USING AN INTEGRATED PROJECT MANAGEMENT APPROACH TO DESIGN GRADUATE PROJECTS AS AN ENGINEERING PRODUCT

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ABSTRACT
The main goal of a master's or PhD student is to obtain their graduate degree, which is dependent on the successful progress of the research. In the context of biotechnology, the design of graduate projects can be conceptualised as an engineering product. The present work explores the design of project management frameworks for the execution of graduate research projects, emphasising their potential to enhance productivity and innovation. Effective project design in graduate studies requires a systematic approach that mirrors engineering principles. Students are encouraged to formulate their research questions and objectives clearly, akin to defining product specifications in engineering. Using a project management framework that integrates soft systems and agile methodologies, can significantly streamline the research process, unfortunately most if not all graduate students in Tecnologico de Monterrey Campus Queretaro don't utilise them during their research project. Employing this integrated tool can help structure pathways toward achieving successful research outcomes and enhance their research effectiveness and contribute meaningfully to advancements in biotechnology.

Keywords: Graduate studies, project management, research, higher education

1 INTRODUCTION
At Tecnologico de Monterrey, the achievement of a scientific graduate degree hinges on the successful completion of a research project and publication of minimum one or two original research papers, depending on the programme. A successful dissertation project needs a structured development plan to produce or contribute to the improvement of science, and similar to an engineering product a graduate project must also demonstrate feasibility and replicability through validation or experimentation. Then, a thesis project may be viewed as an engineering product that all graduate students need to create. By changing the perspective, we must realise that a thesis project needs structural design and execution that can be done through different frameworks and methodologies.
Soft systems methodologies (SSM), also termed as problem structuring methods, aims to provide a way to represent a situation by clarifying the predicaments, identifying mutual issues, and declaring the agreements between parties [1]; it is a systemic method focus on the "whole" which allow the user to understand different perspective on the problem [2]. This method has been applied in both the industrial and academical sector [3-7], nevertheless, none of the graduate students had used SSM in during their dissertation project. Agile methodology's main objective is to create an iterative and adaptive process where the solutions for complex problems come from effective and efficient collaboration between the involved parties [8]. In contrast to SSM, the implementation in agile methodologies in graduate research projects has been previously reported [9-11].
This paper explores the development of integrating these two methodologies into a framework, evolving it into a project management approach that will provide structure and tools for the development of a research project for graduate students. To achieve this, we use a "Lego block" analogy to illustrate the interconnectedness of research activities.

2 METHODS

2.1 Survey: Insight into graduate student's thesis projects

A survey was shared to graduate students of the Biotechnology and Engineering Sciences programmes at Tecnologico de Monterrey, Campus Queretaro (n=13), to gain insights into the main problems or challenges the students have faced and assess and compare their experiences and their familiarity with project management tools. Moreover, the survey also served as a way to verify if both programmes have had students face the same challenges, since Engineering Science graduate students should have some project management knowledge. The survey included questions on common challenges, problem definition and project management tools usage.

A random Biotechnology graduate student was selected for a post-survey interview where we shared the framework and asked how it could impact their research project and made an in-depth analysis of how the framework could be applied to their thesis project.

2.2 The construction of the framework: A Lego block analogy

With the answers of the surveys, we analyse the main problems that graduate students face during their research project and develop the framework using a "Lego block" analogy for a better understanding. Soft systems and agile methodologies were contemplated to create a robust project management framework that can be used as a basis for research projects development. The construction was made during several teamwork sessions, and several drafts were made before the final one that is currently being presented.

2.3 Evaluation of the framework impact in projects

The designed framework was explained to one (n=25; designated as "With LF") of two groups of students, to the other group traditional methods were explained (n=25; designated as "Traditional F"), both groups are coursing Designing a Smart Organisation with the course code IN3001B. To group #1 the Lego block-based framework was explained, while group #2 only traditional methods were presented. Both groups were subjected to an exam after the traditional or Lego block approach presentation and a critical project delivery. The students' project was to create a layout of a production line in both groups, and the task was to establish the layout of the production line. Each student answered 20 questions from an exam database; the questions tested the students on the project management and the quality of the delivery, which was reflected in the exam on the student's capability to retain basic project management, soft systems, and agile methodologies concepts that the students needed to apply for their task. A descriptive statistical analysis and a t-Test of Two-Sample Assuming Unequal Variances was performed to understand the significance the framework had in the student's projects.

3 RESULTS

3.1 Insight survey of graduate students

The survey was answered in almost 1:1 proportion of Biotechnology (n= 6) and Engineering Sciences (n= 7) graduate students. Moreover, its results revealed three key challenges that are faced by both graduate programme students:

- Time Management
- Access to Resources (Funding, materials, and equipment)
- Administrative Delays

The survey also indicated a familiarity of project management tools (n=10) in students of both programmes, with a special focus on Gantt Charts (n=7); however, few actively used them in their research (n=9). A major difference between the answers of both programmes is usage of soft systems and agile methodologies during their research, globally 53.85% of respondents (n= 7) responded that they didn't use either methodology, four of the students responded that they indeed use the methodologies belong to Engineering Sciences programme (30.77%) while only one was from the Biotechnology programme (7.69%).

3.2 Designing the framework: A Lego Block Analogy

The proposed framework is based on a Lego block analogy (Figure 1), it helps visualise the interconnectedness of critical activities for the project. It has a three-axis structure, where time is the length, costs are the width, and the resources are the height of the blocks. Each block represents an activity that can also be considered a process that is affected by the parties involved in and the

connectors. In a traditional framework, the connections between the activities are represented with arrows, in the proposed framework the connections are the green blocks that represent the flow of information.

Moreover, by using a Lego analogy, this process can be transformed into or "built" for the specific needs of each graduate student, where more types of pieces can be used; for example, a flexible tube that connects two blocks in different stages may represent the interconnection between those activities. Thus, makes the proposed framework into a flexible modular project management tool.

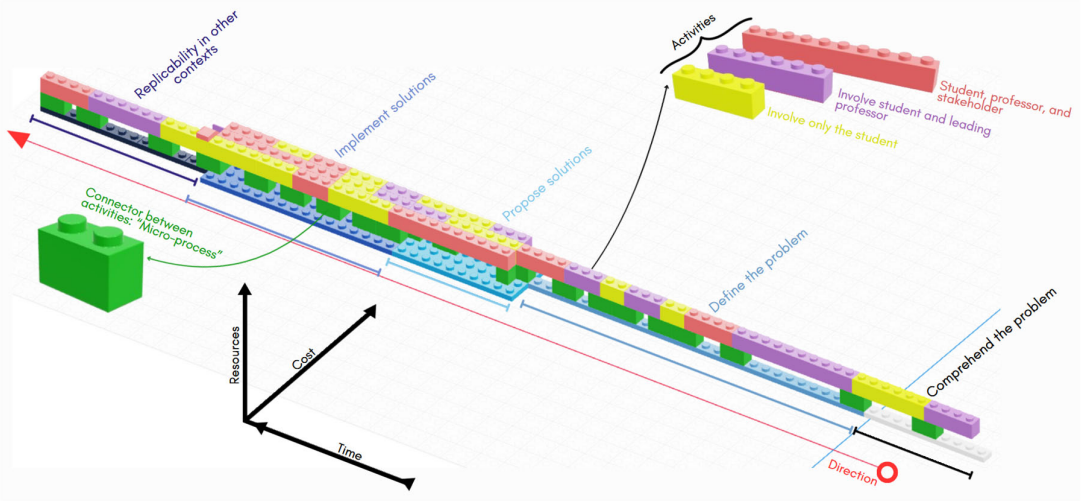

Figure 1. Lego block analogy framework

3.2.1 Core Components and Structure

The framework envisions a project, specifically a graduate thesis, as a series of interconnected stages that could be defined within the 5 steps of the life of a project, which are represented by the slim plate bricks of different shade of blue and white:

1. Comprehend the problem: Understanding the project scope and limitations, particularly crucial for defining the boundaries of a graduate thesis.
2. Define the problem: Articulate the research question or problem statement that the thesis addresses. This stage often presents challenges for students.
3. Propose solutions: Developing the experimental methodology.
4. Implement solutions: Executing the proposed experimental methodology. This stage is often subject to unforeseen issues, such as technical difficulties or administrative delays.
5. Replicability in other contexts: The research methodology must be designed for reproducibility and is shared when it is published so that it can be studied in other contexts.

A specific colour is assigned to each stage, to represent the life of a project steps, and consists of specific activities-turned-processes that are interconnected through connectors which are then turned into micro-processes. A colour is also assigned (yellow, purple, and salmon-pink) to represent the direct responsibilities of the graduate student and other people involved. The connectors, which are the green blocks, are micro-processes that seek to have clear documentation of agreements, discussed topics notes, and the assigned tasks, all specified in meeting minutes and experimental logbook annotations. In a traditional framework it is often visualised as a Maltese cross diagram or a CATWOE, which outlines required inputs, expected outputs, responsible parties, and processes or transformation needed for each activity. To accomplish a good flow-project, our framework also recommends doing a risk assessment, which is done through a traffic light risk assessment, that should often be discussed during meetings and documented in its minutes, where the green or yellow are "GOOD TO GO", while red is "STOP, RE-ANALYSE/DO".

When analysing the framework as a whole (Figure 2), it was identified that this core process must be further influenced by the cultivation of specific thinking styles—prospective, systematic, concurrent, and resilient—to foster a researcher mindset in the graduate student and for them to develop good emotional and social intelligence. Another relation to consider is the collaboration and support of the Thesis Director, their guidance and input should represent a layer of support and expertise for the

graduate student. Nevertheless, there will always be external factors beyond the student's control, such as university or research center policies, available resources, and funding secured by the thesis director that affect the project.

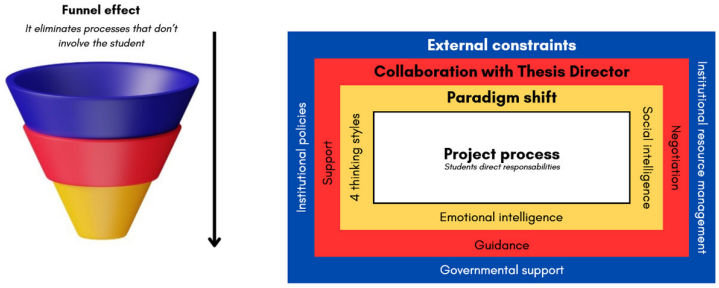

Figure 2. Rich picture of Lego block analogy framework

3.3 post-survey interview: Presenting the framework

The "Lego block" framework, when presented to a subset of students (n=1), was well-received as a means to clearly visualise the research process. The interview highlighted the critical gaps that students have in project planning, responsibility clarity, communication, and early-stage knowledge acquisition; this confirms the challenges mentioned in the survey and adds a few more. Moreover, the human factors—such as advisor-student dynamics— were mentioned that can significantly impact a research project. The interviewee acknowledged that a structured planning framework, such as the Lego block analogy framework, would have helped their project by first visualising the long-term planning and preventing major issues caused by a lack of planning, misunderstandings and miscommunications.

3.4 Evaluation of the framework impact in projects

The research protocol for the evaluation of the impact of the framework was based on the comparison of the exam results between the groups. According to the descriptive statistics analysis (Figure 3), we can see that the framework gave a plus to the student where the Lego block approach was presented, as the mean of grades in the group “With LF” was 93, while the average grade of group “Traditional F” was 86. When considering that a poor grade is less than 80, in Figure 3 both histograms clearly show a difference between the students that understood the corresponding approach, both Lego block-based framework and traditional method, and students that didn’t; having a higher frequency of students that had a difficulty in the exam in the group “Traditional F”.

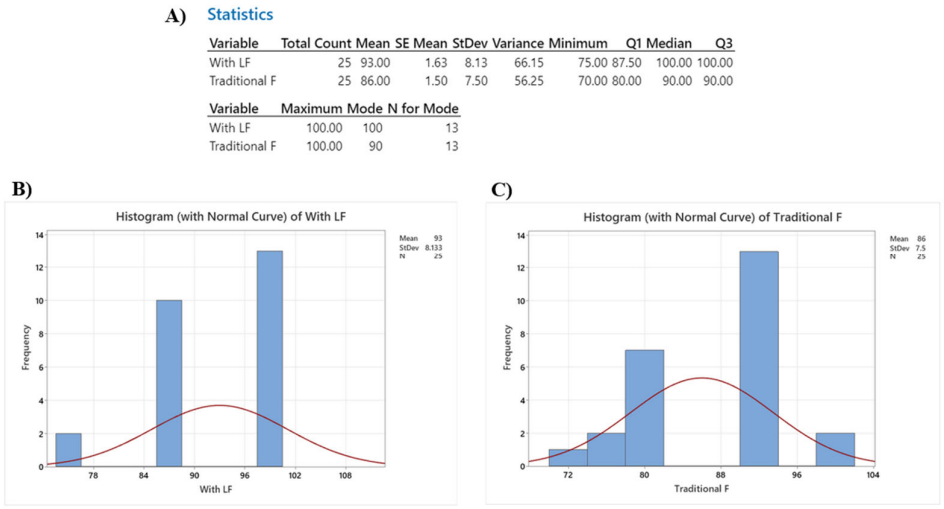

Figure 3. Descriptive statistical analysis results of the impact the Lego block framework had on students; A) Descriptive analysis, B) Histogram with normal curve of group “With LF”, and C) Histogram with normal curve of group “Traditional F”

For the t-Test of Two-Sample Assuming Unequal Variances, the null hypothesis was defined as there wasn't a significant difference when using the framework, while the alternative was that there is a significant difference. The variable was measured through the exam the students presented (Figure 4). The t-Test provides strong statistical evidence that the framework improves exam scores significantly as the p-value is lower than $\alpha = 0.05$ we can reject the null hypothesis, moreover the t-value indicates that the observed mean difference is 3.47 standard errors, which is higher than the critical t-value, which is 2.0, showing that the implementation of the framework is statistically significant.

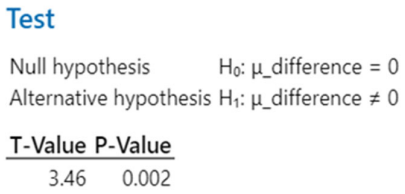

Figure 4. t-Test of Two-Sample Assuming Unequal variance results, showing T-value and P-value

4 DISCUSSIONS

The integration of project management frameworks offers a promising solution to the challenges identified in our survey and interviews. Specifically, the "Lego block" analogy provides a tangible and intuitive way to grasp the interconnectedness of research activities, underscoring the value of a structured approach. This framework leverages Agile principles—iterative development, adaptability, and continuous improvement—through the division of a thesis into manageable stages, customisable "Lego block" components, and proactive risk assessment indicators. While existing literature supports the use of Agile methodologies in dissertation projects, our framework expands upon these concepts by combining them with SSM. This integrated project management framework provides a structured, yet flexible, approach, differentiating itself from studies that explore the application of Agile or SSM individually. By combining these methodologies, the framework aims to not only enhance research productivity but also cultivate critical thinking skills essential for success in the dynamic field of research; it seeks to foster a deeper understanding of the inherent complexities and diverse perspectives within the research process, particularly during the project's initial stages. This approach expects the students to have the change in thinking—incorporating prospective, systemic, concurrent, and resilient thinking, alongside emotional and social intelligence—to achieve effective research management. Moreover, healthy, and efficient communication between the student and thesis advisor, is essential to the project and to create the final product: a research thesis.

5 CONCLUSIONS

This study highlights the potential benefits of integrating project management frameworks into graduate research, especially in biotechnology as most students don't have a project management background. The "Lego block" analogy provides a useful tool for visualising and managing the research process, presenting a novel perspective on project management that can be applicable to both academic (research theses) and industrial contexts. It moves away from concentric circles models towards a modular and flexible approach. By using this approach, the thesis process is broken down into steps that allow constant revision and improvement, taking into account every aspect of the project. It aims to enhance graduate students' research effectiveness, which in return will contribute more meaningfully to advancements in biotechnology. Once integrated in the graduate programme at Tecnologico de Monterrey it is needed to evaluate the long-term impact of this integrated approach on the research product (complete thesis project ~4-5 years); specifically, studies should explore the effectiveness of the modular "Lego block" analogy that can be transformed to meet the needs each graduate students and evaluate the fostering "researcher" mindset (shift of paradigm) among graduate students.

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