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An emerging assessment framework for problem-based learning environments based on Jonassen's design theory of problem solving

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Introduction

This theory/method paper focuses on assessing student learning within a Problem-Based Learning (PBL) context. PBL is a learning approach that presents students with an open-ended, ill-structured, authentic, real-world problem [1]. In this approach, utilizing authentic real-life clinical problems to structure and drive learning, students actively engage in self-directed problem-solving and learning processes in small-group settings to construct knowledge and develop a solution [2]. Overall, PBL has been found to have a generally positive impact on student learning of core knowledge and complementary skills (e.g., problem-solving) aligned with the profession, and supporting student learning in ways that lay "the foundations for a lifetime of continuing education" [3] - [8]. Despite the reported benefits however, the design and implementation of PBL environments for engineering education is challenging for several reasons; problem design, facilitation, and assessment represent specific facets of PBL that are particularly challenging and hinder broader adoption of PBL partly due to the lack of methodological tools for faculty who plan to implement PBL as their course instructional design [9] - [13]. Assessment specifically is of great importance as assessing students' learning provides valuable feedback to students on their grasp of core concepts, problem-solving abilities, and progress in mastering essential skills. It also offers instructors critical insights into students' understanding of the material, highlights areas where additional support or clarification may be needed and helps assess the effectiveness of the instructional strategies employed. For researchers and evaluators, this assessment sheds light on the broader impact of PBL methodologies, as well as the influence of specific interventions on students' ability to tackle complex, real-world problems.

Grounded in the principles of Design-Based Research (DBR), this study stems from an ongoing project aimed at operationalizing Jonassen's design theory of problem solving [14]. The broader project seeks to develop problem-solving experiences by designing problems and facilitating problem-solving processes for an introductory aerospace engineering course at an R1 institution transitioning to integrate PBL into its curriculum. Specifically, this paper presents the assessment framework that emerged from analyzing students' constructed artifacts during the PBL experience. Through development of the assessment framework this study sought to address the following research question: *How can instructors assess the problem-solving process within the product in problem-based learning (PBL) environments in engineering context?*

To address our research question, we detail the methodology used to analyze and code student artifacts from an ongoing PBL implementation project, leading to an assessment framework widely applicable in engineering. We illustrate the application of the framework and discuss its implementation in practice, demonstrating its use in assessing students' artifacts and contrasting it with traditional product-focused assessment and grading approach.

Literature Review

Assessing ill-structured student problems or projects is a notorious struggle for engineering faculty and can be even more challenging when implementing PBL in engineering courses [15]. Because of the inherent goals and learning objectives of PBL (i.e., creating professionally situated, student-directed independent and group work aimed at solving ill-structured problems that can sometimes have distinctly different outcomes), paper-and-pencil style unit tests generally do not accurately capture student performance [15]. In other words, the problem-solving and professional skills students use during PBL are not captured with a traditional testing approach [16]. These traditional assessment approaches lead to constructive misalignment with the intended learning outcomes and the teaching and learning activities in the PBL context and do not match the philosophical tenets of PBL [17] - [19]. The assessment process is even more difficult because assessing meaningful learning such as students' problem-solving performance and process, and knowledge construction requires more than one form of assessment [1]. Prior assessments of problem-solving have been developed both as research instruments and for standardized assessment of students. An extensive thread in this work has been to explore tasks of varying levels of complexity that do not require specialized knowledge or skills to solve. We would refer to these as 'complex puzzles,' as they test reasoning skills, but they do not test the appropriate application of specialized knowledge, as is extensively required in every authentic science and engineering problem [20].

Despite the recognized importance of determining what should be assessed and identifying effective strategies for evaluating student learning in successful implementations of PBL, this area remains understudied in the literature [9], [12], [13], [21]. Much of the existing research on assessment in PBL environments merely offers general recommendations, suggesting various artifacts that could be used to assess students' learning, such as self-reflection, engineering journals, self- and peer-assessments, written and oral reports, content-specific tests, solution debates, and portfolios [22] - [27]. Among these, reflection is the most commonly suggested assessment artifact, though there is limited evidence supporting its effectiveness. Similarly, while several papers discuss when students should be assessed, these suggestions often lack empirical validation [22], [25], [27], [28]. Albanese and Hinman [29] categorize assessment in PBL as either formative or summative. In their view, formative assessment in PBL can take place at various intervals, such as weekly [30], monthly, or at the end of a case study [31]. They also outline important aspects of formative assessment, such as evaluating group processes (e.g., student contributions, interactions among group members, and overall group functionality) [32], assessing group outputs, and reviewing individual progress through methods like peer review, facilitator feedback, portfolios, and self-assessment. However, while these approaches offer various methods for assessment, they do not provide empirical details on which specific aspects, behaviors, and concepts should be observed, measured, and assessed during students' problem-solving engagement in PBL. This gap suggests the need for further exploration into targeted assessment criteria that capture the nuances of students' learning processes and interactions within the PBL framework.

In general, while recommendations for assessment strategies—such as incorporating reflective practices—are frequently offered, there is little robust evidence to support these strategies, particularly within engineering PBL contexts. Much of the research on PBL assessment strategies has been conducted outside of engineering education, in fields like medical, law, and teacher education and not in the field of engineering. While several publications offered insight related to assessment in PBL-based engineering programs, most papers were largely focused on assessing the value of PBL practices as opposed to evaluating the assessment strategies proposed. As a result, these studies often fail to provide a comprehensive understanding of what should be assessed during the problem-solving process in PBL, or how to assess the various components of students' problem-solving alongside their constructed artifacts in an integrated manner.

Conceptual Framework

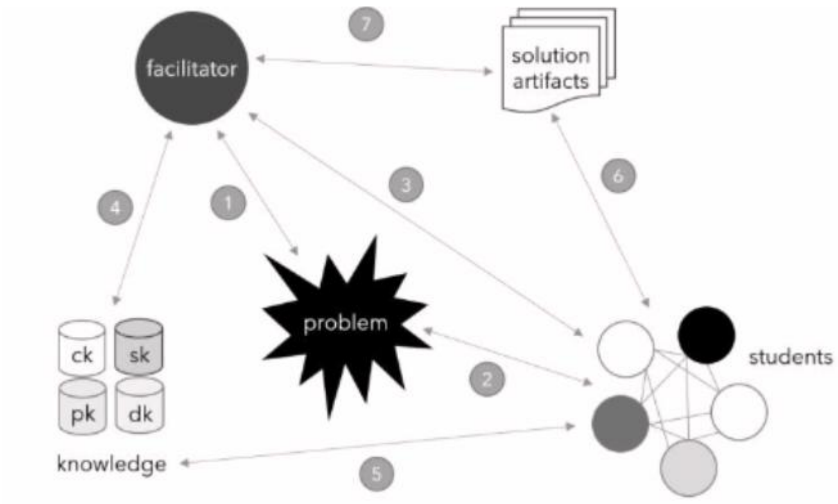

Fig. 1: Conceptual framework of problem-based learning experiences

Figure 1 presents our conceptual framework based on the broader PBL literature and our experience implementing this approach in undergraduate engineering courses. This evolving model is part of our ongoing research on granular-level PBL design and implementation, which applies Jonassen's problem-solving design theory [14] to problem design, facilitation and assessment. The conceptual framework highlights both direct and mediated pathways for interaction between a facilitator and students in a PBL experience. As this study focuses on assessing students, we specifically address pathways 6 and 7. The remaining pathways have been or will be explored in other publications by our research team [38], [39].

Pathway 6 focuses on the information students communicate through solution artifacts, which reflect their engagement with the problem. This information may be conveyed through written, verbal, or other mediums by student groups. In the current study, we explore this pathway by analyzing student-created artifacts (slides) submitted at three checkpoints as groups worked through the problem-solving process. Pathway 7 builds on this by examining how facilitators interpret and assess the information conveyed through student artifacts. This pathway highlights the complexity of the PBL environment, where a rich and multifaceted learning process is condensed into submission of an artifact, leaving much open to interpretation by the assessor. It explores how facilitators extract insights into students' learning processes and problem-solving strategies, emphasizing the role of assessment in decoding the artifacts. This includes evaluating the content, measuring the effectiveness of the proposed solutions, and forming tentative interpretations of what students are communicating through their work. The process requires facilitators to navigate the inherent ambiguity and complexity in students' responses, making the assessment an act of significant interpretation. This is part of the unique challenge of assessment in PBL, as it is not just about evaluating the final product but understanding and interpreting the students' problem-solving process. Doing so is crucial to uncovering what students are truly learning and how they are constructing knowledge, providing a deeper understanding of their cognitive and developmental progress in solving complex, ill-structured problems.

Theoretical Framing: Jonassen's Design Theory of Problem Solving

This work derives from an ongoing project to operationalize Jonassen's design theory of problem solving by leveraging three key facets of his framework: problem typology (which identifies distinct problem-solving strategies for different problem types) problem variation (represented by "structuredness" and "complexity"), and specific types of knowledge (conceptual, domain, structural, and procedural) to design and implement PBL at a granular level [1], [14], [40], [41], [42].

Jonassen [14] proposed a typology of problems on a continuum from well-structured to ill-structured, including categories such as story problems, rule-using/rule-induction, decision-making, troubleshooting, diagnosis-solution, strategic performance, policy, design, and dilemmas. He noted that in engineering, professionals most commonly encounter selection, troubleshooting, and design problems [40], [42].

Beyond problem types, Jonassen also identified four characteristics by which problems vary: structuredness, complexity, context, and domain specificity [1], [14]. This research is limited to consideration of problem complexity and structuredness. Well-structured problems, typically seen in educational settings, provide all necessary information within the problem representation and often require a limited set of prescribed rules to reach a solution. Ill-structured problems, conversely, involve uncertain elements, multiple evaluation criteria and solutions, and require solvers to apply their judgments or beliefs. Essentially, well-structured problems have a single correct solution obtained through a defined process, while ill-structured problems have multiple possible solutions and solution path. Complexity, as defined by Jonassen, involves the number of problem elements (issues, functions, or variables), their interactions, and the relationships between them. If problem elements are changing (dynamic), the complexity of the problem also increases [14].

When solving problems, learners draw upon or construct various types of knowledge. Educators designing and facilitating PBL activities can benefit from identifying the specific knowledge needed to address the problem effectively [14], [38]. The following are the definitions from literature that has already been offered by the research team in previous papers that closely align with Jonassen's ideas [38], [43]. Conceptual knowledge involves understanding fundamental phenomena, such as qualitatively explaining aerodynamic lift. Structural knowledge focuses on recognizing interrelationships among concepts within a domain, often expressed through equations or qualitative descriptions, which are essential for producing problem deliverables and achieving problem-solving success. Procedural knowledge pertains to mastering the steps or methods needed to solve problems, including calculations, statistical analyses, or troubleshooting processes. Finally, domain knowledge encompasses field-specific familiarity and experience, enabling informed decision-making, the formation of assumptions, and the evaluation of solution validity.

Building on these ideas, our research team has developed a toolkit incorporating concept maps and learning hierarchy analysis which provides advanced guidelines for designing problem-based learning (PBL) experiences. Specifically, our research team has employed this methodological toolkit—grounded in problem typologies, structuredness, and complexity—to design ill-structured problems for an introductory aerospace engineering undergraduate course. Detailed discussions of the problem design phase using the toolkit are available in previous works [38]. During the implementation phase of the project, our research focused on examining student-faculty interactions surrounding the designed problems and exploring the use of problem typology diagrams to facilitate student problem-solving. Details of this phase of the project have been presented in prior work [39] and will be further elaborated in an upcoming journal submission that will focus on exploring the impact of problem-typology based facilitation on students' problem engagement.

This current study builds on the described two phases of designing, implementing, and facilitating PBL experience in an introductory aerospace engineering course, focusing on the analysis of student group artifacts as a key data source. The goal of this paper is to propose an emerging assessment framework derived from the analysis of these artifacts and to present the associated coding scheme, grounded in Jonassen's design theory of problem-solving as the guiding theoretical framework.

Methods

This section provides a summary of the methods used for data collection and analysis in our broader Design-Based Research (DBR) study, which explored the impact of problem-typology-based facilitation on students' engagement with problems. While the methodology is discussed in greater detail in a separate paper, we highlight key aspects here, including the development of the coding scheme utilized for analyzing students' artifacts [44].

Current paper follows the design-driven and theory-building principles of Design-Based Research (DBR) [42–44] to propose an assessment framework derived from the design and facilitation of a PBL experience. Data were collected from two sections of a sophomore-level introductory aerospace engineering course at a major research institution during the Fall 2022 semester, marking the first iteration of the PBL intervention. In this one-credit-hour course, meeting weekly for 75 minutes, students with limited prior PBL experience worked in teams of three to solve a multi-week, ill-structured, and complex case analysis problem (MVP), with deliverables submitted at three checkpoints (details in Appendix A.1).

To analyze the artifacts, we employed Hatch's Interpretive Analysis model [42] alongside Jonassen's problem-solving design theory as our guiding theoretical framework. To capture a diverse range of student experiences, we used maximum variation sampling [43], selecting three groups with the highest (100), median (83), and lowest (73) grades. This approach ensured representation across performance levels, resulting in the systematic coding of artifacts from nine groups per section (eighteen total). Each artifact was analyzed to generate both descriptive and analytical insights into students' engagement with problem-solving.

The methodological rigor of the analysis was ensured through a structured process. Initial analytic memos were collaboratively drafted during research meetings to establish consensus on key insights. Individual team members then composed detailed memos for each artifact, which were later discussed extensively in group meetings to align interpretations with emergent themes. In subsequent stages, we iteratively reviewed memos to refine themes and insights while applying

Jonassen's theoretical framework. Subcodes for each theme were developed, capturing hierarchies of student engagement [42] - [44] These codes were systematically applied across all artifacts. The coding process combined deductive approaches informed by the theoretical framework with inductive themes derived from memo analysis.

To ensure reliability, regular research meetings were conducted to verify code assignments and resolve any disagreements through discussion, resulting in high interrater reliability. To confirm thematic saturation, an additional round of artifact analysis was performed, involving six artifacts from each section. No new themes emerged during this phase, confirming saturation and contributing to analytic triangulation [45]. In total, artifacts from 15 groups per section—30 groups overall—were coded. Operational definitions for all subcodes were carefully documented to ensure consistency in application across researchers and overtime.

Findings

This section details the coding scheme developed from our analysis of students' artifacts, as described in the qualitative analysis methodology outlined earlier. Emergent from this coding scheme, we propose an assessment framework that enables instructors to evaluate and categorize students' artifacts. Additionally, we demonstrate how the framework can be used to assess students' problem-solving skills and learning by analyzing their activities and how they represent their engagement throughout the problem-solving process. This approach is contrasted with the predominantly product-focused assessment and grading methods employed during the course implementation.

Artifact Coding Scheme informing the Assessment Framework

Our artifact coding scheme is grounded in six key themes identified through systematic analysis and coding: **Problem Framing**, **Problem Type Identification**, **Resolution of Ill-Structuredness**, **Narrative Communication**, **Resolution of Complexity**, and **Outcome Correctness**. Each theme encompasses specific codes that categorize the extent and manner in which these aspects are observable in students' artifacts. By applying these codes to student work, the framework enables a structured evaluation of how students demonstrate their problem-solving processes and activities related to each theme. Appendix A.2 presents the artifact coding scheme.

We propose that this coding scheme can serve as an assessment framework for instructors to more accurately assess students' problem-solving performance. It offers a structured approach to evaluating whether students effectively engage with key aspects of solving authentic problems, including addressing their ill-structured nature and resolving inherent complexities. This involves activities such as framing the problem, identifying its type, narrating and communicating their problem-solving process and decision-making, that ultimately will result in delivering a final solution. Additionally, the framework enables instructors to assess the correctness of the final product or solution in relation to the intended outcome.

Description of each theme, including its definition and the corresponding codes used to analyze student artifacts, is provided below:

- Problem Framing: Problem framing is a critical component of problem-solving, particularly in addressing ill-structured problems [42], [48]. It involves prompting students to restate the problem, consider multiple perspectives, and identify the main objective or goal [48]. Students may approach this task with varying levels of depth, from merely restating the problem or naming basic objectives to demonstrating a deeper understanding by articulating the problem's main goal in their own words, showcasing agency and comprehension.
- Problem Type Identification: Identifying the type of problem is essential for effective problem-solving, as it enables students to select appropriate strategies and approaches [41]. Different problem types require distinct cognitive processes. In our context, the problem is a case analysis, and students who quickly recognize this are better positioned to navigate its complexity and arrive at a solution.
- Narrative Communication: Solving ill-structured problems requires students to narrate their thought process, justify decisions, and explain assumptions and actions. This helps instructors assess students' learning, problem-solving skills, and decision-making while providing targeted feedback. However, students often omit narratives due to familiarity with well-structured problems. When narratives are present, they may lack justification or clarity. Clear, logical narratives, whether technically correct or incorrect, enhance understanding and evaluation of students' approaches.
- Resolving Ill-Structuredness and Complexity: The problem tasked students with addressing multiple phases of flight (e.g., takeoff and landing), developing mathematical models such as Free Body Diagrams and equations, and integrating these phases into a comprehensive analysis. Resolving such complexity necessitates applying conceptual, procedural, and structural knowledge that students have constructed. Additionally, students were required to make assumptions, estimates, and judgments due to incomplete information in the problem statement, setting this apart from traditional structured problems [14]. They were also expected to articulate opinions, beliefs, and justifications for their decisions. By addressing ill-structuredness, students actively use and construct domain-specific and conceptual knowledge critical to problem-solving.
- Outcome and "Correctness": Products represent the outcomes of tasks, phase activities, and overall problem-solving efforts, reflecting students' ability to address open-ended problems—an essential skill sought by employers in engineers.

Exploratory implementation of the assessment framework to assess artifacts

As mentioned earlier, our larger research effort is exploratory in nature, with our research team focusing on investigating differences in problem engagement between two sections of an introductory aerospace engineering course where the facilitation approach varied (One section was supported through an instructional scaffold in the form of an abstracted process diagram corresponding to the type of problem [14], [40], [41], while the other section was not). As the primary focus of the study was on facilitation, assessment and grading were not the central concerns, and a traditional, product-focused approach was used to evaluate students' artifacts. However, as we analyzed the students' artifacts to understand their problem-solving engagement, insights began to emerge regarding assessment. These insights highlighted the ways in which we might extend Jonassen's theory into the assessment process, using the coding scheme to show how problem-solving strategies aligned with problem characteristics could be assessed in addition to the final product.

While the correctness of the final solution and the construction of the intended product are critical performance indicators, we argue that equal or greater emphasis should be placed on assessing the underlying problem-solving strategies and processes leading to the solution. Although others have highlighted the importance of evaluating processes, it is not always clear what this entails. Our contribution lies in offering a grounded approach to process assessment by focusing on how students address the challenging characteristics of problems, such as resolving complexity and ill-structuredness. As a simple illustration, Table 1 provides a detailed comparison of how students' artifacts from Checkpoint 3 were assessed using our framework versus their grades under the traditional product-focused approach. For instance, artifacts from groups A07, A14, A11, and B09 illustrate varying degrees of alignment between the two assessment approaches.

Table 1: Implementation of assessment framework for artifacts

Themes	**Group**			
	A07	***A14***	***A11***	***B09***
Problem Framing	PF-2O	PF-0	PF-1O	PF-1O
Problem Type Identification	PT-A	PT-A	PT-A	PT-A
Narrative Communication	NC-3	NC-1	NC-1	NC-1
Resolution of Complexity	RC-1; RC-2TD; RC-3; RC-4	RC-0	RC-1; RC-2TD; RC-3	RC-1; RC-4
Resolution of Ill-Structuredness	RIL-2	RIL-0	RIL-2	RIL-0
Outcome and "Correctness"	Yes	No	No	Yes
Grade	100%	73%	73%	83%
Alignment between process focused and product focused assessment approach	Converging	Converging	Diverging	Diverging

Group A07 exemplifies strong alignment, as their high performance across the framework's themes aligns with their high grade. Specifically, they demonstrated effective problem framing (PF-2O), accurate identification of the problem type, clear and logical narrative communication (NC-2), and substantial activities to resolve both complexity and ill-structuredness (RC-1, RC-2TD, RC-3, RC-4; RIL-2). They also delivered the correct final product, earning a grade of 100%. Conversely, group A14 shows poor performance across most themes, failing to frame the problem (PF-0), resolve complexity or ill-structuredness (RC-0; RIL-0), or provide clear reasoning or narrative (NC-1). They also fail to present a final solution, resulting in a grade of 73%, consistent with their performance under the framework.

However, groups A15 and B09 reveal instances of misalignment between the framework and traditional grading. Group A11, for example, performed well in resolving complexity and ill-structuredness (RC-1, RC-2TD, RC-3; RIL-2) and provided some problem framing (PF-1O) and narrative communication (NC-1), albeit with limited clarity. Despite these strengths, their inability to present a correct outcome resulted in a grade of 73%, categorizing them as low performers under the product-focused approach. In contrast, group B09 provided a correct final solution, earning a higher grade of 83%, despite weaker performance in resolving ill-structuredness (RIL-0) and complexity (RC-1, RC-4). Their framing of the problem and narrative communication (PF-1O; NC-1) were comparable to group A11, yet their grades do not reflect their limited process-oriented performance. These examples highlight how traditional grading can overlook key problem-solving processes, emphasizing the need for a framework that holistically evaluates both process and product while be theoretically grounded in process relevant characteristics.

Discussion and Implications

Traditional assessment of student coursework typically emphasizes evaluating accuracy in relation to knowledge content. While this might provide insights into what students know, it often overlooks the processes underlying more transferable aspects of their problem-solving efforts. A robust assessment system should evaluate students' learning and problem-solving performance in a manner that aligns with the principles of Problem-Based Learning (PBL) epistemology. This entails assessing both the organization of students' knowledge base and their application of problem-solving skills and processes [49]. Our emergent assessment framework addresses these needs by shifting the focus from solely evaluating the correctness of final products to examining the processes that lead to those outcomes.

Using Jonassen's design theory as our guiding framework, we have developed a grounded approach to process assessment by focusing on how students address the challenging characteristics of problems—specifically, resolving their ill-structuredness and complexity. These two high-level activities serve as the cornerstone of the proposed assessment framework, with other problem-solving tasks nested within them. This hierarchical approach emphasizes that effectively assessing students' processes requires evaluating their ability to navigate and mitigate these inherent challenges.

Through this work we argue that resolving **ill-structuredness** entails activities such as framing the problem, identifying its type, setting objectives, and determining strategies. It also involves making judgments, assumptions, and decisions while articulating reasoning and justifications. Our findings underscore the close integration of resolving ill-structuredness with narrative communication. For instructors to infer whether students are appropriately engaging with an ill-structured problem and resolving its ambiguities, students must clearly narrate their reasoning and judgments and provide well-structured argumentation. The ability to articulate these processes is not only indicative of deeper engagement with the problem but also aligns with broader challenges in teaching technical communication skills in engineering education.

Similarly, resolving **complexity** involves breaking the problem into individual components (demonstrating procedural knowledge), modeling and solving these components (indicating conceptual and structural knowledge), and synthesizing them to understand how their interrelations affect the system as a whole. This process also requires students to consider the relationships between components and their cumulative impact on the problem's solution. Resolving complexity thus reflects a holistic grasp of procedural, domain, conceptual, and structural knowledge, showcasing how students can manage interconnected problem-solving tasks. Students' ability to resolve complexity through de-/re-compose strategies is important because relevant theory as encountered in textbooks and lectures is often presented in isolation. Assessing their ability to integrate isolated theoretical elements within PBL is vital to their development as problem solvers.

By centering the framework on these core activities, we emphasize the critical interplay between cognitive strategies and effective communication. This approach not only advances process assessment in PBL by addressing the significant gap in methods that often prioritize product outcomes, but it also underscores the essential role of narrative communication, argumentation, and oral discussion in understanding students' learning. Furthermore, it highlights the importance of developing these skills, which are often underdeveloped among engineering students, as integral components of their education.

Beyond assessment, the framework serves as a powerful tool for improving instructional practices and student learning outcomes. By providing targeted, actionable feedback, instructors can help students identify areas where they need to improve, such as framing problems more effectively or resolving complexity and ill-structuredness. This type of feedback goes beyond traditional grading systems, which often fail to convey what is missing or how students can enhance their problem-solving. Moreover, the framework supports the design of scaffolds tailored to students' specific needs, whether through structured interventions (hard scaffolds) or adaptive facilitation during class discussions (soft scaffolds) [10], [50]. By integrating assessment with instructional design, the framework aligns with the overarching goals of PBL, promoting both skill acquisition and the capacity for lifelong learning.

The implementation of this framework involves assigning codes to student artifacts based on six key themes, allowing for a nuanced analysis of their problem-solving approaches**.** In our study, three researchers independently evaluated and coded student artifacts, achieving a high level of agreement. This consistency demonstrates the framework's reliability and its potential for use by instructors and teaching assistants. Furthermore, the framework is adaptable to various types of student artifacts, including reports, reflection essays, slides, and portfolios, provided that the criteria for each theme are clearly defined and the key activities related to addressing the problem's ill-structuredness and complexity are appropriately distinguished.

Our assessment framework presents numerous opportunities for future exploration and development. First, it serves as a starting point for rethinking assessment, especially in PBL learning environments, emphasizing the process of problem-solving and activities students engage with during this process alongside the correctness of final products. By operationalizing Jonassen's ideas about resolving ill-structuredness and complexity, this framework offers a practical approach to integrating these critical aspects into student assessment. Future work will involve further refining the emerging themes and codes within the assessment framework, implementing it in practice, and investigating how it translates into courses and artifact evaluations. Another important avenue of research is examining the time and effort required to integrate this tool into action, exploring how educators perceive its usability, and identifying potential challenges in its implementation. Additionally, we aim to study the impact of this framework on students, particularly its influence on their problem-solving engagement and learning outcomes. The ultimate potential of this framework lies in its ability to support faculty in implementing PBL or PBL-like experiences while fostering a vibrant PBL community of practice. By reducing barriers to adoption and promoting a culture of collaboration and resource sharing among educators, it aims to make PBL a more accessible and appealing pedagogical approach for engineering education.

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Appendices

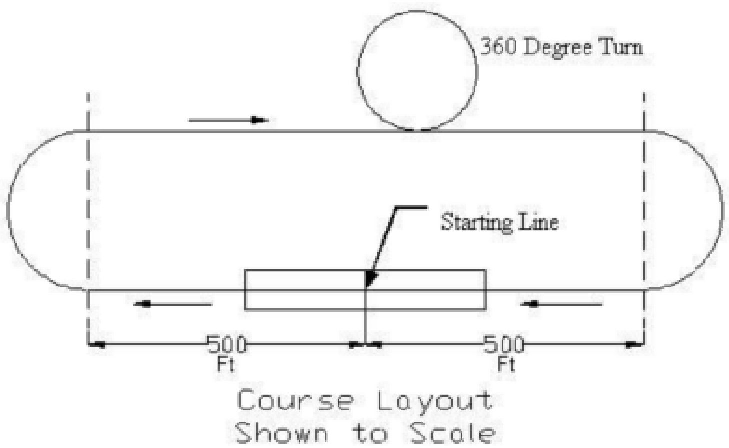
A.1. Problem Statement

<u>Multi lecture problem #1</u>

September 9, 2022

You and your group are entering the AIAA Foundation Design/Build/Fly (DBF) competition. This is a yearly competition that is a partnership between the AIAA Foundation, Cessna Aircraft Company, and Raytheon Missile Systems. Student teams entering this competition have an opportunity to design and build a radio-controlled aircraft to perform a specific mission. At least 1/3 of the team members must consist of freshman, sophomores or juniors. Invited teams bring their plane to a central location for a flyoff, where winners are determined via a score that is calculated based on a submitted report and flight performance.

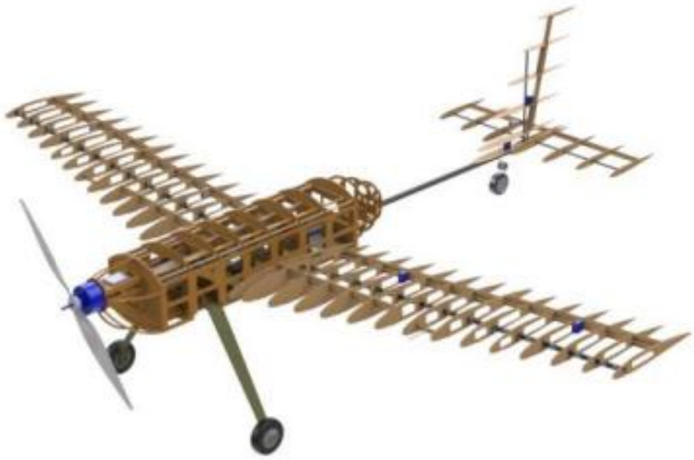
The AIAA DBF competition requires that teams design, fabricate, and demonstrate their flight capabilities of an unmanned, electric-powered, radio-controlled aircraft that meets a specified mission profile. The host site for your competition will be Provo, UT. The course layout being used for this year is:



The following requirements have been defined by the AIAA DBF competition committee:

- A payload of 3 lb must be carried by the aircraft.
- Takeoff field length is 25 feet from the starting line.
- Aircraft TOGW (take-off gross weight with payload) must be less than 55-lb.
- Propulsion power total stored energy cannot exceed 100 watt-hours. Teams may choose between NiCad/NiMH or Lithium Polymer batteries (only one battery type can be used in the system).
- Teams must complete 3 laps within a flight window of 5 minutes.
- The upwind turn will be made after passing the upwind marker. The downwind turn will be made after passing the downwind marker. Upwind and downwind markers will be 500 ft from the starting line. Aircraft must be "straight and level" when passing the turn marker before initiating a turn.
- No form of externally assisted take-off is allowed. All energy for take-off must come from the on-board propulsion battery pack(s).
- Must be propeller driven and electric powered with an unmodified over-the-counter model electric motor.
- Motors may be any commercial brush or brushless electric motor.
- No structure/components may be dropped from the aircraft during flight
- A successful landing means that the aircraft must land on the paved portion of the runway. Aircraft may "run-off" the runway during roll-out. Aircraft may not “bounce” off the runway.
- Flight altitude must be sufficient for safe terrain clearance and low enough to maintain good visual contact with the aircraft.

Your team has progressed through the early conceptual development of the aircraft. You have settled on a monoplane with a low-wing configuration. Your design has a conventional tail, with two wheels connected to the fuselage via a common strut or fairing and one wheels connected to the tail. The propulsion system is a tractor configuration, consisting of a single motor on the front of the aircraft.



Now that your team has a rough shape of the aircraft (such as the non-dimensioned representation shown above), it must be scaled appropriately. This requires considering the scale of the airframe in conjunction with the propulsion system. For example, if you determine that you can get a certain performance out of a particular combination of wing area and engine power, you may be able to get the same performance by switching to a more powerful propulsion system and reduce the wing area. Doing so will allow us to make two key design decisions later in the process: a selection of wing area and a choice of the powerplant.

As a starting point, your team also has the following information:

- Competitive lap times are often less than 30 seconds
- The aerodynamics sub-team is interested in using a MH114 or NACA 5410 airfoil

Your task is conducting a trade analysis that determines feasible combinations of wing loading (W/S) versus power-to-weight ratio (P/W), then explaining the tradeoffs between viable combinations, so that the aircraft can be scaled.

A.2. Artifact Coding Scheme

Theme	Description	Code
Problem Framing	Not present *[PF-0]*	[PF-0]
	Low-level (describe weekly objective) *[PF-1]*	Regurgitation of the problem Statement [PF-1R]
		Reframing in their own words [PF-1O]
	High level (overall objective) *[PF-2]*	Regurgitation of the problem statement [PF-2R]
		Reframing in their own words [PF-2O]
Problem Type Identification	Not present	[PT-0]
	Selection problem/Focus on components	[PT-S]
	Analysis problem	[PT-A]
Narrative Communication	Not present	[NC-0]
	Present but ambiguous or lacking justification – does not tell the story of why they are doing what they are doing, or lacks quantitative reasoning	[NC-1]
	Clear/logical (but could be conceptually or technically wrong)	[NC-2]
	Clear/logical (conceptually and technically correct)	[NC-3]
Resolution of Complexity	Not present	[RC-0]
	Acknowledge need to decompose into phases of flight (Indication of procedural knowledge)	[RC-1]
	Representing different phases of flight either with text, diagrams, or both (Indication of conceptual knowledge)	[RC-2T, RC-2D, RC-2TD]
	Represent equations for each phase (Indication of structural knowledge)	[RC-3]
	Synthesis to full model	[RC-4]
Resolution of Ill-Structuredness	No evidence of treating as ill-structured; presenting like well-structured problems (e.g. listing knowns and unknowns based ONLY on info in the problem statement	[RIL-0]
	Evidence of treating as ill-structured by use of domain knowledge to make the problem tractable	[RIL-1]

	(assumptions, judgements, beliefs) but NO JUSTIFICATION	
	Evidence of treating as ill-structured by use of domain knowledge to make the problem tractable (assumptions, judgements, beliefs) w/ SOME JUSTIFICATION	[RIL-2]
	Evidence of treating as ill-structured by use of domain knowledge to make the problem tractable (assumptions, judgements, beliefs) w/ CLEAR, LOGICAL + CONSISTENT JUSTIFICATION	[RIL-3]
Outcome and "Correctness"	yes or no (they got to a final deliverable that is consistent w what instructor intended/expected)	[YES or No]