areas for improvement. Course interdependencies were mapped, feedback was collected from students and industry partners, and the importance of each course was analyzed. Comparing data between the 2013 and 2014 curricula confirmed PDCA's effectiveness in supporting systematic enhancements within educational programs. A study in Malaysia highlights PDCA's potential to enhance STEM education by engaging secondary students in hands-on pre-engineering activities aimed at fostering STEM interest and developing creativity, innovation, and ICT skills [9]. The findings revealed increased STEM awareness, along with noticeable improvements in creativity and ICT skills.

Methodology

This study was conducted in Fall 2024 in ENGR 1210 - Introduction to Engineering, an introductory course that includes students who may be underprepared, uncertain about their engineering specialization, or undeclared their major. The objective was to investigate how first-year engineering students can use Lean Systems and engineering management tools—specifically the cause-and-effect diagram—to identify and address academic and personal challenges. By encouraging students to apply structured, industry-based problem-solving methodologies, the study aims to:

1. Empower students to perform self-assessments that uncover root causes of their difficulties.
2. Enhance students' critical thinking and problem-solving skills through visualizing and categorizing challenges.
3. Demonstrate the adaptability and effectiveness of engineering tools, like the fishbone diagram.
4. Provide insights into how such methodologies can be applied across various academic disciplines to foster a culture of continuous improvement in educational settings.

Students were asked to respond to two prompts: "*Use the cause-and-effect diagram* - Figure 1(a) - *to solve a problem in your life*," and "*Use the 5Whys method to identify the root cause of a daily life problem by completing the chart* - Figure 1(b). *Apply this method to address a challenge you are facing as a freshman student*."



(a) (b)

Figure 1: (a) Cause-and-effect diagram used by students to identify and analyze a personal problem. *Source: Tim's Printables* [10]. (b) 5Whys chart used by students to identify the root cause of a challenge they face as freshman students. *Source: TapRooT* [11].

Results & Observations

In response to the prompt, "*Use the cause-and-effect diagram to solve a problem in your life*", the 17 students in the Fall 2024 ENGR 1210 course identified several main effects, which were categorized into five primary areas, as shown in Figure 2.

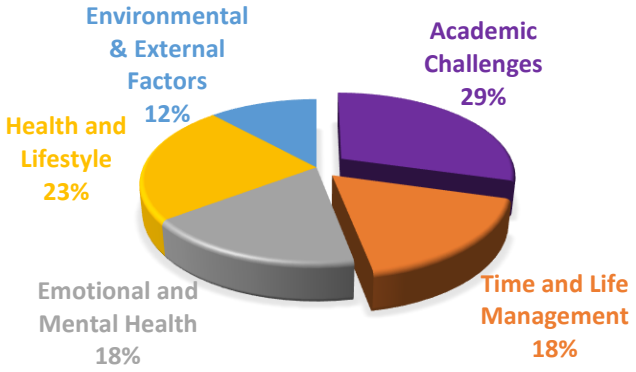


Figure 2: Categories of the effects identified by the 17 surveyed students using the cause-and-effect diagram.

Academic challenges, particularly in math and calculus, were the most prominent issue, affecting 5 (29%) students as summarized in Table 1. While 18% of the students directly reported time and life management as their main problem (effect), a significant 41% indicated that time-related issues, such as procrastination and poor time allocation, were either a direct problem or a major cause contributing to their struggles as freshmen. Additionally, 24% of the students identified sleep issues as either a problem or a major contributing cause. Emotional and mental health issues affected 18% of the students, with reports of feeling unhappy, homesick, or lacking motivation to study. These students expressed challenges such as emotional exhaustion, overthinking, and poor sleep, all of which affected their ability to focus and engage in their studies. The specific causes leading to struggles with math and calculus were linked to insufficient study time, poor sleep, ineffective note-taking strategies, and exhaustion during class

and study sessions. Students frequently mentioned being tired, inefficient use of their available time, and the need for more active engagement during class. For instance, in Calculus 2, students highlighted issues such as poor time management, external distractions (e.g., friends or roommates), procrastination, and neglect of mental and physical health, which compounded their struggles with understanding and retaining homework material.

Regarding time management challenges, students pointed to specific causes such as a lack of planning, absence of a structured routine, failure to prioritize tasks, inefficient use of time, diversion of time to non-essential activities, and underestimating the time required to complete tasks. These issues were frequently intensified by emotional and mental health stresses.

Table 1: Categories, effects, and major causes identified using the cause-and-effect diagram.

Category	Effect	Major Causes
Academic Challenges	Homework not done *(Student # 1)*	Hobbies, Entertainment, School, Work, People, Mind
	Failing Grades *(Student # 6)*	Not Understanding, Bad Test, Not doing HW, No Study, Can't Focus, Late for classes
	Not studying *(Student # 12)*	Social Distractions, Time Management, Personal Organization, Technical Challenges, Environment, Study Resources
	Struggle in Calc 2 *(Student # 13)*	People, Time Management, Study Habit, Health, Schedule, Homework
	Not feeling confident on math test *(Student # 14)*	Study, Sleep, Notes, In class
Time and Life Management	Procrastinating *(Student # 2)*	Tired, Distracted, No Time, Anxiety, Overwhelmed, No Motivation
	Procrastinating Homework *(Student # 5)*	Homework, Business, Time with Friends, Time Management
	Busy a lot *(Student # 7)*	Class, Clubs, Frat, Friends, Sports, Gym
Emotional and Mental Health	Feeling unhappy *(Student # 11)*	No money, No plans, No sleep, Bad grades, Unhealthy, Depressed
	Don't feel like studying *(Student # 16)*	Emotional/Mental State, Coping Mechanism, Mental Load, Physical/Mental Health
	I am homesick *(Student # 17)*	Dorm, Food, Money, Friends, Family, Work
Health and Lifestyle	Poor Sleep *(Student # 4)*	Environment, Stress, School, Liquids/Food, Electronics, Lifestyle
	Tired during day *(Student # 9)*	Phone, Friends, School Work, Gym
	Poor work ethic *(Student # 10)*	Study Habits, Sleep, Procrastination, Gym, Laziness, Environment
	I eat bad food *(Student # 15)*	Feelings, Place, Time, Cost
Environmental/External Factors	Late for work/school *(Student # 3)*	Environment, People, Materials, Method
	No Vehicle *(Student # 8)*	No $, High Insurance, Truck at dealership

The emotional and mental health effects reported by students stemmed from a variety of factors. Feelings of unhappiness were often linked to financial difficulties, lack of plans or structure, poor sleep, unhealthy habits, and overthinking. Academic stress from bad grades, boredom, and unhealthy routines further amplified these emotions. A lack of motivation to study was primarily driven by emotional exhaustion, overthinking, and poor sleep, leaving students feeling disconnected from others and unable to focus. Homesickness was triggered by discomfort in dorm life, missing friends and family, and financial concerns, which were further compounded by the stress of schoolwork and a longing for familiar routines and support systems.

The 5Why methodology was introduced to familiarize students with a common tool used in Lean Systems and to encourage them to brainstorm and analyze their most pressing challenges during their first semester as engineering students. While some students applied the 5Why technique to further investigate problems initially identified through the cause-and-effect diagram, others used it to explore additional issues. This dual approach allowed for deeper reflection, enabling students to identify root causes behind their struggles and think critically about potential solutions.

When using the 5Whys methodology in response to the prompt, "*Use the 5Whys method to identify the root cause of a daily life problem by completing the chart*," students initially identified academic challenges and time and life management as primary effect categories. However, when using the 5Whys method, the proportion of issues related to time and life management rose to 29%, making it equally significant as academic challenges, as illustrated in Figure 3 and Table 2. Notably, the health and lifestyle category was highlighted by only 2 students (about 12%) during the 5Whys exercise, compared to 4 students (approximately 23%) in the cause-and-effect diagram exercise.

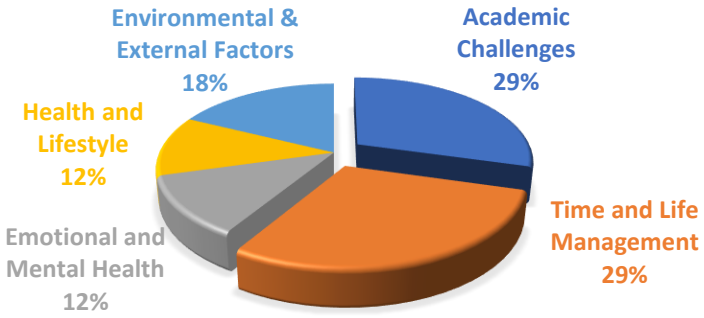


Figure 3: Categories of the effects identified by the 17 surveyed students using the 5Why methodology.

Discussion & Insights

The results reveal several core challenges that first-year engineering students face, including academic, time management, and personal well-being issues. The cause-and-effect diagram and 5Whys methodology provided insights into these problems' root causes and underlying patterns. Academic challenges, notably struggles with math and calculus, were often attributed to insufficient study time, ineffective note-taking, and external distractions. Time management

issues were widespread, with students identifying procrastination, lack of planning, and inefficient time use as key obstacles. These problems frequently overlapped with emotional and mental health concerns, such as stress, homesickness, and lack of motivation, further complicating students' ability to cope with academic demands.

Table 2: Categories, effects, and major causes identified using the 5Why methodology.

Category	Effect	Major Causes
Academic Challenges	Studying Ability *(Student # 1)*	Movies
	Failed Quiz *(Student # 2)*	Not enough rest
	Doing bad on test *(Student # 8)*	Learning how to study so much
	Chemistry is hard *(Student # 17)*	It is a class and a lab
	Poor Grades *(Student # 4)*	Not trying hard enough
Time and Life Management	Turned in work late *(Student # 3)*	Distracted
	Bad Grades *(Student # 5)*	Missing out in past
	I Sleep in *(Student # 7)*	Got back to dorm late
	Getting up early *(Student # 10)*	Poor work ethic
	Overslept Drafting class *(Student # 14)*	I was being lazy
Emotional and Mental Health	Unhappy *(Student # 13)*	Overwhelmed
	Not enough sleep *(Student # 15)*	I need to say no
Health and Lifestyle	Tired during day *(Student # 9)*	Distracted, wanting to have fun, don’t want to miss out
	Can't sleep *(Student # 11)*	I don’t care for myself
Environmental/External Factors	Dirty Shoes *(Student # 6)*	Stayed up playing games
	Truck is not running *(Student # 16)*	Not efficient enough
	Parking ticket *(Student # 12)*	Lots of people

To address these challenges, the university could enhance support through structured study skills training and time management workshops. Greater access to counseling services would aid students in managing emotional and mental health concerns affecting academic performance. A mentorship program for freshmen could provide guidance and foster connections, reducing homesickness and stress. The 5Whys analysis also indicated that health and lifestyle issues, while less frequent, impacted academic experiences, highlighting the need for wellness programs focused on sleep hygiene, stress management, and balancing academics with self-care. Workshops on effective study techniques and structured sessions for difficult subjects like calculus would also be beneficial.

Incorporating Lean Systems tools, such as the cause-and-effect diagram, into the ENGR 1210 course provided first-year engineering students with a structured approach to analyze and address their challenges. By introducing students to these engineering concepts, the study empowered them to not only identify the root causes of academic and personal difficulties but also apply industry-based problem-solving methodologies to other areas of their lives. The fishbone diagram, for example, helped students visualize and categorize their challenges, enhancing their critical thinking and problem-solving skills. The use of Lean Systems tools also demonstrated their adaptability, as students recognized how these methods could be applied across various academic disciplines and environments. This approach highlighted the potential of Lean tools in fostering a culture of continuous improvement, not only within engineering education but in broader contexts, encouraging students to use them for ongoing personal and academic growth.

In conclusion, introducing Lean Systems tools within the ENGR 1210 course proved to be a valuable approach for helping students analyze their challenges systematically. By continuing to implement these problem-solving frameworks, alongside targeted support services, the university can better equip freshmen to succeed academically and personally.

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