Streamlining Industry-Sponsored Capstone Documentation with MBSE: Enabling Architecture Trade Studies and Early System Level Simulation

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Abstract

This full paper reports an evidence-informed academic practice from the Electrical and Computer Engineering Department at the University of South Florida that applies Model-Based Systems Engineering (MBSE) to address a recurring challenge in industry-sponsored capstone projects: documentation that is inconsistent across teams and difficult for sponsors and faculty to review efficiently, particularly when multiple design alternatives must be compared and justified. Building on a program-wide systems engineering foundation aligned with the V-model, USF integrates MBSE across the curriculum, from the Professional Formation of Engineers (PFE) sequence, through the two-semester capstone, supported by a Canvas module with curated MBSE and Systems Modeling Language (SysML) project examples. In Capstone I, teams use an MBSE-informed workflow implemented with modeling tools to produce a model-centered "digital thread," using diagrams and tables that link stakeholder needs, requirements, functions, candidate architectures, trade-study criteria, and verification intent.

Within this workflow, teams document architecture alternatives and conduct trade-off analysis using explicit evaluation criteria tied to requirements, supporting transparent design decisions. Where appropriate, teams also use AI-assisted tools to support requirements refinement and accelerate architecture exploration. The workflow requires an early feasibility check in the form of a high-level system simulation, defined here as a simplified executable representation that validates key functional behavior and interfaces at the system level, rather than detailed component modeling, completed by the end of Capstone I. Observed outcomes and lessons learned are synthesized from sponsor/SME feedback, poster-session evaluator input, including a standardized rubric summarized descriptively using Fall 2025 as an illustrative compiled example, and faculty observations. Across these evidence sources, stakeholders consistently emphasized clearer requirements, stronger decision traceability, more effective stakeholder communication, and increased attention to early verification planning. The paper describes the curricular integration and minimum artifact set, summarizes recurring patterns identified across evidence sources, and outlines next evaluation steps and tooling directions as SysML capabilities evolve.[1]

Introduction

Industry-sponsored capstone projects increasingly require students to approach the design process from a multidisciplinary perspective that integrates mechanical, electrical, software, and human-centered considerations. Traditional document-centric workflows often struggle to manage this complexity, resulting in inconsistent artifacts and inefficient stakeholder communication [1].

[1] This material is based upon work supported by the National Science Foundation under Grant No. 2022299

Model-Based Systems Engineering (MBSE) helps address these challenges by using digital models as the primary means to capture and relate requirements, behavior, and architecture [1], [2]. These integrated model repositories reduce inconsistencies across stakeholder views, support lifecycle decision-making, including architectural trade-off analysis, improve traceability, and strengthen verification and validation planning. Adoption across aerospace, automotive, and healthcare sectors illustrates how MBSE supports distributed engineering teams operating under safety and regulatory constraints. [3], [4], where it helps distributed teams coordinate designs under rigorous safety and regulatory constraints. The Systems Engineering Vision 2035 projects a future in which model-centric practices are pervasive across the system life cycle [5], supported by digital threads and digital twins. In July 2025, the Object Management Group approved the final adoption of SysML v2, including a standardized API, underscoring the timeliness of MBSE education and improved tool interoperability [6]. In this paper, Systems Modeling Language (SysML) refers to a standardized modeling language used in MBSE to represent requirements, structure, behavior, and interfaces with traceability to verification intent; while SysML v2 is being piloted in projects starting this semester, the evidence reported here reflects the workflow as implemented before full SysML v2 adoption.

Within engineering education, students increasingly engage in complex industry-sponsored projects that demand a comprehensive and systematic development process. Often, students pursue solutions they perceive as optimal at the moment, without a full understanding of stakeholders' requirements or project objectives. Adopting a well-established systems engineering methodology provides the structured framework needed to define, develop, and validate a product effectively. Such an approach guides the creation of a development roadmap that ensures alignment with stakeholder needs and establishes clear validation pathways throughout the project lifecycle; in the process, students develop systems thinking and digital engineering competencies needed for model-centric environments. Yet many programs still rely on traditional document-based design methods and offer limited exposure to MBSE or SysML.

Capstone projects, which require students to integrate technical knowledge, teamwork, and project management, often exhibit high variability in documentation practices and communication with project stakeholders, reducing efficiency and traceability. At the University of South Florida, the Electrical and Computer Engineering Department embarked on a program transformation supported by a National Science Foundation (NSF) RED (Revolutionizing Engineering Departments) grant beginning in 2020. A central outcome of this effort, the TRUE initiative, expanded industry-defined capstone projects; today, more than 90% of projects are sponsored by industry partners. Sponsors and evaluators have highlighted opportunities to improve documentation consistency, communication efficiency, and early technical validation across teams. This paper describes an MBSE-informed documentation workflow supported by a Canvas module of MBSE/SysML project examples and integrated from the Professional Formation of Engineers (PFE) sequence through Capstone I. The workflow is designed to streamline capstone documentation, support structured trade-off analysis of candidate architectures, improve communication among students, faculty, and industry SMEs, and require an early feasibility check through high-level system simulation planning by the end of Capstone I.

This paper reports observed outcomes and lessons learned derived from implementation evidence that includes: (a) capstone documentation artifacts, i.e., Concept of Operations (ConOps), requirements, architecture alternatives, trade-study matrices, and verification intent artifacts), (b) sponsor/SME feedback and poster-session evaluator input collected during reviews and poster evaluations, and (c) instructor observations across multiple project cycles. Qualitative themes emphasize documentation clarity, decision traceability, stakeholder communication, and early feasibility/verification planning; where available, standardized poster-session evaluation rubric summaries, reported descriptively using Fall 2025 as an illustrative compiled example, provide structured external context for these themes.

To guide the reader, this paper contributes an MBSE-informed approach to engineering education practice by: (i) introducing a replicable capstone workflow structured around a minimal artifact set aligned with the V-model; (ii) integrating architecture trade studies with traceable requirements to support transparent design decision-making; (iii) requiring early system-level simulation as a feasibility check to promote verification thinking by the end of Capstone I; (iv) synthesizing stakeholder feedback to identify recurring challenges in documentation quality, communication, and verification readiness; and (v) proposing a transferable "artifact spine", i.e., stakeholder needs → requirements → architecture → verification, that can be adopted across programs without full MBSE tool dependence.

2 Literature Review

Prior work in engineering design education shows that introducing systems-engineering structures in capstone design courses, such as System Level Diagrams and requirement/architecture allocations, improves students' design skills, system-level understanding, and team communication [7]. Studies on teaching Model-Based Systems Engineering (MBSE), including MBSE for Industry 4.0 and active-learning-based MBSE instruction, further demonstrate that model-based representations help students manage system complexity, articulate and refine requirements, and plan verification at the system level rather than only at the component level [8]. In addition, literature research on industry-sponsored capstone projects finds that well-structured experiential projects with clear processes, expectations for deliverables, and strong sponsor engagement enhance students' creativity, problem solving, professionalism, and workforce readiness [9], [10], [11], [12].

2.1 Model-Based Systems Engineering and Digital Transformation

MBSE is a methodology that employs graphical languages and digital models to represent system requirements, design, analysis, verification, and validation. Unlike document-based approaches, MBSE centralizes behavioral and structural representations in a unified repository, thereby enhancing consistency and reducing errors later in the life cycle. INCOSE describes four pillars of MBSE: the modeling language, modeling tools, methodology, and assurance, including safety and reliability [1], [5]. Adoption of MBSE in aerospace, automotive, and healthcare sectors demonstrates its ability to manage complex, multidisciplinary systems. The Systems Engineering Vision 2035 predicts that by 2035, MBSE will be integrated with digital threads, digital twins, and artificial intelligence to support life-cycle system exploration [5]. MBSE descriptive models facilitate abstraction and maintain a separation of views, enabling stakeholders to work at appropriate levels of detail. Furthermore, MBSE is increasingly connected to cybersecurity paradigms such as the Zero Trust Architecture [13]. The Carnegie Mellon University Software

Engineering Institute notes that Zero Trust emphasizes least-privilege access and continuous evaluation of trust and recommends MBSE-based mission thread modeling to support secure systems development.

2.2 MBSE in Engineering Education

Recognizing that industry demands graduates proficient in systems methods and modern engineering tools, some programs have begun integrating systems engineering into capstone courses. Looft's 2016 ASEE paper developed a course to teach systems engineering topics using an inverted classroom [14]; students watched videos and completed readings before class, then applied SE methods to capstone design problems. The paper argued that SE methods support ABET outcomes related to system design, problem formulation, and the use of modern tools. More recently, Chandra et al. proposed a modular approach to integrate MBSE and systems thinking into second- and third-year courses leading into capstone projects [15]. The modules, drawn from a digital engineering certificate program, teach systems modeling languages such as UAF and SysML, emphasize human-centric design, and include experiential projects where students define stakeholders, develop use cases, and build digital models. This approach responds to the U.S. Department of Defense Digital Engineering Strategy, which calls for transitioning from document-based design to model-analyze-build processes [16].

Pallavi Singh's 2024 dissertation demonstrates the potential of MBSE for simulating educational systems [17]. She describes MBSE as an evolution of traditional systems engineering that uses models as the primary means of communication. The dissertation highlights MBSE's benefits for engineering education, including improved collaboration, data-driven decision making, identification of inefficiencies, and adaptability to change. Singh notes that MBSE frameworks leverage the V-model, emphasizing early and continuous verification and validation throughout the development cycle.

2.3 MBSE tools and SysML v2

MBSE tools fall into three categories: functional decomposition, SysML-based object-oriented modeling, and mathematical modeling. SysML, an extension of Unified Modeling Language (UML), is a widely used modeling language for MBSE and is supported by commercial tools such as No Magic Cameo Systems Modeler™ [2]. In 2025, the Object Management Group approved SysML v2, which enhances precision, communication, and interoperability [6]. SysML v2 provides textual and graphical representations, supports nested hierarchies, and defines a standard API for tool integration. These features facilitate traceability across complex system hierarchies and encourage adoption across industries. In the context of this paper, the reported evidence reflects a SysML-based workflow implemented prior to full SysML v2 adoption; SysML v2 is being piloted in projects that began this semester as part of ongoing tooling evolution.

2.4 MBSE Adoption in Industry and Implications for Education

The adoption of MBSE across sectors underscores the need for graduates proficient in digital engineering. In the automotive industry, MBSE helps coordinate mechanical, electrical, and software subsystems. Aerospace projects use MBSE to manage interfaces and verification activities. Healthcare applications rely on MBSE to ensure safety, accommodate diverse user needs, and integrate with existing infrastructure. An industry survey by NASA found that using SysML and MagicDraw improved traceability from mission concept to requirements in the SporeSat CubeSat project compared with document-based approaches [4]. These examples illustrate how MBSE enhances clarity, traceability, and performance, supporting the argument for its integration into engineering curricula.

2.5 Curricular Integration at USF

A cornerstone of the NSF RED TRUE initiative is the Professional Formation of Engineers (PFE) sequence, a three-course progression, EGS 2070, 3071, and 3072, designed to introduce systems thinking and the foundations of the systems engineering V-model early in the curriculum and to prepare students for a later transition to MBSE. Unlike the senior capstone courses, which employ SysML-based modeling environments and structured verification/simulation planning, the PFE sequence is intentionally tool-agnostic. It emphasizes the systems-thinking mindset, stakeholder awareness, and disciplined documentation and traceability practices that later support an MBSE-informed 'artifact spine', i.e., ConOps/stakeholder needs, system requirements, architecture, verification intent. As shown in Figure 1, students become familiar with key phases of the life cycle, from Concept of Operations (ConOps) and requirements elicitation through architecture definition, verification planning, and final validation with an industry sponsor during the end-of-year poster presentation.

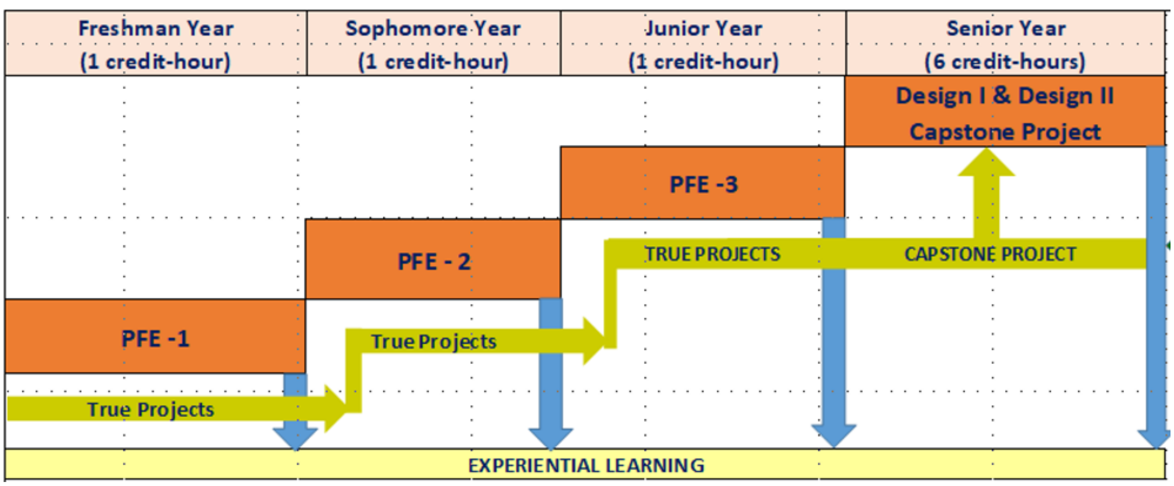


Figure 1: Progression from Professional Formation in Engineering (PFE) to Industry-Driven Capstone

3.1 Professional Formation Sequence

One of the USF Electrical and Computer Engineering Department's transformation initiatives begins in the Professional Formation of Engineers (PFE) sequence, a set of three one-credit courses inspired by NACE career readiness competencies [18]. These courses encourage students to build professional networks, develop ethical awareness, and introduce foundational concepts of systems engineering methodology. While not exclusively focused on MBSE, the sequence introduces systems thinking and highlights the importance of documenting stakeholder needs and requirements, maintaining documentation traceability, and considering scenarios, feasibility, and troubleshooting during early concept development. Students learn to formulate action plans and receive feedback on teamwork and professionalism. The sequence thus lays a foundation for MBSE by emphasizing reflection, communication, stakeholder awareness, and ethical design considerations.

Phase 1: PFE 1 Technology Investigation and Inquiry

In the first stage of the Technology Development Project Evolution, students engage in small-team investigations of existing patented technologies. Students identify patent awardees, analyze original design processes, and map technological precursors by identifying prior patents cited in applications. Teams propose modifications to adapt these technologies for USF campus applications, effectively performing an early V-model step: stakeholder needs identification and initial problem framing.

Phase 2: PFE 2 Lean-Launchpad and Requirement Elicitation

The second stage shifts toward a customer-discovery model, where students apply Lean-Launchpad methodologies to validate their proposed enhancements. Each team conducts stakeholder interviews as part of requirements elicitation. Students begin tracking schedules and individual task lists, introducing core project-management and data-management discipline without requiring digital system models.

Phase 3: PFE 3 Architectural Definition and Project Planning

The final course in the sequence requires the creation of a comprehensive Technology Development Project Plan. Students define a high-level architecture, hardware/software requirements, and external interface requirements. This stage mirrors the left side of the V-model, moving from abstract stakeholder needs to high-level technical specifications. While students identify safety, security, and quality considerations, the focus remains on the logic and traceability of the plan rather than executing models in simulation software. This tool-agnostic approach helps students internalize the underlying logic of MBSE, connecting stakeholder needs, requirements, functions, and components, before being introduced to the complexity of SysML-based modeling environments. Digital thread implementation and monitoring. While the PFE sequence builds the mental model, the department also uses digital dashboards to track student formation and deliverable progress across the multi-year sequence.

3.2 MBSE Oriented Course Sequence

MBSE concepts and tools are introduced through multiple, coordinated pathways. First, the department developed a graduate Systems Engineering course more than a decade ago for a master’s program serving working professionals. Approximately three years ago, this course evolved into a combined graduate/undergraduate elective on MBSE, digital engineering, and digital twins, aligning with workforce-development needs in critical industries [19]. In parallel, MBSE-relevant ideas are reinforced in technical courses. For example, in Linear Control Systems, students learn block diagram representations and system dynamics that naturally map to behavioral and structural modeling. The dedicated MBSE elective then formalizes these ideas by teaching the V-model, SysML notation, and the use of MBSE tools to support architecture modeling, traceability, verification planning, and early feasibility assessment. Students develop a Concept of Operations (ConOps), perform feasibility analysis, derive and manage requirements, build functional and physical architecture models, and define verification and validation plans. Together, these experiences create a coherent learning continuum that prepares students to apply an MBSE informed workflow in the capstone sequence.

3.3 Capstone Design Sequence

The two-semester capstone sequence, Capstone I and Capstone II, is the culminating undergraduate design experience and the primary venue for applying an MBSE-informed workflow. At the start of Capstone I, the lead instructor establishes a documentation and review workflow aligned with the V-model to streamline documentation outputs and support structured trade-off analysis of candidate architectures. The Concept of Operations (ConOps) is a stakeholder-oriented description of the system being developed [20]. A comprehensive ConOps presents multiple views of the system corresponding to key stakeholder groups, which may include operators, owners, developers, maintainers, management, and in some cases, end users. The ConOps is intended to be reviewed by stakeholders to obtain agreement on the system description, operational context, and maintenance concepts. In the Vee model, the ConOps provides the upstream basis for deriving system requirements and establishing validation expectations for the system being built. Student teams use MBSE tools such as No Magic Cameo Systems Modeler™, MathWorks System Composer™, and Dalus to develop SysML-based artifacts that capture stakeholder needs, requirements, functional decompositions, component architectures, interfaces, and verification intent. A key expected outcome is improved communication among students, faculty, and industry SMEs through shared, model-based views of the system.

Teams are also required to complete an early feasibility check by the end of Capstone I. In this context, early system-level simulation is defined as a simplified, executable representation of the system that captures key functional behaviors and interfaces at an abstract level, enabling teams to evaluate feasibility and major design assumptions before detailed component design or prototyping. This requirement is operationalized through a high-level system simulation plan and, when feasible, an initial simplified executable model used to assess system behavior against requirement-driven criteria. The MBSE/V-model/AI framework developed under the NSF TRUE project [21] integrates model-based design tools, architecture trade studies, verification and validation workflows, and performance tracking. Teams establish traceable linkages among requirements, design elements, decisions, and verification intent to reduce "oral-history design" and support sponsor review. Finally, a competency-based portfolio supports team formation by mapping each project's required EE Knowledge, Skills, and Abilities (KSA), derived from the project description to student KSA profiles captured through a structured survey.

Phase 4: Competency-Based Team Formation for Capstone Design

Following the department's competency-based team-formation process, students are assigned to industry projects using a two-stage optimization strategy grounded in multicriteria integer programming (MCIP) [22]. In Stage 1, student skill profiles, i.e., technical competencies, interests, and availability, are clustered using a Weighted Hybrid Model (WHM) with K-means to identify compatible groups. In Stage 2, single-objective optimization algorithms refine team assignments to satisfy project constraints, i.e., required skills, citizenship or export-control constraints when applicable, and balanced team composition, while maximizing overall fit for team-based learning (TBL). An MBSE-enabled portfolio database strengthens this process by providing structured evidence of student competencies, i.e., requirements artifacts, architecture models, and verification plans, rather than relying solely on self-reported skills.

To improve sponsor engagement and communication, industry SMEs receive a concise orientation to the MBSE-informed workflow used in capstone. This briefing focuses on how to review ConOps and requirements artifacts, how to interpret architecture trade studies, and how traceability supports timely, actionable feedback. Establishing this shared modeling literacy helps SMEs mentor teams more effectively and supports MBSE as a common language across stakeholders.

Phase 5: Capstone Execution and Industry Validation

The final phase of the V-model involves execution and validation of industry-sponsored projects. Teams apply systems engineering and MBSE-informed practices, i.e., structured requirements, functional analysis, traceability to verification intent, and documented trade studies, to address real-world problems provided by industry sponsors, with recurring reviews used to validate that the evolving solution remains aligned with stakeholder needs. In some cases, the department also provides brief MBSE workflow orientation to industry mentors to strengthen shared understanding and reduce onboarding friction. To reduce variability in capstone start-up, the department is piloting a Canvas module aligned with the PFE sequence that shares MBSE/SysML project examples and exemplar deliverables for student teams to use as references.

Table 1. Minimum Artifact Set by End of Capstone I

ConOps	Stakeholder needs, operational views, scenarios/use cases
Requirements (structured + traceability)	Candidate architectures (2–3)
AI tools to support requirements refinement	AI tools to support architecture exploration and trade studies
Trade study criteria + decision record	Verification plan outline
High-level simulation definition + expected outputs	Risk/assumptions list (optional)
Bill of Materials (BOM)	

3.4 Example of an MBSE Project: Insulin Infusion Pump Testing Design

As a pedagogical exemplar of MBSE in an academic–industry capstone (Spring 2025), a student team developed a mechatronics, robotics, and control concept inspired by an insulin infusion pump. Using No Magic Cameo Systems Modeler™, the team produced a SysML-based digital thread linking stakeholder needs, functional behavior, candidate architectures, and verification intent, including planned test cases. Regulatory-inspired constraints and safety considerations were treated as realistic design drivers to strengthen requirements and verification thinking, not as compliance claims. The team compared architecture alternatives using an explicit trade-off matrix tied to requirements and defined an early feasibility check through a high-level system simulation plan, understood as a simplified executable representation used to evaluate key behaviors and interfaces at the system level rather than detailed component modeling.

Figures 2-6 provide representative snapshots of the model artifacts used in the project, including system context and use cases, a structured requirements hierarchy, verification relationships linking test cases to requirements, and behavioral views used to plan early simulation. Together, these artifacts illustrate how an MBSE-informed workflow can support consistent documentation, sponsor/faculty review, and transparent design decision-making in Capstone I.

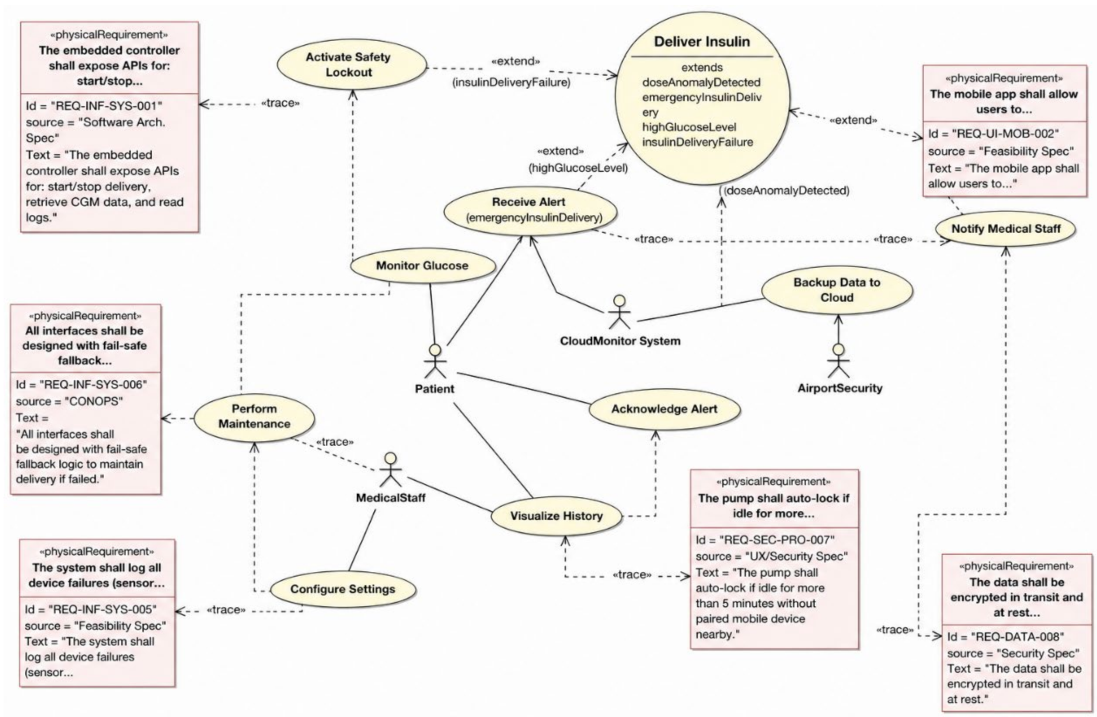
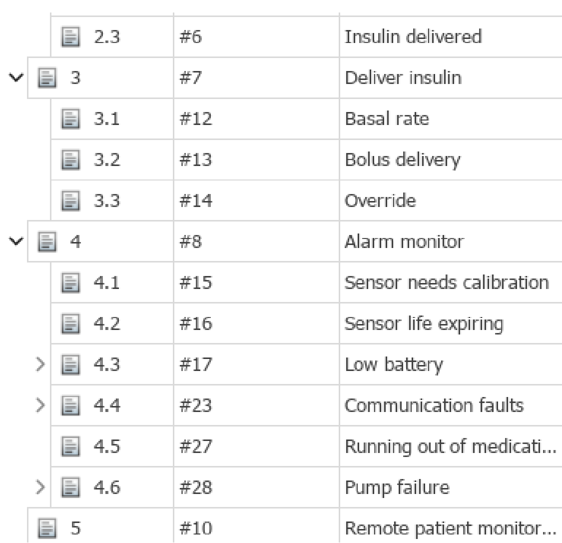


Figure 2. Insulin infusion pump exemplar: system context and use cases.



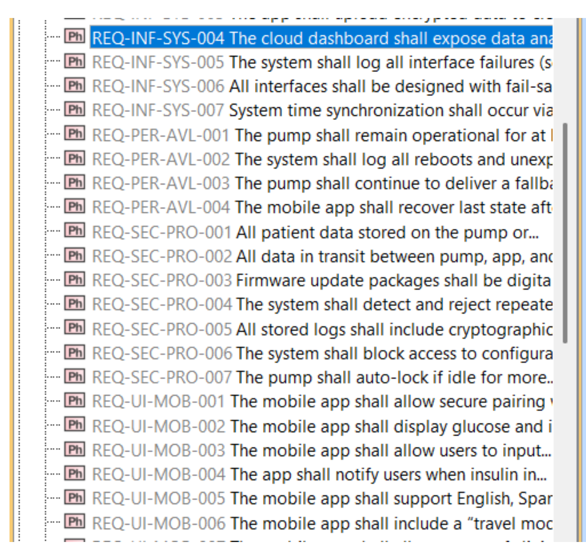


Figure 3. Requirements list. Figure 4. Structured index for requirements hierarchy.

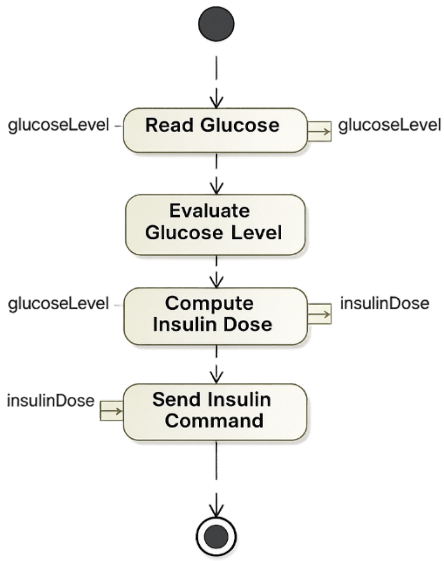


Figure 5. Activity diagram used to plan behavioral validation.

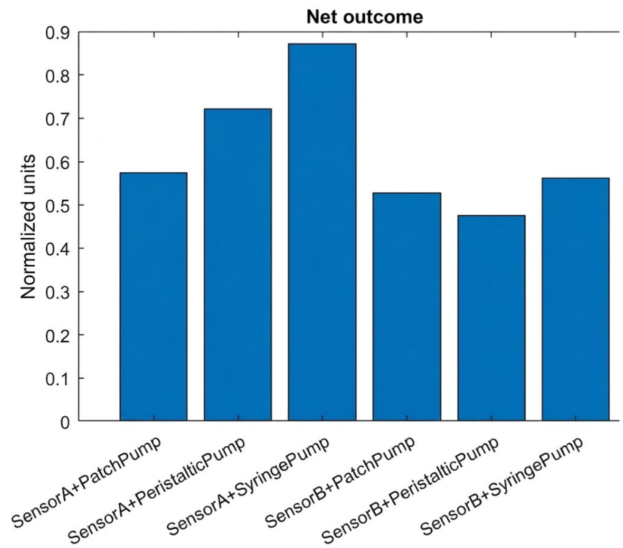


Figure 6. Parametric view supporting early performance exploration.

4 Evidence Sources and Synthesis Approach

4.1 Evidence sources and collection context

The evidence in this paper is drawn from implementation feedback collected through the NSF RED TRUE initiative activities. We use three complementary qualitative sources: (1) structured testimonials and review feedback from industry sponsors and Subject Matter Experts (SMEs) mentoring capstone teams, (2) written comments and rubric-based ratings from external evaluators during capstone poster sessions, and (3) faculty observation memos recorded during recurring project reviews.

The poster-session evaluator instrument is a standardized rubric aligned with ABET Student Outcomes 1-5 and is completed by external evaluators, i.e., Industrial Advisory Board members, Faculty, Ph.D. students, and SMEs, during the end-of-semester capstone poster event. This rubric has been administered each semester for approximately the past 5 years; however, at the time of this submission, only the Fall 2025 dataset has been compiled into an analyzable format and summarized descriptively. Accordingly, fall 2025 is reported here as an illustrative example of the structured external evidence available for triangulation with sponsor and faculty feedback.

Across these sources, feedback emphasized documentation reviewability, decision traceability, and stakeholder communication, especially when teams employed structured systems engineering practices, i.e., V-model framing, atomic requirements, and traceability to verification intent. These recurring observations motivate the next stage of work: deeper integration of MBSE artifacts, i.e., SysML-based model views, traceability links, and early simulation planning, to further strengthen architecture trade-study communication and verification planning; multi-semester rubric consolidation and analysis are planned as future evaluation.

4.2 Synthesis method

We synthesized the implementation evidence using a reflexive thematic analysis approach appropriate for program-focused educational practice work in which the authors are also instructors/designers. The goal of the synthesis was to identify recurring, actionable patterns in stakeholder feedback that could inform the adoption and refinement of the practices described in Sections 3.1 - 3.3.

Qualitative text was compiled from (a) sponsor/SME written testimonials and review notes, (b) open-ended comments provided by poster-session evaluators, and (c) faculty observation memos recorded during recurring reviews. Quantitative poster-rubric ratings (1 - 5 scale) were aggregated descriptively by team and outcome to provide context for the qualitative themes; these rubric summaries were not used to make causal claims about MBSE impacts.

4.3 Iterative synthesis process.

1. Compile & review: Consolidate all qualitative text into a single corpus and review it in full.
2. Code: Apply inductive codes capturing what stakeholders emphasized as working well, needing improvement, and recommended next steps, i.e., requirements clarity, decision traceability, stakeholder communication effectiveness, verification-planning readiness.
3. Cluster: Group codes into candidate themes and refine them through comparison across evidence sources (sponsors/SMEs, poster evaluators, faculty memos).
4. Define & map: Finalize theme labels/definitions and map each theme to the practices and artifacts in Sections 3.1 - 3.3, i.e., structured requirements, traceability mechanisms, trade-study documentation, verification, and planning documentation outputs to support transferability.

4.4 Reflexivity and positionality.

Because the authors are involved in designing and delivering the capstone sequence, reflexivity was treated as a required step. We maintained an audit trail, i.e., coding notes and theme revisions, and clearly distinguished direct stakeholder statements from author interpretation. Where feasible, themes were emphasized only when there was convergence across at least two evidence sources, i.e., sponsor feedback and evaluator comments, or evaluator comments and faculty memos. This approach supports transparent reporting while recognizing the limits of program-internal evidence.

4.5 Reporting convention.

In the results shown in Section 5, each theme is presented as an observed outcome/lesson learned and paired with (a) the evidence sources that supported it, and (b) the corresponding practices/artifacts to enable adoption by other programs.

5 Results and Discussion: Observed Outcomes and Lessons Learned

5.0 Overview of evidence supporting the themes

The themes reported in Section 5 were derived from the qualitative synthesis described in Section 4, using sponsor/SME feedback, poster-session evaluator comments, and faculty observation memos. We additionally include descriptive summaries of the Fall 2025 poster-session evaluator rubric results, see Table 2, as structured external context. These statistical quantitative summaries are used for contextualization and triangulation and are not used to make causal claims.

Table 2. Poster evaluator rubric descriptive results (Fall 2025; 1–5 scale).

ABET Student Outcome	Descriptor (short)	# Items	Mean (1–5)
SO1	Problem solving	5	4.53
SO2	Engineering design	5	4.43
SO3	Communication	3	4.69
SO4	Ethics/impact	3	4.47
SO5	Teamwork	6	4.68

5.1 Theme 1: Requirements clarity and reviewability improved with structured artifacts

Across sponsor/SME feedback, poster evaluator comments, when provided, and faculty memos, stakeholders repeatedly emphasized that teams were easier to evaluate when needs and constraints were expressed in structured formats, i.e., use cases, requirement tables/diagrams, and explicit assumptions. Reviewers noted faster identification of gaps and fewer late-stage clarifications when requirements were written atomically and linked to stakeholder needs and constraints. This theme aligns with the intended role of early capstone artifacts in establishing a stable baseline for architecture exploration and verification planning.

Implication for adoption: Requiring a minimal structured requirement set early in Capstone I, explicit assumptions, constraints, and traceable stakeholder needs, can improve review efficiency and reduce rework during later design phases.

5.2 Theme 2: Decision traceability supported architecture trade-offs and reduced "oral-history design"

Stakeholders reported improved transparency when teams could explain architecture selections by referencing documented trade studies, constraints, and requirement allocations rather than relying on informal discussions or undocumented rationale. Where teams maintained a decision record and traceability links, i.e., ConOps/stakeholder needs, system requirements, design decisions, sponsors indicated it was easier to provide timely, actionable guidance and to detect misalignment early during design reviews. This theme maps directly to the paper's emphasis on model- and artifact-supported decision reasoning.

Implications for adoption: In practice, sponsors reported that decision records paired with trade-study artifacts reduced clarification cycles during design reviews, especially in sponsor-facing capstone work where sponsor time is limited.

5.3 Theme 3: Shared visualizations improved stakeholder communication and review cadence

Sponsors, evaluators, and faculty noted that diagrams and shared views helped anchor discussions, enabling more focused technical exchanges and reducing misunderstandings. This was most visible when teams used a consistent "artifact spine" to structure reviews, i.e., stakeholder needs, requirements, architecture, verification intent. Even when full MBSE tooling was not uniformly applied across teams, consistent visual artifacts improved the communication cadence and reduced backtracking caused by ambiguous requirements or undocumented decisions.

Lesson learned: Non-MBSE stakeholders may require a brief orientation, i.e., a short primer on SysML-style views and how to interpret model outputs. Once a common vocabulary and navigation approach are established, sponsor feedback tends to become more specific and more actionable.

5.4 Theme 4: Early verification thinking increased perceived readiness for industry use

Review feedback repeatedly highlighted the value of teams explicitly planning verification early, identifying what would be tested, how it would be tested, and what acceptance criteria would indicate success. Evaluators described higher confidence when verification intent was visible before prototyping, particularly when teams connected verification plans to requirements and to key architecture decisions. This theme is consistent with the intervention goal of shifting capstone teams from "build-first" behavior to an engineering workflow that anticipates validation constraints earlier.

Implication for adoption: Requiring a preliminary verification matrix, even before full procedures exist, supports sponsor confidence, improves alignment with industry expectations, and provides an early mechanism to identify feasibility and risk.

5.5 What this evidence does and does not claim

The outcomes above represent stakeholder-reported benefits and recurring patterns observed across multiple review cycles and evidence sources. The findings are presented as implementation outcomes and lessons learned intended to support adaptation by other programs; they do not establish causal impact, consistent with the scope of practice-oriented conference contributions or quantify effect sizes. The primary contribution of this paper is a replicable set of practices and artifacts (Sections 3.1-3.3) paired with observed outcomes and transfer-oriented implications (Sections 5.1-5.4).

5.6 Limitations and next evaluation steps

This work is limited by reliance on qualitative feedback and by the number and composition of sponsors and external evaluators available in each cycle. Additionally, teams varied in their degree of adoption of MBSE-specific modeling, i.e., SysML-based model views, explicit model-to-requirement traceability, and early simulation planning, which limits attribution of observed outcomes to MBSE tooling versus baseline systems engineering structure.

The poster-session evaluator rubric has been administered each semester for approximately the past 5 years. In this paper, we use Fall 2025 as an illustrative example to demonstrate the structure of the rubric dataset and the type of descriptive summaries that can be produced from compiled evaluator forms. Future evaluation will also (a) add a formal student instrument and (b) incorporate a small set of objective indicators, i.e., number of requirement changes after baseline, review-cycle rework counts, time-to-closure of sponsor action items, and artifact completeness scores, to better characterize incremental effects associated with deeper MBSE integration.

6 Conclusion and Future Work

This paper describes a program-level approach at USF for moving an industry-sponsored capstone sequence from document-centric reporting toward an MBSE-informed, artifact-driven workflow designed to support consistent documentation, stakeholder communication, and early verification thinking. Building on V-model foundations introduced in the Professional Formation of Engineers (PFE) sequence, Capstone I teams develop an evolving “artifact spine”, i.e., stakeholder needs, requirements, architecture, verification intent, and where appropriate, implement a model-centered digital thread to connect requirements, candidate architectures, trade-study criteria, and verification planning.

Observed outcomes and lessons learned were synthesized from implementation evidence drawn from (1) sponsor/SME feedback collected during recurring reviews, (2) external poster-session evaluator feedback, including a standardized ABET-aligned rubric, and (3) faculty observation memos. Using Fall 2025 as an illustrative compiled example of the rubric dataset, descriptive summaries were used to contextualize the qualitative themes. Across these evidence sources, stakeholders consistently emphasized improved requirements clarity and reviewability, stronger decision traceability for architecture trade-offs, more effective stakeholder communication anchored in shared visual artifacts, and increased attention to early verification planning. A key implementation milestone is an early feasibility check, supported by a high-level system simulation plan and, when feasible, an initial simulation, completed by the end of Capstone I to de-risk major design choices before prototyping. In summary, the proposed methodology provides a practical and scalable approach to integrating MBSE-informed practices into industry-sponsored capstone design, supporting students’ professional formation, improving stakeholder communication, and aligning program outcomes with modern digital engineering expectations.

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