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Failure Analysis for Project-Based Learning (PBL) in Engineering

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This paper analyses the failure of project-based learning, to help students analyse their main issue of project failure and develop better solutions. A Return on Failure analysis for Engineering Design courses has been developed in this study. The engineering design courses, which are often included in the first, second, and third years of undergraduate engineering courses at the School of Engineering, provide a distinctive setting for the practice of engineering project-based learning (PBL). The PBL is a commonly utilised method that can be used to accomplish two main educational objectives: confirming the theoretical concepts learned in previous disciplines and developing the professional qualities required for graduates, such as teamwork and good communication. We have incorporated the usage of Return on Failure analysis in project-based learning courses to improve the knowledge of project failure in order to further develop the students' failure analytical skills. Students are required to build the Ping-Pong Robot, a robot that can play ping-pong, as part of their "Engineering Design & Communication" project. It was a really multidisciplinary project because the skills and knowledge required not only robotics but also design, material selection, and engineering mechanics. From the first-year engineering students, more than 85 Return on Failure analyses were gathered. The failure analyses that were gathered were frequently used in undergraduate and graduate courses as surveys, teaching, and learning techniques.

Keywords: Engineering project; Failure analysis; Project-Based Learning; Education reform

I. INTRODUCTION

Failures (Berk, 2009) are frequently a source of highly important knowledge. It is not a matter of if you will experience difficulties or failure, but rather when. It is essential that we view failure as an investment in which we might seek a return if we are to fully profit from the setbacks and errors we experience. Failure and making mistakes are essential components of learning. Accidents, misunderstandings, disobeying rules or directions, or disobeying natural laws can all lead to failures and blunders. When the right response or solution is absent or has not yet been found, failures can also come from trial and error.

Many research publications presenting the analysis of engineering failures and related studies were widely discussed based on the literature reviews in (Clegg, 2009; Kumar, 2023). Articles on the structure, characteristics, and behaviour of engineering materials were included, especially those that go into detail about how materials parameters are applied to issues with engineering structures, components, and designs. The interacting domains of mechanical, manufacturing, aeronautical, civil, chemical, corrosion, and design engineering are also taken into consideration in addition to the field of materials engineering. Engineering failures and research help engineering materials operate over long periods of time and experience fewer failures.

Failure analysis is an important aspect of engineering project-based learning, as it helps students understand the potential causes of failures and how to prevent them in future projects. Here are some steps you can take to conduct a failure analysis for your engineering project:

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i. Define the problem: Clearly define the problem or failure that occurred during the project. This will help you focus your analysis on the specific issue that needs to be addressed.

ii. Gather information: Collect as much information as possible about the project, including design drawings, specifications, test results, and any other relevant data. This information can help you identify potential causes of the failure.

iii. Identify potential causes: Analyse the information you have gathered to identify potential causes of the failure. This can involve looking at factors such as design flaws, material defects, manufacturing errors, or human error.

iv. Evaluate potential causes: Once you have identified potential causes, evaluate each one to determine its likelihood and impact. This can involve conducting tests, simulations, or calculations to determine whether the cause is plausible and what its potential consequences might be.

v. Determine the root cause: Based on your evaluation, determine the most likely root cause of the failure. This may require further testing or analysis to confirm.

vi. Develop corrective actions: Once you have identified the root cause of the failure, develop corrective actions to prevent similar failures from occurring in future projects. This may involve revising design specifications, changing manufacturing processes, or improving quality control measures.

vii. Document findings: Document your failure analysis process and findings, including the root cause and corrective actions taken. This can help inform future projects and provide a reference for other students or professionals who may encounter similar issues.

By following these steps, you can conduct a thorough failure analysis for your engineering project-based learning and use the insights gained to improve future projects.

To assess the effectiveness of various communication techniques and biomedical data, a variety of performance analyses and failure comparisons were proposed in (Wang, 2010; Tung, 2013; Le, 2010). The mechanical characteristics of materials and how they behave when affected by structure, process, and environment are highlighted in (Leong, 2008). It is important to underline how various materials might be used in actual engineering settings. Metallic, polymeric, ceramic, and natural materials are all included. Furthermore, included is the utilisation of a case-study-based methodology. Engineering failures can be avoided in the future thanks to the Engineering Failure Analysis (ESI, 2005; Berk, 2009), which offers crucial reference material and insightful criticism of the design process.

Because students may provide feedback and analyse the causes and effects of the problems, they can further progress in their subsequent endeavours, it is vital that the problem and failure analyses serve as the basis for the learning process. The learning process' direction is likewise determined by this analysis, which emphasises the question's framing over its resolution. Additionally, the analysis enables the learning material to be connected to the context, which improves student engagement and comprehension. The guiding force must be congruent with how the educational process is driven by assessment.

The collected analyses were extensively used as feedback, survey, teaching, and learning methods in undergraduate and postgraduate courses once Return on Failure analysis was incorporated in project-based learning.

II. LITERATURE REVIEW

The formal evaluation procedure is crucial for businesses working on huge projects. Using resources from outside the organisation where the failing project is running will be more effective and efficient. According to (Berk, 2009), the project assessment process is divided into five key stages: defining the assessment charter, creating the assessment plan, carrying out the assessment, analysing the data collected, preparing the findings, and informing stakeholders of the findings.

The assessment must thoroughly look into project variables common to most projects, such as the work breakdown structure (WBS), risks, deliverable defects, resources, timeline, and processes, in addition to concentrating on assessing the project's actual, present status.

The fundamental four-step problem-solving procedure for systems failure analysis has been covered in (Estzer, 2007; Leong, 2014a; Leong, 2019). A clear, mutually agreed-upon problem definition is reached after obtaining all relevant data as part of the failure analysis process. The failure analysis should identify and unbiasedly assess each probable failure factor. The failure analysis team will utilise this to direct them towards the system failure under investigation's root cause. To stop such failures, the failure analysis team must assess and put into place corrective measures for both the failure's established root cause and any additional possible failure-causing factors. To ensure collaboration and objectivity while solving problems, the failure analysis team should comprise experts from engineering, manufacturing, quality control, buying, field service, and other disciplines.

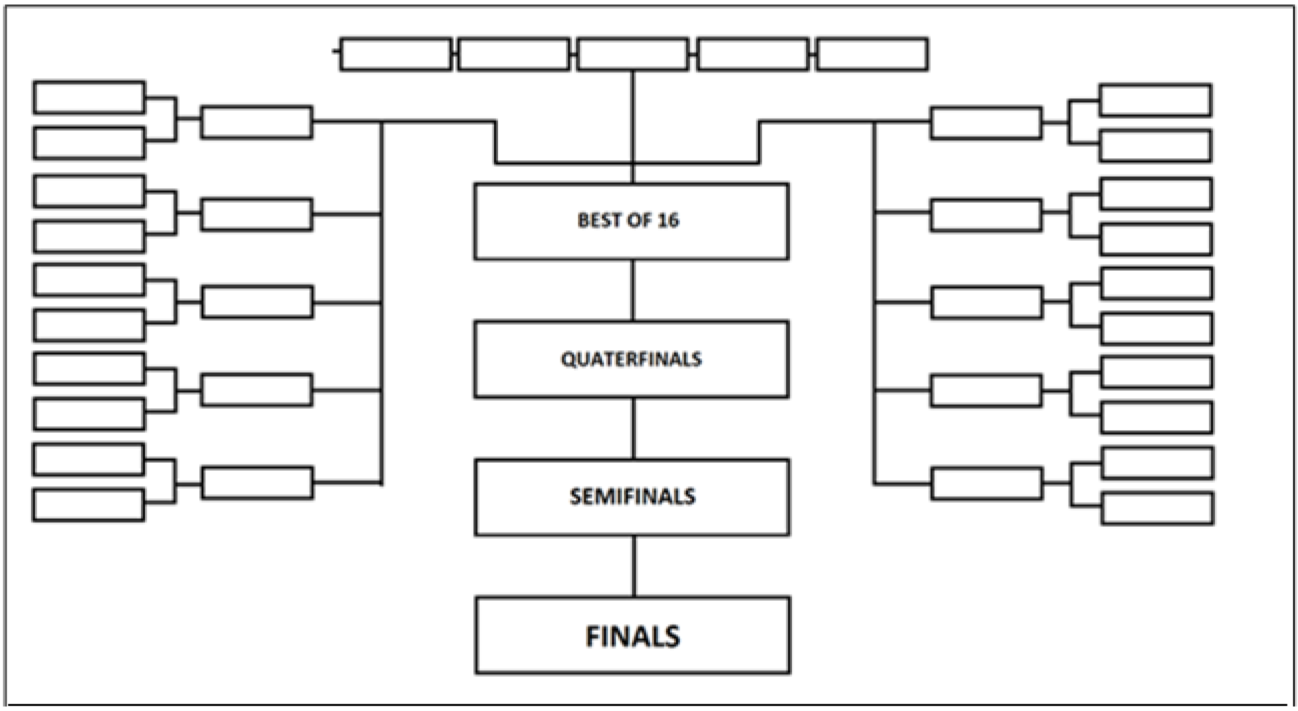


Figure 1. Proposed ladder structure for the competition

It was covered in (Leong, 2005; Han, 2012) how the dominant coalition's information system was used to declare project success. According to the analysis, if the primary users did not use the system as intended, the project's objectives would not have been met. To the top management board, the project committee reported project success. They can track how various stakeholders assigned various meanings to the system introduced over time by using a multi-methodological approach. Using a narrative methodology, the rhetorical devices are examined. To comprehend the various interests impacting the organisational dynamics, they make use of the social construction of technology and the idea of pertinent social groupings. The notions of organisational power and cultural fit between the new system and the various subcultures are used to complement this strategy (Leong, 2022b; Leong, 2023a). They discovered that this various method effectively explains how the acceptance of the new software processes was perceived differently by the software supplier, as well as within the organisation. Notwithstanding its limitations, the case study illustrates how the multiple research approach can be used to socially construct the success or failure of an information system.

III. RETURN ON FAILURE ANALYSIS

Return on Failure (ROF) analysis is a concept used in business management and decision-making processes. It involves evaluating the potential return or benefits that can be gained from taking calculated risks and attempting innovative or unconventional approaches, even if they ultimately result in failure.

ROF analysis involves weighing the potential gains or benefits against the potential costs or losses of a particular endeavour. This analysis can help businesses determine whether it is worth taking the risk of pursuing a particular strategy or innovation, even if there is a significant chance of failure.

ROF analysis can also help businesses learn from past failures and adjust their strategies for future endeavours. By analysing the reasons for failure, businesses can identify areas for improvement and make changes to increase the chances of success in future endeavours.

Overall, ROF analysis encourages businesses to take calculated risks and pursue innovative approaches, while also being mindful of the potential costs and learning from past failures to improve future outcomes (Leong, 2006b; Leong, 2006a).

Table 1. Return on Failure Analysis

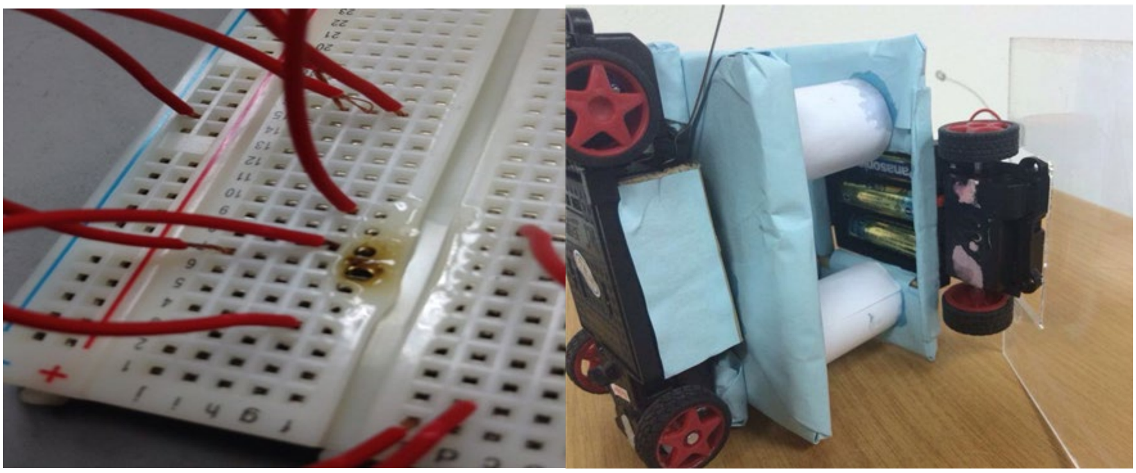
No.	Return on Failure
1.	Explain the error or failure you are analysing, including its physical, technological, relational, or other characteristics. Describe the cutting edge you are investigating as well if the failure was the result of a trial-and-error procedure. Failure may occur while you test a novel procedure or apparatus or as you practise a novel skill. If required, use illustrations, sketches, and diagrams.
2.	Analyse the failure's root cause (ask five why questions beginning with "Why did this failure occur?"). If the response is that the failure happened as a result of "X," ask "Why X happened?" five times. This will reveal the failure's root cause.)
3.	Are there any other possible reasons why you might not have succeeded in achieving your goals? (Here, try to foresee further scenarios in which failure could have occurred.)
4.	Explain how you'll put this knowledge to use to reduce or eliminate failure risk in the future.
5.	What additional important lessons can be drawn from this failure?

The engineering design courses, which are often included in the first, second, and third years of undergraduate engineering courses at the School of Engineering, provide a distinctive setting for the practice of engineering project-based learning (PBL). More than 85 first-year engineering students were assigned the task of building two ping pong robots with dimensions of 15 cm x 15 cm x 15 cm in the "Engineering Design & Communication" curriculum. As these pupils were given a price range to work with, the task grew more difficult.

The main goal of this project was to build a Ping-Pong-playing robot that can be controlled remotely. Students were able to effectively collaborate with one another and have strong collaboration inside the group by doing this. The construction of a robot utilising primarily recycled materials and a budget of less than RM100 was another major goal of this project. In addition, the initiative was designed to assist students in deepening their understanding of the module course they were enrolling in by teaching them how to solve analytical and real-world challenges and foster effective teamwork. Similarly, their primary goal was to win the next Ping-Pong robot competition and establish themselves as champions. They are required to abide by the rules and regulations that have been imposed on the tournament in order to avoid being disqualified. They must use their own knowledge and research when building robots.

Figure 1 depicts the suggested format for the competition, which calls for the division of the 20 teams into two groups of ten each. Each team will play one match against a team chosen at random from the other group. The remaining victorious teams proceed to the next round. The competition then continues in a best-of-16 format with quarterfinals, semifinals, and a final between two teams.

The application of Return on Failure analysis was used in project-based learning courses to improve the knowledge of project failure in order to better develop the students' failure analytical skills. In Table 1, a Return on Failure Analysis for Engineering Design courses has been created to assist students in analysing and improving their failed projects. Each student is required to explain their error or failure and to look into its underlying causes as well as possible solutions.



(a) (b)

Figure 2: Possible root cause of failures: (a) Impropriate use of voltage and connection, (b) Battery overweight

Figure 2(b) illustrates another potential cause of the robots' failure, which is the bat and the higher vehicle may tumble down while playing the game. Figure 2(a) displayed the failure caused by improper usage of voltage and connection. As the movement of the bat is controlled by the rotation of the wheels, the upper vehicle may collapse if they continue to move the bat.

We received over 85 Return on Failure Assessments from 20 different groups. Table 2 showed a quick explanation of one of the Return on Failure Assessments. The student clarified whether the error or failure was due to a technical problem, a relationship issue, or something else. The student also provided information on how to minimise or completely avoid future failures.

Table 2. Summary of the Return on Failure Analysis

Problem	**Root Cause**	**Failure Prediction**	**Lesson Learnt from Failure**	**Solution**
When the returning ball is struck, the ball's speed decrease.	The board strength affects the speed of the returning ball.	The speed of the returning ball might be too fast.	Different type of board used has a different amount of strength.	Use the strongest, hardest,a nd cheapest board available in the market.
The distance the ball travels when it is returned.	The precise angle between the board and the body of the remote control car.	If the angle between the board and the car is approximately below 45 degrees, the ball might fly over the car. While if the angle of the board is more than 45 degrees, the ball might not pass the net.	A different amount of angle affects the distance of the ball's projectile.	An angle between 40 degrees to 70 degrees is the perfect angle to be used.
The short lifespan of the battery.	Different type of batteries with the different brand has different lifespan.	The batteries used might have a short lifespan depending on the brand of the battery used.	Different type of batteries used has a different amount of lifespan.	Buy good quality batteries such as Energizer or Panasonic Evolta batteries.
Both of the remote	The frequency	If the frequency is the	Never buy the same	Use a different car

control cars have the same frequency.	channels are the same on both remote control cars.	same, another remote control car might be affected by one remote control only.	car with the same frequency.	with different frequencies.
The short lifespan of the battery.	Different type of batteries with the different brand has different lifespan.	The batteries used might have a short lifespan depending on the brand of the battery used.	Different type of batteries used has a different amount of lifespan.	Buy good quality batteries such as Energizer or Panasonic Evolta batteries.
Both of the remote control cars have the same frequency.	The frequency channels are the same on both remote control cars.	If the frequency is the same, another remote control car might be affected by one remote control only.	Never buy the same car with the same frequency.	Use a different car with different frequencies.
The speed of the car when the board is attached to it.	The weight of the board installed affects the speed and acceleration of the remote control car.	The speed and acceleration of the car might be reduced after installing the board onto it.	The speed and acceleration of the car will be affected by the weight of the board.	Use a lightweight board.
The blueprint of the car.	Different remote control car has a different quality.	This affects the movements of the car when controlled.	Never ever buy a remote control car even though the price is cheap.	Buy a better-quality car.

Table 3. A summary of the feedback

Failure Analyses		
Technical Mechanism Failure		**Number of Feedback**
Hitting mechanism	Unable to be lifted as expected when there are no buttons pressed. The flipping board is unable to hit the ball.	31
Co-channel Interference	The 2 robots have frequency interference and are unable to control both robots separately.	14
Incorrect Alignment	The robot keeps on moving to the right instead of moving straight. The force distributed towards the ping pong ball will be less and the angle of deflection will not be correct resulting in the ping pong ball possibly go out of the ping pong table making us lose a point	11
Return the ball to the opponent's side	Insufficient force to hit the ball over. The paddle can only turn at 45°. Not enough bouncing force to hit the ping pong ball back to the opposite side of the table.	4
Gear system	When the bat spins, there is a noise produced and sometimes the bat can't even spin. The gear system and motor were either tightened too much together or loosened. Both these factors stopped the bat from spinning.	4
Design/Prototype	The rotating bat doesn't spin well or doesn't spin at all and there were loud, disturbing noises heard.	18
Unable to control	The robot easily slips, not moving and has good manners, and is not effective to return the ping pong ball after hitting the ball. During the testing period, we discovered that the main motor was running inverted. When we made it run forward, instead it would go backward.	21
Communication Failure		
Miscommunication	Miscommunicated with teammates. Members don't listen to ideas. The time chosen is inconvenient for members.	6
Passive members	Some group members don't want to put effort into the project. They gave many excuses to avoid the meeting or building the robot. Don't worry about the project. Lack of participation.	8
Disputes and Arguments	The opinion was rejected and neglected. Conflicts within the members.	6

Rules and Regulations	Misunderstood rules and regulations. Unable to follow and adhere to the rules.	4
	Planning Failure	
Waste of Materials	From the start of the project, planning was not made properly and materials were simply bought without any knowledge. Many materials were wasted when piled up every material that was thought to be useful but there were not. Failure in planning wasted money on unnecessary materials.	5
Time management	Should have a specific plan for myself and my group, I should take a picture and take note of everything I have faced during the project. Therefore, now I realised that with those mistakes. It had barred me from working on my portfolio, getting experience, and having a good project as well.	4
Insufficient Time	Just completed the project before the due date. Lack of time for testing and modifying.	1
	Lack of Knowledge	
Lack of Knowledge	Must spend hours reading and learning all about Electronic Speed Controller on Google and Youtube. How it works, how it sends signals, how much power it needs, how much power will it give out, how it connects, and so on.	4
Tools and Machines	Not familiar with machines and tools at the workshop. We had to go through many times to get used to the machinery tools.	3

IV. RESULTS AND FAILURE ANALYSES

All 85 Return on Failure Analyses were received, and after investigation, they were divided into four categories (Table 3): technical mechanism failure, communication failure, planning failure, and lack of knowledge.

The majority of the comments were in response to technical system failure. Most of the striking devices couldn't be lifted, and they couldn't hit the ball to the other site. The teams also struggle with robot control. After hitting the ping pong ball, the robot was unable to return it. Co-channel interference has created a lot of issues and failed to operate the robots individually because the majority of robots use remote controls to generate movement.

According to additional Return on Failure Analyses compiled and displayed in Table 5, the primary failure experienced in this project was a technical failure. The motor-connected flipping paddle could not flip with great accuracy (See Figure 3). The 200g flipping paddle had dimensions of 10x12x12cm and was composed of aluminium. The wheels that were attached to an external engine were stuck to the end of the paddle. Directly taken from a used toy vehicle and inserted in the robot is the portion of the exterior motor and wheel. When the external motor started, the paddle attached to the wheel began to rotate very slowly. When the paddle had rotated 70 degrees from its starting point, it ceased to turn. According to Table 4, the majority of the students illustrated the mechanical failures with drawings, sketches, and diagrams.

V. POTENTIAL AND CHALLENGES OF RETURN ON FAILURE ANALYSIS

"Return on Failure Analysis" in the context of engineering project-based learning refers to the practice of extracting valuable insights and knowledge from failures encountered during the course of a project. This approach recognises that failures are inevitable in complex engineering projects, and rather than viewing them purely as setbacks, they can be analysed to yield important lessons for future success.

Table 4. A summary of the diagrams used in the failure description

Failure Description with Pictures, Sketches, and Diagrams	
Technical Mechanism Failure	24
Communication Failure	0
Planning Failure	0
Lack of Knowledge	1

Here are some potential benefits and challenges associated with Return on Failure Analysis in engineering project-based learning:

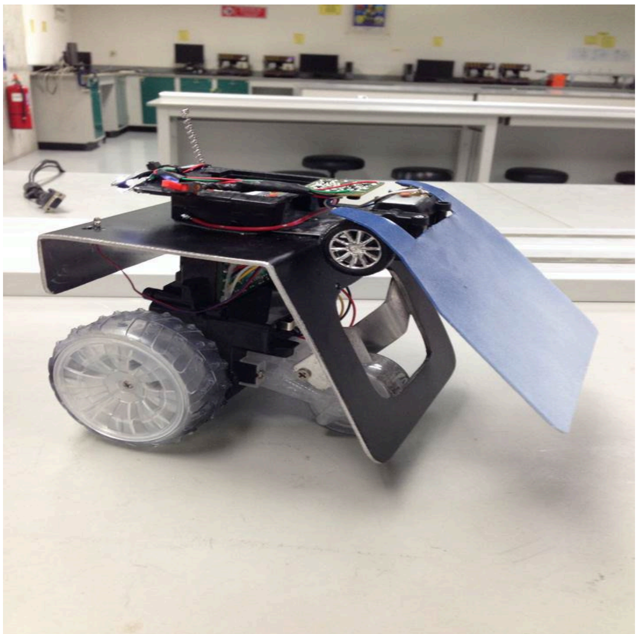


Figure 3. Failure brought on by a paddle flip

Potential:

i. Learning from Mistakes:

Embracing failure as a part of the learning process allows students to understand the real-world challenges and complexities of engineering projects.

Students can learn from their mistakes and develop problem-solving skills that are essential in professional engineering practice (Leong, 2012; Leong, 2005; Leong, 2014b; Leong, 2023b).

ii. Iterative Improvement:

Failure analysis promotes an iterative approach to problem-solving. Students can refine their designs and strategies based on the lessons learned from failures, leading to continuous improvement.

iii. Critical Thinking and Reflection:

Encourages students to critically reflect on their decisions, methodologies, and assumptions, fostering a deeper understanding of the engineering principles involved in the project (Mohankumar, 2017; Mohankumar, 2017).

iv. Preparation for Professional Challenges:

Experiencing failure in a controlled learning environment prepares students for the challenges they may encounter in their professional careers, where failure can have real-world consequences (Tee, 2018; Wang, 2009; Xu, 2023).

v. Team Building:

Collaborative failure analysis can strengthen team dynamics. When students collectively analyse failures, they develop communication skills and learn to work together to find solutions.

vi. Risk Management Skills:

Helps students develop skills in risk identification, assessment, and mitigation, which are crucial in engineering project management.

Challenges:

i. Fear of Failure:

Students may be hesitant to take risks and innovate if there is a fear of failure. Creating a supportive learning environment where failure is seen as a natural part of the learning process is crucial.

ii. Time Constraints:

Project timelines may be tight, making it challenging to allocate time for in-depth failure analysis. Balancing the need for timely project completion with the desire to thoroughly analyse failures is a constant challenge.

iii. Resource Limitations:

Lack of resources, whether in terms of materials, equipment, or expertise, can hinder the ability to conduct comprehensive failure analyses.

iv. Balancing Curriculum:

Integrating failure analysis into the curriculum without sacrificing coverage of essential content can be challenging. Striking a balance between theoretical knowledge and practical experience is key.

v. Subjectivity in Analysis:

The interpretation of failures can be subjective, and different individuals or teams may draw different conclusions. It's important to guide students in conducting objective and evidence-based analyses.

vi. Documentation and Communication:

Properly documenting failures and communicating the lessons learned can be overlooked. Developing effective communication skills is essential to share insights with peers and future project teams.

In summary, while Return on Failure Analysis has the potential to enhance engineering project-based learning, addressing the associated challenges is crucial to maximize its benefits (Mohankumar, 2016a). Creating a culture that embraces failure as a stepping stone to success and providing the necessary support and resources can contribute to a more effective learning experience.

Table 5. Summary of the failure's description and group members' identification

Failure Description and Identification within the Group members								
				Failure Identification				
	Group Name	**Number of Members**	**Technical**	**Communication**	**Planning**	**Lack of Knowledge**	**Total**
1	4CE1EE	5	5	0	2	0	7
2	Alliance	3	3	0	0	0	3
3	Big Bang Theory	5	5	0	0	0	5
4	Black Box	5	4	1	0	1	6
5	BLENKO	6	5	3	1	0	9
6	Cereal Killers	4	5	1	0	0	6
7	Dealer	4	4	0	0	0	4
8	Designer	5	5	1	1	0	7
9	Ebot	5	5	2	0	0	7
10	ES1	5	4	1	1	1	7
11	Eternity	3	6	0	0	0	6
12	Girl Day	5	7	0	0	0	7
13	Just Build It	5	5	0	4	1	10
14	LOKI	3	9	0	0	0	9
15	Marcus and Friends	5	9	1	1	0	11
16	Matrix	5	4	1	0	1	6

17	MAXIM	3	5	0	0	0	5
18	Newbieee	3	2	2	0	0	4
19	Pompeii	6	11	10	0	3	34
20	Prime	5	5	2	1	3	11
	Total	85	108	25	11	10	154

VI. CONCLUSIONS

According to the Return on Failure Analysis, the majority of students have paid close attention to what and how failure happens and have learned from numerous events and their outcomes to find themselves striving for success. Failure is best characterised by the mindset of the students, who set out with great ambition and then give up so readily when they receive results that are insignificant or nonexistent in relation to their objectives.

This is the demotivation they experience when their attempts to succeed fail (Leong, 2022a; Mehrotra, 2009; Mohankumar, 2016b). The majority of them would try to err on the side of success rather than failure, and if they failed to do so, they became satisfied with their failures and, instead of striving with the ambition they once had, they would just give up on the idea of achieving something great because their mentality spoke that it might never happen the way they want it to, which causes them to perform the assessment mediocrely rather than working on it with full force. They had numerous ideas for their ping pong robot from the beginning, but as each one failed, all they wanted to do was get something working so that they had something to show off. This was their main failure because they lost all motivation to complete anything that might have been better or more significant because of their discouragement towards themselves as a result of failing.

According to our views, there are a variety of ways they could have fallen short of their goals, but failing to plan would have been the greatest and most important one. Failure to plan will eventually cause their fellow group members to become frustrated and dissatisfied because everything will be in a state of chaos. By failing to plan, they leave themselves open to unanticipated events, such as purchasing a DC motor for the toy car's foundation that is incompatible with any other parts of the toy vehicle. This takes a lot of time and money to complete, which will not just cause discontent. The degree to which they cooperate with one another also has a significant impact on whether they succeed in achieving their goals.

The only way to build trust between one another and create a productive workload that is evenly distributed among all members of the team is to collaborate and develop ideas as a team (Leong, 2020). Assigning roles to one another and completing the task at hand will significantly minimise the workload and strengthen the link between group members, who will eventually become friends. Without cooperation, problems would remain unsolved as each party would place the blame on the other rather than work to resolve them. If an internal disagreement between team members is not resolved, all initiatives will ultimately fail. In other words, how good your ideas are is less important than how you connect with those around you and persuade them that the project will succeed by receiving the necessary collaboration.

As was mentioned above, failure is related to a variety of issues, and there are methods that may be taken to mitigate or completely eliminate this risk. First and foremost, we need to alter the way we think. Rather than adopting the mentality of (SUCCESS⇔ME⇔Failure), we should adopt the mentality of (ME ⇒ FAILURE ⇒ SUCCESS), whereby failure is embraced and seen as a necessary step on the path to success. According to the proverb, failure is the means of transportation, and success is the goal. Today, failure is not only necessary for success but also a possibility that each and every one of us must accept. Failure should not discourage us; rather, we should rejoice in it since it moves us one step closer to success. As each thought was exhausted, if we were to shift our perspective and accept failure, the result would be different and unquestionably better since we would be motivated and aim for excellence.

The main lesson from this result, according to the Return on Failure Analysis, is that no one truly has any real influence over what you do. The effort to strive for excellence must come from inside; simply doing tasks for their own sake won't get you very far. Giving all that you have to your ambitions in order to feel good about yourself. Last but not least, they need to remember that failure is not their enemy but rather their teacher.

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