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A Design Thinking-Informed Framework in Early STEM Education: An Exploratory Study of Cognitive Workload in Project-Based Problem Formulation

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Abstract

This study examines the implementation of a design thinking-informed framework in early-stage STEM education, focusing on students perceived cognitive workload during project formulation. The proposed framework integrates elements from design thinking and project structuring tools to support early-stage project-based learning. An exploratory case study was conducted with 99 undergraduate students from engineering and management programs. The NASA Task Load Index (NASA-TLX) was used to assess perceived cognitive workload across six dimensions following a structured instructional session. Results indicate that the activity was experienced within a moderate range of cognitive workload, suggesting that the framework can be implemented without introducing excessive cognitive demand. Correlation analysis revealed significant associations among workload dimensions, particularly between temporal demand, mental demand, and frustration. These findings provide initial evidence regarding the feasibility of implementing structured design thinking-informed approaches in early-cycle STEM education. The study provides empirical evidence on perceived cognitive workload during the implementation of a structured framework in early-stage project-based learning.

Keywords: design thinking; cognitive workload; NASA-TLX; project-based learning; STEM education; project formulation

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1. Introduction

In early-stage STEM education, students are frequently required to engage in project-based learning activities that involve open-ended and ill-defined problems. These contexts demand not only technical reasoning but also the ability to structure ideas, define problems, and organize project elements in a coherent manner. However, novice learners often lack the experience needed to navigate these processes effectively, which can result in increased cognitive demand during early project formulation.

Design thinking has been widely adopted in engineering and management education as an approach to support problem framing, ideation, and user-centered solution development (Brown, 2008; Razzouk & Shute, 2012). In educational contexts, design thinking-informed tools are typically used to guide students through stages such as problem definition, idea generation, and concept development. For example, students may begin by identifying a problem grounded in their immediate context and then structure potential solutions by outlining key elements such as users, resources, and constraints.

While these approaches provide structured guidance, the extent to which they influence students' perceived cognitive workload during early-stage project formulation remains underexplored. This is particularly relevant in early-cycle STEM education, where excessive cognitive demand may hinder students' ability to engage effectively with complex tasks. To address this gap, this study examines the implementation of a design thinking-informed framework intended to support early-stage project formulation. The framework integrates elements related to problem definition, resource identification, and project structuring into a unified template designed for use in project-based learning contexts. The study is guided by the following research question: *How do students perceive cognitive workload during the implementation of a design thinking-informed framework for early-stage project formulation in STEM education?* An exploratory case study was conducted with undergraduate students from engineering and management-related programs. The study focuses on assessing perceived cognitive workload during the implementation of the framework using the NASA Task Load Index (NASA-TLX).

This study focuses on perceived cognitive workload as an observable dimension of student experience during early-stage project formulation. In this way, it contributes to the literature by examining workload as a complementary perspective to outcome-based approaches in project-based STEM education, while also providing initial evidence on the feasibility of implementing structured, design thinking-informed frameworks without introducing excessive cognitive demand.

2. Theoretical Background

2.1. User Experience and Task Engagement

Understanding how students experience structured tasks requires considering how different modes of engagement influence cognitive demand. Reversal Theory proposes that individuals alternate between distinct meta-motivational states, such as goal-oriented (telic) and activity-oriented (paratelic) modes (Apter, 1989). While these states are not directly measured in this study, they provide a useful conceptual lens for understanding how students may approach project-based tasks.

In goal-oriented modes, individuals tend to focus on achieving specific outcomes, favoring structured activities that support task completion. In contrast, activity-oriented modes are associated with exploration and intrinsic engagement, where the process itself becomes central. In educational contexts, students often shift between these modes when engaging with open-ended tasks such as project formulation.

Building on this perspective, Hassenzahl (2003) introduces the concept of usage modes in user experience research, distinguishing between goal mode (task-oriented interaction) and action mode (exploratory interaction). Previous studies have shown that these modes can influence perceived workload. For instance, the presence of structured goals may increase mental effort in some contexts, while in others it may reduce uncertainty and support task execution (Hassenzahl & Ullrich, 2007; Wechsung et al., 2010). In the context of early-stage project formulation, students are required to balance exploratory idea generation with structured problem definition. This tension may influence how cognitive workload is experienced. For example, structured frameworks may reduce ambiguity by guiding students through predefined stages, while simultaneously introducing demands related to organizing and integrating multiple elements of a project.

From this perspective, variations in perceived mental demand, effort, and frustration can be interpreted as reflecting how students navigate between exploratory and structured modes of engagement. These concepts provide a theoretical basis for understanding how task structure may shape perceived cognitive workload, which is the primary focus of the empirical analysis in this study.

2.2. Sociocultural Perspectives on Learning and Structured Problem-Solving

From a learning perspective, sociocultural theory provides a relevant framework for understanding how students engage with complex tasks in educational settings. Vygotsky's sociocultural theory emphasizes that learning occurs through social interaction and the use of cultural tools that mediate cognitive processes (Vygotsky & Cole, 1978). A central concept within this framework is the zone of proximal development (ZPD), which refers to the difference between what learners can accomplish independently and what they can achieve with appropriate guidance or support. Tasks situated within the ZPD are typically associated with manageable levels of cognitive challenge, where effort is required but remains within the learner's capacity when supported by appropriate structures.

In engineering and management education, students are often required to address open-ended and ill-defined problems during early-stage project formulation. Without guidance, these tasks may lead to high levels of uncertainty, which can increase perceived cognitive demand and frustration. Structured approaches, including design thinking-informed frameworks, can therefore be understood as forms of scaffolding that support students in organizing and approaching such tasks. From a cognitive workload perspective, scaffolding does not eliminate task demands but may help regulate how they are experienced. For example, structured templates can reduce ambiguity during problem definition, potentially moderating mental demand and frustration. At the same time, the requirement to organize information into predefined components (e.g., resources, constraints, stakeholders) may introduce additional effort and temporal demand as students structure their ideas.

Within this perspective, project-based learning activities supported by structured tools enable students to engage with complex tasks while maintaining manageable levels of cognitive workload. This balance between challenge and support is consistent with the notion of tasks operating within the ZPD. In the present study, these concepts provide a theoretical basis for interpreting how structured frameworks may influence perceived cognitive workload during early-stage project formulation, rather than serving as a basis for evaluating learning outcomes directly.

2.3. NASA-TLX for Measuring Experience

The assessment of cognitive workload has been widely studied in contexts involving complex task execution, where individuals are required to allocate attention, effort, and time under varying conditions of demand. In this context, the NASA Task Load Index (NASA-TLX) has been extensively used as a multidimensional instrument to capture perceived workload across different domains (Hart & Staveland, 1988).

NASA-TLX evaluates workload through six dimensions: mental demand, physical demand, temporal demand, effort, performance, and frustration. These dimensions provide a structured way to examine how individuals experience tasks that require cognitive engagement, allowing for a more nuanced understanding of workload beyond single aggregated measures. In educational settings, particularly in project-based and design-oriented activities, students are often exposed to tasks that involve problem definition, idea structuring, and decision-making under uncertainty.

These processes can generate varying levels of cognitive demand, making workload a relevant dimension for understanding how students experience instructional approaches. For example, when students are asked to formulate a project proposal, they may experience increased mental demand when defining a problem, temporal demand when managing limited time, and frustration when dealing with uncertainty or unclear outcomes. In this sense, NASA-TLX provides a useful framework for capturing how different aspects of the task contribute to the overall experience.

Previous studies have applied NASA-TLX in educational and design-related contexts to assess perceived workload during learning activities and interaction with structured tools (Grier, 2015; Nikulin et al., 2019). These applications suggest that workload measures can complement traditional evaluations by providing insight into how tasks are experienced during their execution.

In the present study, NASA-TLX is used as the primary instrument to assess perceived cognitive workload during the implementation of a design thinking-informed framework for early-stage project formulation. The focus is not on evaluating performance outcomes, but on understanding how the activity is experienced across different workload dimensions during a short-term instructional session.

3. Method

3.1. Study Design

This study was designed as an exploratory case study to examine how undergraduate students experience the implementation of a design thinking-informed framework during early-stage project formulation. The focus of the study is on perceived cognitive workload as reported by students during a structured instructional activity.

3.2. Participants and Context

A total of 99 undergraduate students participated in the study, all enrolled in programs associated with STEM-oriented education and applied problem-solving. The sample included students from Administrative Management (n = 34), Accountable Management (n = 28), and Management Engineering (n = 37). All participants were engaged in early-cycle courses involving project-based learning, where they were required to develop structured project proposals addressing real-world problems. This context provided a relevant setting for examining how students experience structured frameworks during early-stage project formulation.

3.3. Instructional Procedure

The design thinking informed framework was implemented during a single instructional session conducted in a regular classroom setting. The activity was structured in two stages: a theoretical introduction (1 h) followed by a practical application (2 h). During the introductory phase, the instructor presented the structure and purpose of the framework, including its components related to problem definition, resource identification, and project organization.

In the context of this case study, students were invited to develop project ideas in areas of personal interest. This approach was used to situate the activity within contexts familiar to students, allowing them to engage with early-stage project formulation tasks grounded in their own experiences. Within this setting, students were required to balance idea generation with structured project development, organizing elements such as problem definition, resources, constraints, and expected outcomes. These activities reflect common challenges in early-stage project-based learning, where learners must translate abstract ideas into structured proposals. The framework applied in this study integrates elements from multiple models and tools commonly used in design thinking and project development. As illustrated in Figure 1, these include components related to user experience, design-driven innovation, and structured planning approaches.

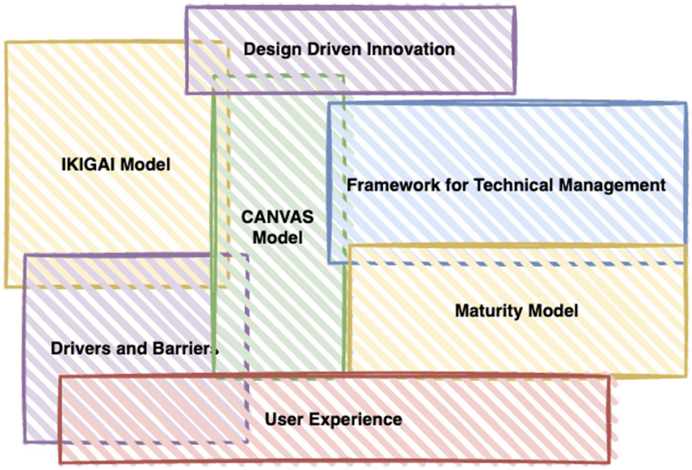

Figure 1. Integration of Models and Tools for a Project Framework for the Initial Cycle.

Figure 2 presents the structured template used by students during the activity. This template guided students in articulating project proposals by organizing key elements such as problem definition, individual purpose, available resources, perceived barriers, and planned actions within a coherent format. During the practical phase, students applied this template to develop a project proposal. This process involved identifying a problem, structuring potential solutions, and organizing relevant information within the framework. The activity was completed within the same session, allowing for the assessment of students' immediate perceptions during early-stage project formulation.

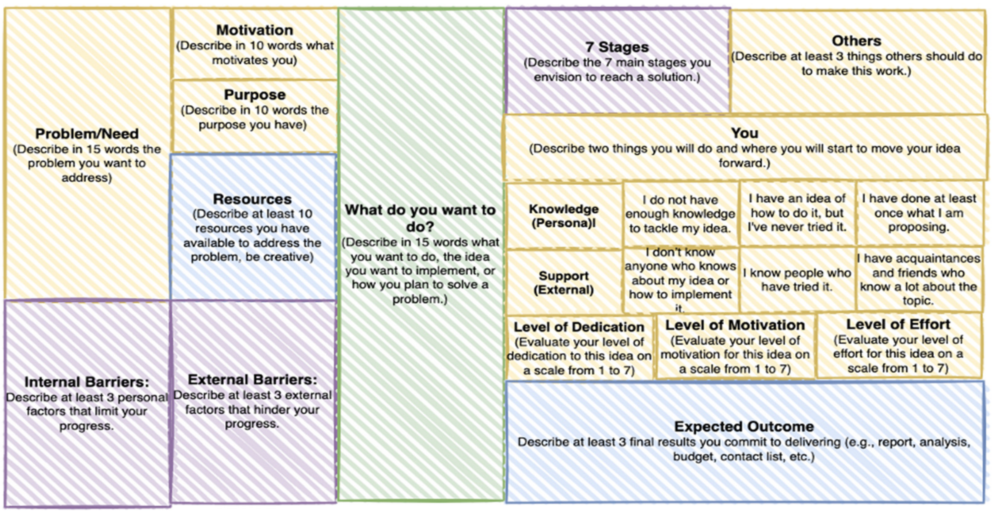

Figure 2. Structured Project Formulation Template for Students in the Initial Cycle.

3.4. Conceptual Foundations and Design Rationale of the Framework

The design of the proposed framework is informed by prior work on creative and design methods, particularly the classification approach presented by Nikulin et al. (2019), which organizes methods according to the needs of specific design tasks and project contexts. Such approaches are relevant in STEM education, where ill-defined problems require structured yet flexible guidance to support exploration, iteration, and decision making (Brown, 2008; Razzouk & Shute, 2012). Building on these contributions, the framework adopted in this study integrates conceptual elements from design thinking, user experience, and motivational perspectives. These elements are not operationalized as variables in the empirical analysis; rather, they serve as conceptual foundations guiding the structure of the framework and the organization of the learning activity.

In early-stage project-based learning, students are often required to select and apply design methods without sufficient prior experience, which may create challenges during problem framing and ideation. For example, when asked to define a project, students may struggle to translate abstract ideas into structured proposals or to identify relevant resources and constraints. In this context, structured frameworks can provide guidance by organizing key components of the project formulation process.

The proposed framework was therefore designed with the following objectives:

- To provide a structured yet flexible template that supports the organization of project elements, including problem definition, resource identification, and staged development.
- To offer accessible design thinking-informed tools that support early-cycle STEM students in advancing project ideas through iterative exploration and structured decision-making.
- To facilitate the externalization of ideas into explicit representations, allowing students to articulate assumptions, constraints, and proposed solutions within a project-based context.
- To support communication and coordination among participants through a shared structure that enables reflection and alignment during project development.

From a broader educational perspective, these design choices are consistent with approaches that emphasize active engagement, meaning-making, and collaborative learning in complex environments (Zettinig et al., 2021). These principles informed the development of the framework but are not directly evaluated in this study. Table 1 summarizes the main theories, models, and techniques that informed the design of the proposed framework, highlighting the key characteristics integrated into its structure.

Table 1. Methods for the Development of the Methodological Proposal.

Model/Methodology/ Technique Considered for the Model	Description	Purpose in the New Model
IKIGAI Model	Originating in Japan, this model proposes finding the ideal combination between what you love, what you are good at, what the world needs, and what you can be paid for. This multidimensional approach promotes a sense of purpose and life satisfaction. IKIGAI can be applied in various fields, including engineering, to help students identify their passions, skills, potential contributions, and professional opportunities. By integrating these dimensions, individuals can make decisions more aligned with their values and goals, enhancing their well-being and professional effectiveness (Erdogan et al., 2020).	Focus project proposals on motivating aspects of students.
CANVAS Model	Developed by Osterwalder and Pigneur (2010), this strategic tool helps visualize and analyze business models. It consists of nine blocks, including customer segments, value propositions, and distribution channels, among others. This approach fosters innovation, facilitates the identification of areas for improvement, and helps understand the viability of a business systematically. It is widely used in engineering to design and optimize products and services, promoting a holistic understanding of key interactions between different business components.	Organize and provide direction for the consistency of the project's value proposition.

Table 1. *Cont.*

Model/Methodology/ Technique Considered for the Model	Description	Purpose in the New Model
Design Driven Innovation	This concept focuses on the idea that design innovation is driven by key factors such as technology, sustainability, and user needs. This holistic approach fosters the creation of ingenious and effective solutions in engineering. Integrating these drivers into the design process enables engineers to develop products that address contemporary challenges efficiently and creatively (Verganti, 2009).	Create and propose solutions that involve people/clients with students.
Framework for Technical Management (FORMAT)	A systematic approach to managing complex technical projects in engineering. It is based on four pillars: Functions, Organization, Resources, and Metrics, which guide project planning and execution. FORMAT provides a structured framework for decision-making, resource allocation, and outcome evaluation, helping optimize project efficiency and quality. Its application enables more effective management of technical and organizational aspects, contributing to successful engineering project implementation.	Organize resources, define roles, and outline stages to ensure project progress.
Drivers and Barriers Theory	"Drivers and Barriers" are factors influencing the adoption of technologies or practices in engineering. "Drivers" promote change, such as economic, environmental, or social benefits, while "barriers" hinder adoption, such as costs, lack of knowledge, or cultural resistance. Understanding these elements is crucial for sustainable technological development.	Identify potential obstacles to project progress. Prospect development and address challenges with the team.
Maturity Scale	A tool used in engineering to evaluate the level of development and competence of an organization or team in specific areas, such as project or process management. It is based on criteria ranging from initial to advanced levels. The evaluation provides a holistic view of an organization's capacity to meet quality and efficiency standards. This approach helps identify areas for improvement and set realistic objectives for organizational growth (Essmann & Du Preez, 2009).	Self-assessment to determine how the team should prepare to continue advancing knowledge and support networks during the learning process.
User Experience (UX)	Refers to how users perceive and experience interacting with a product, system, or service. It encompasses emotional, cognitive, and physical aspects. UX aims to optimize user satisfaction by improving usability, accessibility, and pleasure in interaction. Engineers consider UX from the design phase to implementation, integrating feedback for continuous improvement. Good UX design enhances efficiency, reduces errors, and fosters user loyalty (Hassenzahl, 2003).	The project development experience (learning) should be enjoyable, and the proposal should be achievable to maintain low frustration levels (Nikulin et al., 2019)

3.5. Data and Measurement Instruments

Perceived cognitive workload was assessed using the NASA Task Load Index (NASA-TLX), administered immediately after the completion of the instructional session. The questionnaire was applied in Spanish to ensure comprehension and minimize potential language bias. The translation process followed established guidelines for cross-cultural adaptation of measurement instruments (Cruchinho et al., 2024). NASA-TLX evaluates workload across six dimensions: mental demand, physical demand, temporal demand, effort, performance, and frustration. Each dimension was rated on a 0–100 scale. Scores were calculated using the raw (unweighted) scoring method, based on the average of the six dimensions. This approach is widely used in applied and educational contexts due to its simplicity and comparable sensitivity to the weighted procedure (Grier, 2015). The instrument was used to capture students perceived cognitive workload during the implementation of the framework, providing a standardized measure of their experience across multiple dimensions. To assess sample-specific reliability, McDonald's omega (ω) was calculated for the NASA-TLX dimensions. This approach was selected given the multidimensional nature of the instrument, which captures distinct but related aspects of perceived workload rather than a single underlying construct.

4. Results

4.1. Perceived Cognitive Workload

This section presents the results derived from the application of the NASA Task Load Index (NASA-TLX). A total of 99 questionnaires were collected at the end of the instructional session. All reported values correspond to raw NASA-TLX scores expressed on a 0–100 scale. The analysis focuses on students perceived cognitive workload across the six NASA-TLX dimensions. To facilitate interpretation, a range-based scale was defined to categorize workload levels: 0–20% (very low), 20–40% (low), 40–60% (moderate), 60–80% (high), and 80–100% (very high).

To assess sample-specific reliability, McDonald's omega (ω) was calculated for the NASA-TLX dimensions. The overall omega coefficient was $\omega = 0.641$, indicating an acceptable level of internal consistency given the multidimensional nature of the instrument. Item-level analysis showed that removing individual dimensions resulted in omega values ranging from 0.553 to 0.678. The largest increase in reliability was observed when Physical Demand was excluded ($\omega = 0.678$), suggesting that this dimension may be less aligned with the predominantly cognitive aspects of workload assessed in this context. This finding is also consistent with its inverse relationship within the scale. Despite these variations, all dimensions contributed meaningfully to the overall construct, supporting the inclusion of the full NASA-TLX in the analysis. Overall, the results are consistent with the conceptualization of workload as a multidimensional construct and provide evidence of the internal coherence of the instrument in this explorative experiment.

Figure 3 summarizes perceived workload across the six NASA-TLX dimensions. The overall average workload ranged between 50% and 60%, corresponding to a moderate level according to the predefined scale. This suggests that the activity was experienced within a manageable range of cognitive demand during the implementation of the framework.

A more detailed examination of each dimension is presented below:

(i) Effort: Reported values for the Effort dimension ranged between 50% and 60%, indicating a moderate level of perceived effort during the activity. These results suggest that students engaged with the task without reporting extreme levels of exertion.

(ii) Mental Demand: The Mental Demand dimension showed values between 40% and 60%, with an average tendency toward the upper range (mean = 58%). This indicates that the activity required a moderate level of cognitive processing during project formulation.

(iii) Physical Demand: Physical Demand scores were consistently low, with an average of approximately 22%. This result is expected given the nature of the activity, which primarily involved cognitive rather than physical effort.

(iv) Temporal Demand: The Temporal Demand dimension averaged approximately 51%, indicating a moderate perception of time pressure during the activity. Variability in responses suggests differences in how students managed and distributed their time across tasks.

(v) Performance: The Performance dimension ranged from 60% to 80%, with an average of 66%. As a self-reported measure, this dimension reflects students' perceived effectiveness in completing the assigned tasks.

(vi) Frustration: The Frustration dimension yielded an average score of 44%, indicating a moderate level of perceived frustration. Given that NASA-TLX conceptualizes frustration as a continuous subjective experience, this result suggests that participants experienced some degree of tension or uncertainty during task execution, although not at extreme levels.

Overall, the distribution of scores across dimensions indicates that the framework was implemented within a moderate range of perceived cognitive workload during a short-term instructional session.

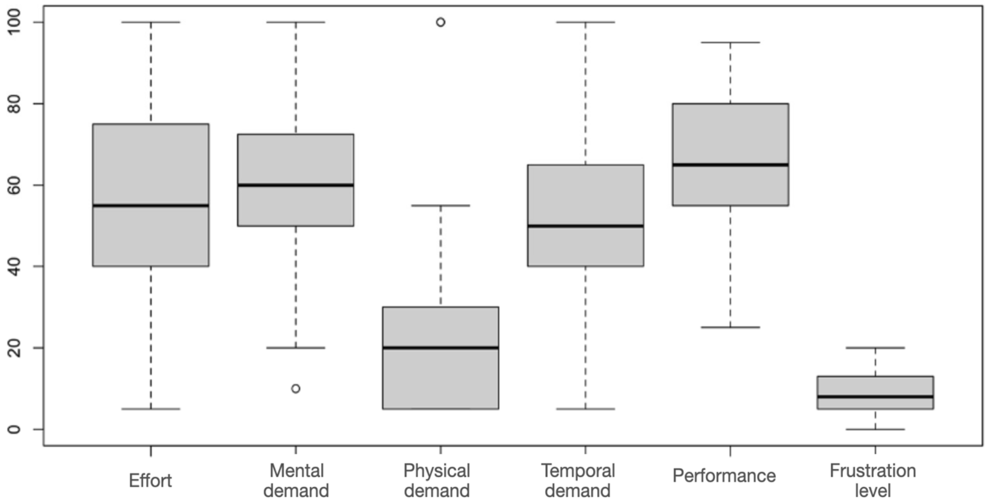

Figure 3. Result of the Application of NASA-TLX for the Model Proposed by the Authors. The box represents the interquartile range (IQR), the line inside the box indicates the median, the whiskers represent the minimum and maximum values within 1.5 × IQR, and the circles indicate outliers.

To examine relationships between workload dimensions, a Pearson correlation analysis was conducted using the NASA-TLX data (n = 99) (Table 2). The results indicate that several statistically significant correlations were observed across dimensions.

Table 2. Correlations Between NASA-TLX Dimensions.

	Effort	Mental Demand	Physical Demand	Temporal Demand	Frustration Level
Effort	---				
Mental Demand	0.345 **	--			
Physical Demand	0.003	−0.339 **	---		
Temporal Demand	0.206 *	0.409 **	0.061	---	
Performance	−0.143	−0.216 *	0.064	−0.248	---
Frustration Level	0.145	0.315 **	0.000	0.539 **	−0.422 **

Note * $p \leq 0.05$; ** $p \leq 0.01$.

Among the strongest relationships, Temporal Demand and Frustration showed the highest positive correlation (r = 0.539, $p \leq 0.01$), followed by Mental Demand and Temporal Demand (r = 0.409, $p \leq 0.01$). Additionally, Mental Demand was positively correlated with Effort (r = 0.345, $p \leq 0.01$) and Frustration (r = 0.315, $p \leq 0.01$).

A moderate negative correlation was observed between Performance and Frustration (r = −0.422, $p \leq 0.01$). Performance was also negatively correlated with Temporal Demand (r = −0.248, $p \leq 0.05$) and Mental Demand (r = −0.216, $p \leq 0.05$).

These results indicate the presence of associations among perceived workload dimensions within the context of the activity. However, these relationships are correlational and do not imply causal effects.

4.2. Complementary Qualitative Insights

To complement the quantitative findings, a basic thematic analysis was conducted on qualitative data collected through short post-activity student responses. These data were analyzed using a descriptive approach, focusing on recurring patterns in how students described their experience with the framework. The analysis identified five main themes.

Problem Structuring Tool

First, students consistently described the framework as a tool for structuring and organizing project ideas. Participants referred to it as a way to *"explain the problem"* and to make sense of its components, in some cases comparing it to a business-oriented structure. As one student noted, *"it is like explaining the problem, similar to a business model"* (male student). Another participant summarized it more directly as *"a way to solve a problem"* (female student). This suggests that the framework was perceived as a practical structuring device rather than an abstract methodological concept.

Challenges in Linear Organization

Second, students reported difficulties related to the organization of ideas within the stages of the model. In particular, the linear structure of the framework was described as challenging during the development of ideas, as students needed to translate evolving concepts into predefined stages. One participant explained: *"when developing the idea, what is most difficult is structuring it into the stages proposed by the model… one gets confused by the linearity of the process"* (male student). This difficulty reflects the cognitive demands associated with structuring ill-defined problems.

Complexity of Variable Identification

Third, participants highlighted the identification of internal and external variables as one of the most demanding aspects of the activity. As one student stated, *"identifying internal and external variables was the most difficult part"* (female student), while another emphasized the need to *"see all the variables that a project will have"* (male student). This indicates that integrating multiple dimensions of a project, such as constraints, resources, and contextual factors, may contribute to perceived cognitive workload during early-stage formulation.

Support for Idea Organization

Fourth, despite these challenges, students reported that the framework supported the organization and clarification of their ideas. Participants indicated that it helped them understand key aspects such as target users, available resources, and potential barriers. For instance, one student explained: *"it helped me structure everything, understand who it is for, what we will use, and what our barriers are"* (female student). This suggests that the framework may function as a cognitive scaffold during project development.

Limitations of Self-Reported Motivation

Additionally, some participants questioned the use of self-reported motivation within the framework, noting that such responses may not always reflect their actual level of engagement. As one participant observed, *"motivation is not always completely sincere, so that could be changed"* (male student). This observation highlights potential limitations in the use of subjective motivational constructs in structured project tools.

These qualitative insights are consistent with the quantitative results and provide additional context for interpreting how students experience the framework during early-stage project formulation.

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5. Discussion

The findings of this study indicate that the implementation of the proposed framework is associated with a moderate level of perceived cognitive workload during early-stage project formulation in STEM education. This result is particularly relevant in project-based learning contexts, where students are required to engage with ill-defined problems that demand both cognitive effort and structured reasoning. From a theoretical perspective, these findings are consistent with the expectation that structured frameworks may help regulate, rather than eliminate, cognitive demand during complex tasks (Jia et al., 2025; Eticha et al., 2025). As outlined in the theoretical framework, early-stage project formulation involves a tension between exploratory and goal-oriented modes of engagement.

In this context, structured guidance may reduce ambiguity during problem definition while simultaneously introducing demands related to organizing and integrating multiple project elements. The observed workload patterns reflect this balance. Mental demand and effort remained within moderate ranges, suggesting that students engaged cognitively with the task while maintaining manageable levels of perceived workload. This aligns with the notion of scaffolding within the zone of proximal development, where tasks are experienced as challenging but achievable when supported by appropriate structures (Tang et al., 2016). At the same time, the correlations among workload dimensions provide further insight into how these demands are experienced. The strong association between Temporal Demand and Frustration (r = 0.539, $p \leq 0.01$) suggests that time-related pressure plays a key role in shaping the emotional dimension of the task Similarly, the positive relationships between Mental Demand, Effort, and Frustration indicate that increases in cognitive complexity are accompanied by higher perceived effort and emotional strain.

These patterns are consistent with the expectation that structuring ill-defined problems requires sustained cognitive engagement. Conversely, the negative correlation between Performance and Frustration (r = -0.422, $p \leq 0.01$) suggests that students who perceived greater control over the task experienced lower levels of frustration. This may reflect the role of structured guidance in supporting task comprehension and organization, reducing uncertainty during project formulation. Together, these findings support the interpretation that structured frameworks function as mechanisms for organizing cognitive workload. Rather than reducing task complexity, they appear to redistribute cognitive demands in a way that maintains engagement while limiting excessive frustration. This interpretation is consistent with both sociocultural perspectives on scaffolding and user experience approaches that emphasize the balance between guidance and exploration.

Importantly, these results should be interpreted within the scope of a short-term instructional intervention. The findings reflect students' immediate perceptions during early-stage project formulation and do not provide evidence regarding long-term learning outcomes, creativity, or performance.

From a methodological perspective, this study contributes to the use of NASA-TLX as a tool for examining perceived cognitive workload in educational contexts. By focusing on workload as an observable dimension of student experience, the study offers a complementary perspective to outcome-based approaches, which do not always account for how tasks are experienced during their execution. Overall, the findings provide initial evidence regarding the feasibility of implementing structured, design thinking-informed frameworks in early-cycle STEM education without introducing excessive cognitive demand. In this sense, the contribution of the study lies not in evaluating effectiveness in terms of learning outcomes, but in providing insight into how such frameworks are experienced under real instructional conditions, supporting the development of workload-informed approaches to project-based learning.

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6. Conclusions

This study addresses the challenge of supporting structured project development during the early academic cycles of engineering and management education in STEM-oriented contexts. Grounded in design thinking principles and informed by motivational and user experience perspectives, the Motivation Integrated Project Framework (MIPF) was developed as a structured approach to guide early-stage project formulation.

The framework integrates elements related to project organization, resource identification, and staged development into a coherent structure intended to support students in articulating project ideas within a human-centered perspective. By combining different conceptual components into a unified template, the framework provides a structured way to organize problem definition, proposed solutions, and implementation considerations during early project stages.

The exploratory case study conducted with 99 undergraduate students provides initial evidence regarding the perceived cognitive workload associated with the implementation of the framework. The use of NASA-TLX allowed for the assessment of workload across multiple dimensions, indicating that the activity was experienced within a moderate range of cognitive demand during a short-term instructional session.

These findings should be interpreted within the scope of a single-session implementation and reflect students' immediate perceptions during early-stage project formulation. No conclusions can be drawn regarding long-term effects on learning, motivation, or project quality. Instead, the results suggest that the framework can be implemented in classroom settings without introducing excessive perceived cognitive load.

Overall, this study contributes to ongoing discussions on the design and evaluation of instructional frameworks in STEM education by focusing on perceived workload as a relevant dimension of early-stage project-based learning. The MIPF offers a structured and adaptable approach that can be further examined in future research. Subsequent studies should incorporate longitudinal designs, comparative conditions, and additional evaluation instruments to assess learning outcomes, motivational constructs, and project quality more comprehensively.

7. Limitations

This study presents several limitations that should be considered when interpreting its findings. First, the research was conducted as an exploratory case study within a single academic institution, involving 99 undergraduate students from engineering and management-related programs. While suitable for examining early-cycle STEM education, this context-specific sample limits the generalizability of the findings to other disciplines, institutional settings, and cultural environments. Future research should expand the participant pool across diverse contexts to strengthen external validity.

Second, the framework was implemented within a pedagogically selected context rather than in comparison with alternative instructional approaches. As a result, the findings reflect students' experiences within a specific learning setting and do not allow for comparative evaluation. In addition, the exploratory nature of design thinking introduces variability in how students approach project tasks, which may influence perceived cognitive workload depending on individual strategies and prior experience.

Third, although project-development templates were used to support idea structuring and project formulation, they were not systematically analyzed using a formal evaluation framework. No scoring rubric or inter-rater reliability procedures were implemented to assess the quality of project outputs. Importantly, evaluating learning outcomes, creativity, or performance was beyond the scope of this study, which focused on perceived cognitive workload during early-stage project formulation. Future research should incorporate structured evaluation criteria to examine how workload relates to project quality and learning outcomes more rigorously.

Fourth, the use of the NASA Task Load Index (NASA-TLX) provided a structured measure of perceived cognitive workload, but it captures a specific dimension of the student experience. Other relevant aspects, such as learning outcomes or motivational constructs, were not directly measured, as the aim of this study was to examine how the framework is experienced in terms of workload rather than to assess its effectiveness. Future studies may integrate complementary instruments to explore these dimensions.

Finally, the short duration of the intervention, conducted within a single session, restricts the findings to immediate perceptions of workload during early-stage project formulation. Longitudinal and comparative designs are needed to examine how the framework performs over extended learning processes and across different instructional conditions.

Despite these limitations, the study provides initial evidence regarding the feasibility of implementing a structured, design thinking-informed framework in early-cycle STEM education without introducing excessive perceived cognitive workload. Addressing these limitations in future research will support more comprehensive evaluation approaches and contribute to the further development and adaptation of the proposed framework.

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Data Availability Statement: The data presented in this study are available on reasonable request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions.

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