6M Framework: From Motivation to Mastery: Explore an Innovative Learning Framework, A Case Study

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Abstract

After World War II, engineering education gradually shifted from a practice and hands-on oriented model to an engineering science paradigm emphasizing mathematical and scientific rigor. Although this transition strengthened the scientific foundation of engineering disciplines, it also distanced students from authentic "making" experience, which is essential to spark intrinsic motivation and the formation of professional identity. Abstract topics and concepts such as phase diagrams in materials science continue to be taught primarily through lecture-based pedagogy and assessed via structured problem-solving approaches, and those approaches emphasize factual knowledge and conceptual understanding, which only touch at the lower levels of Bloom's Taxonomy. While lectures and structured problem-solving ensure conceptual accuracy, they rarely foster curiosity, reflection and metacognition, or a sense of ownership in learning, and most importantly, they frequently fail to support students form their identities as engineers.
As generative AI becomes increasingly integrated into engineering education, there is a growing concern that lecture-based learning may become less effective or even less relevant when students can easily access AI for explanations and examples. This rapid emergence of AI in engineering education underscores the urgent need for new learning frameworks that are not only AI-resilient but also attuned to the learning preferences of today's students, who are deeply immersed in social media and video-sharing platforms. Such frameworks should reimagine "making" as an integrative process that combines physical experimentation, reflective practice and digital creation to restore authenticity, motivation and engagement in engineering learning.
This paper introduces the 6M Framework (From Motivation to Making, from Multimedia to Meaning, from Metacognition to Mastery), a transferable and innovative learning framework that integrates hands-on experimentation with reflective multimedia creation to promote deeper learning and engineering identity formation. Grounded in Kolb's experiential learning cycle, Multimedia Learning Theory (MLT) and Self-Determination Theory (SDT), the framework aligns active experimentation and reflective articulation with students' needs for autonomy, competence, and relatedness. To illustrate its application, the 6M framework was used to examine the learning process of a female engineering student enrolled in an upper-level materials engineering course. In this course, the student independently fabricated a copper–Tin alloy and produced a series of short videos and posted on YouTube: documenting and articulating her making processes. A subsequent semi-structured interview revealed that her experiences reflected the complete cycle of the 6M framework, demonstrating its potential to enhance motivation, engagement, and metacognitive awareness in engineering learning, which led to the mastery of phase diagram through alloy making and multimedia creation process.

Introduction

The evolution of engineering education in the post-World War II era was fundamentally shaped by the shift toward an engineering science paradigm [1]. While this transition successfully infused mathematical rigor into the curriculum, scholars argue it inadvertently marginalized the "practice-oriented" experiences that historically defined the profession [2]. This separation of theory from practice has been particularly detrimental to the development of engineering identity, as students frequently struggle to connect abstract derivations with the tangible reality of professional work [3].

This pedagogical gap is particularly acute in upper-level engineering courses, where foundational concepts, ranging from control systems to thermodynamics, often become increasingly abstract and mathematical intense. Traditional instruction in these courses frequently fall into learning the lower levels of Bloom's taxonomy by recalling theoretical derivation or solving structured, well-defined problems with single right solutions. However, research indicates that deep conceptual understanding requires moving beyond passive reception toward active construction of knowledge [4, 5]. To address this, educators have increasingly adopted Kolb's Experiential Learning Theory, which posits that deep learning occurs through a recursive cycle of Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation [6]. However, despite widespread theoretical acceptance, the practical translation of Kolb's cycle into the classroom remains inconsistent. Faculty often acknowledge the value of active learning strategies, they face significant implementation barriers, often reverting to traditional lectures due to a lack of concrete operational models [7]

The need to rethink the engineering science paradigm is amplified by the rapid integration of Generative AI into the engineering education landscape. As large language models (LLMs) become capable of solving standard textbook derivation problems and explaining theoretical concepts with high accuracy, traditional lecture-exam model faces an existential challenge. If a student can instantly retrieve a perfect explanation of a copper-Tin cool curve in the Phase diagram, the educational value of assigning such passive tasks diminishes.

This technological disruption underscores an urgent need for "AI resilient" learning frameworks. Assessment must move beyond what AI can generate to what it cannot yet simulate: authentic physical experience combined with personal reflection. The physical act of making - handling heat, alloying, machinery –is un-fakable. One cannot hallucinate a cast ingot or digitally fabricate the specific, localized errors that occur during a physical melt. Furthermore, when this physical process is coupled with multimedia with student's unique narrative voice through video to articulate the connection between theory and practice, it generates meaning, foster metacognition, and cultivate the professional identity necessary for true mastery. To operationalize this holistic approach, this paper introduces the 6M Framework: From Motivation to Making, from Multimedia to Meaning, from Metacognition to Mastery. This framework is a pedagogical model designed to restore authenticity and engagement in the age of artificial intelligence.

Literature Review

The 6M Framework is not merely a sequence of activities but a synthesis of three distinct learning theories. To understand how "Making" and "Multimedia" lead to "Mastery," it is necessary to examine the underlying cognitive and psychological mechanisms defined by Kolb's Experiential Learning Theory, Self-Determination Theory, and Multimedia Learning Theory.

The mechanism of experience: Kolb's cycle

At the core of the framework is Kolb's Experiential Learning Theory (ELT), which defines learning as "the process whereby knowledge is created through the transformation of experience" [6]. Kolb posits that for deep learning to occur; a learner must traverse a recursive four-stage cycle:

1. Concrete Experience (CE): Engaging in a tangible activity (feeling, doing).
2. Reflective Observation (RO): Stepping back to viewing the experience from different perspectives (watching, reviewing).
3. Abstract Conceptualization (AC): Distilling reflections into logical theories or models (thinking).
4. Active Experimentation (AE): Testing these theories in new situations (doing).

Kolb's ELT is widely recognized as a foundational model for engineering laboratory design. However, qualitative research reveal that traditional implementations of ELT often fall shorts. In a qualitative study of engineering students engaging in an experiential project, Chan [8] utilized focus groups to map student experiences directly to Kolb's four stages and the finding revealed that while CE and AE are easily achieved in engineering projects, the RO phase is frequently rushed or bypassed entirely without deliberate pedagogical intervention. Similarly, Abdulwahed and Nagy's analysis of engineering laboratory education concluded that without structured reflection, hands-on experiments fail to translate into abstract conceptualization [9] The 6M framework explicitly addresses this gap by mandating the multimedia phase as the vehicle for reflective observation.

The Engine of Engagement: Self-Determination Theory (SDT)

While Kolb describes *how* learning happens, Self-Determination Theory (SDT) explains *why* students engage. Deci and Ryan argue that intrinsic motivation—doing something for its own sake rather than for a grade—is sustained only when three basic psychological needs are met [10]:

- Autonomy: The need to feel ownership over one's actions. In contrast to "cookbook" labs where the outcome is predetermined, open-ended "making" projects allow students to make high-stakes decisions about material selection and process design.
- Competence: The need to feel effective and capable. The physical feedback loop of fabrication (e.g., successfully casting an ingot) provides immediate, tangible validation of competence that abstract grades cannot.
- Relatedness: The need to feel connected to others. This is often the most neglected component in engineering curricula, which can encourage solitary, competitive study. By requiring students to publish their work to an audience (e.g., via YouTube), the learning process becomes a social contribution, satisfying the need for relatedness and fostering a sense of belonging within the engineering community.

STD has increasingly been utilized to understand the persistent retention and engagement challenges in engineering education. In a mixed-methods study of electrical and computer engineering students, Trenshaw et al [11] redesigned a sophomore course specifically around STD principles and the qualitative data demonstrated that students' sensor of autonomy and competency significantly enhanced when shifting from mandatory exams to student-selected design projects, leading to deeper intrinsic motivation. Within the 6M Framework, Self-Determination Theory (SDT) functions primarily as the theoretical foundation for Motivation. By allowing students to select their own physical projects, the framework satisfies the SDT need for Autonomy, providing the intrinsic drive necessary to initiate the learning cycle.

The Cognitive Tool: Multimedia Learning Theory (MLT)

To transform the "Making" experience into "Meaning," the framework leverages Mayer's Cognitive Theory of Multimedia Learning (MLT). Mayer posits that humans possess separate channels for processing visual and verbal material and that learning is deepest when both channels are engaged simultaneously: a process known as Dual Coding [12]. Creating an instructional video is a cognitively demanding task that forces this integration. To explain a physical phenomenon (like a cooling curve) in a video, a student must:

- Select relevant images and text.
- Organize them into a coherent narrative structure.
- Integrate verbal explanations with visual evidence.

As students create their raw footage to teach an audience, they are forced to move up Bloom's Taxonomy from simple Application to Synthesis and Evaluation [13, 14]. They cannot simply repeat a textbook definition; they must translate their physical experience into a language that an audience can understand, a process that exposes gaps in their own understanding.

Metacognition and Engineering Identity

The convergence of experiential, self-determination, and multimedia learning theories culminates in two critical outcomes for students: the activation of metacognition and the formation of professional identity. To understand how the 6M framework facilitates these learning outcomes, it is necessary to operationalize these constructs within the context of engineering education.

Metacognition is defined as active monitoring and consequent regulation of one's own cognitive processes [15]. In engineering education, operationalizing metacognition means evaluating a student's ability to recognize their own knowledge gaps and adjust their problem-solving strategies accordingly [16, 17, 18].In the context of the 6M framework, this metacognitive regulation is triggered when the "Ideal" (Abstract Conceptualization) clashes with the "Real" (Concrete Experience).When a student's physical result deviates from theoretical textbook model- such as a phase diagram-they are forced to engage in metacognitive monitoring. They might ask *"Why did this fail? Is the theory wrong, or is my process wrong?"* Navigating this ambiguity requires students to step outside their immediate task and evaluate their own thinking, move beyond rote application to higher-order critical evaluation of Bloom's taxonomy [19].

Furthermore, the successful metacognitive regulation serves as the foundation for engineering identity development. Engineering identity is not merely a subjective feeling, but is operationalized through three intersection constructs [20]:

1. Performance/competence, measured as the belief in one's ability to understand and execute engineering tasks.
2. Interest, measured through the desire to engage in the subject matter; and
3. Recognition, measured through perceiving oneself and being perceived by others as an engineer

Traditional lecture formats often fail to support the recognition construct because the student's work is only seen and assessed by grades. The 6M framework directly addresses this gap. By successfully reconciling theoretical models with physical realities through making and articulating and publishing their findings via multimedia phase, students demonstrate competence and demand recognition from an audience.

The 6M framework

Building upon the theoretical foundations of Experiential Learning, Self-Determination Theory, and Multimedia Learning, this paper proposes the 6M Framework. This model is designed to guide students through a complete cognitive and physical learning cycle, explicitly bridging the gap between abstract theory and engineering practice. It consists of six distinct stages, organized into three transitional pairs:

- Phase 1: Engagement and execution (motivation and making): The learning cycle is initiated by intrinsic curiosity (STD's autonomy) which drives the students to step away the textbook and grapple with the ill-structured (Design and engineering problem solving space), multi-sensory reality of physical fabrication (Kolb's CE).
- Phase 2: The Cognitive Bridge (Multimedia & Meaning)**:** To process the physical event, the student acts as an instructor. Utilizing dual-channel processing (Mayer's *MLT*), they organize their raw footage and map abstract mathematical or structural models (Kolb's *Abstract Conceptualization*) directly onto their physical results to create an explanatory narrative
- Phase 3: Reflection and Identity (Metacognition & Mastery): The student critically evaluates the discrepancies between the "ideal" textbook theory and their "real" physical artifact. The cycle culminates in the public publication of their multimedia artifact, satisfying the fundamental psychological need for community contribution (SDT's Relatedness) and establishing a professional engineering identity.

Table 1 outlines the comprehensive alignment, detailing how each stage of the 6M framework connects to its foundational theory, targets specific cognitive levels within Bloom's Taxonomy and generates tangible, AI-resilient assessment artifacts for the instructor.

Table 1 6M framework

6M Stage	Theoretical Anchor	Bloom's Taxonomy Level	Pedagogical Activity	AI-Resilient Assessment Artifact
Motivation	SDT: Autonomy (Intrinsic Drive)	Analyze: Identifying knowledge gaps	Inquiry-Based Learning: Student formulates a "Why" question based on personal curiosity and future professional alignment, rather than an instructor-provided prompt.	The Research Proposal: Student submits a specific, self-generated inquiry (e.g., "Why does Bronze harden differently than Pure Copper?").
Making	Kolb: Concrete Experience	Apply: Executing procedures	Physical fabrication (melting, casting, etc.) requires the student to navigate complex, unpredictable real-world variables.	The Physical Artifact: The cast ingot, circuit, or prototype (Serves as proof of physical labor; cannot be AI-generated).
Multimedia	Mayer: Cognitive Theory of Multimedia Learning (Dual Channels)	Create: Organizing elements	Learning-by-Teaching: Student films the physical process and edits the footage, forcing them to select and organize visuals to explain the "Making" phase to a lay audience.	Curated Visual Assets: The specific selection and chronological arrangement of video clips that accurately demonstrate the phenomenon.
Meaning	Kolb: Abstract Conceptualization	Synthesize: Connecting real-life data to theory	Student overlays theoretical models (e.g., Phase Diagrams) directly onto their physical footage in the video editor.	The Narrative Voiceover: The accuracy of the student's script in explaining why the physical event occurred using formal theoretical terminology.
Metacognition	Flavell: Cognitive Monitoring / Kolb: Reflective Observation	Evaluation: Judging internal consistency	Student actively identifies discrepancies between the "Ideal" (Theory) and the "Reality" (Physical Artifact), articulating their discrepancies within the video narrative.	The Metacognitive Reflection: The specific segment of the video where the student articulates what failed, why it failed, and how they adapted.
Mastery	SDT: Relatedness & Competence (Identity Formation)	Create: Public Contribution	Publishing video to a community (YouTube etc). This marks the transition from Student to Contributor.	The Published Video: The final, public-facing multimedia artifact that demonstrates conceptual mastery and demands peer recognition.

Methodology

Research Design

This study employs a qualitative, single-subject case study design (N=1) to explore the cognitive and affective mechanisms of the 6M Framework. While single-subject designs are most frequently associated with medical or health interventions, they are increasingly utilized in STEM education to establish the foundational validity of pedagogical models before scaling [21, 22]. By prioritizing depth over breadth—a strategy supported by Sochacka et al.'s narrative analysis of engineering empathy—this research is framed as a design-based, exploratory proof-of-concept rather than a generalized, scale-level evaluation.

Central to this approach is a Collaborative Autoethnography (CAE) design [23]. In this model, the primary researcher and the participant—who also serves as a co-author—reflexively analyze their shared educational experience to understand broader pedagogical phenomena. While the participant's dual role as a co-author provides an "insider" perspective with unique metacognitive depth, the authors acknowledge the inherent limitations regarding researcher-participant bias and the non-random nature of the recruitment.

Participant Context

The participant, a female undergraduate materials engineering student, was purposively identified after she self-initiated an independent project to fabricate a bronze (copper-tin) alloy and document the phase transformation process. Because the project was self-initiated, it perfectly mirrored the "Autonomy" construct of Self-Determination Theory; the student operated without external instructor rubrics or formal grading incentives.

The task required the participant to physically cast the alloy and subsequently produce an educational YouTube video explaining the metallurgy. This self-motivated multimedia task served as a naturalistic vehicle for the Reflective Observation phase of Kolb's cycle.

Data collection

Data was collected through a semi-structured interview conducted after the project's completion to probe the students' cognitive and affective states across the six dimensions of the framework. To ensure analytical rigor, the interview was recorded, transcribed, and subjected to thematic analysis. The analysis mapped the participant's responses against the 6M dimensions to demonstrate how the synthesis of Experiential Learning, Self-Determination, and Multimedia Learning theories supports the learning process and identity formation.

The study creates a triangulation of data between physical artifacts, digital media, and oral reflection.

- The Making Task: The participant independently identified a research question regarding the hardening properties of bronze and fabricated a 9:1 copper-tin alloy using a furnace and crucible.
- The Multimedia Task: To document the "Reflective Observation" phase, the participant filmed, edited, and published a video narrative of the process to YouTube, explicitly connecting her physical results to theoretical phase diagrams.
- The Interview: Primary data was collected through a semi-structured interview conducted after the project's completion. The interview protocol was designed to probe the students' cognitive and affective states at each stage of the framework. The interview was recorded, transcribed, and thematically analyzed to map the co-author's responses against the six dimensions of the framework.

Results: Case Study Analysis

The thematic analysis of the interview transcript provides robust empirical evidence for the efficacy of the 6M Framework. The co-author's reflections trace a clear trajectory from curiosity to conceptual mastery, validating the specific mechanisms proposed in each stage of the model.

Motivation: The Power of Autonomy

The study indicates that deep engagement began not with an external mandate, but with a self-generated question rooted in personal experience, supporting the Self-Determination Theory

(SDT) principle of *Autonomy*. The student, who had a background in hobbyist blacksmithing, noted that prior to the class, she asked herself

" if steel gets malleable when it's hot, why does bronze get harder? ...I knew what I was going to be looking into prior [to the research]. Instead of studying an entire topic, I knew which specific things I was looking for."

By allowing the research question to stem from her personal curiosity, the framework transformed the learning process from a passive requirement into an active investigation.

Making: Anchoring Theory in Reality

The physical "Making" process served as the Concrete Experience (Kolb) necessary to ground abstract concepts. The student described a specific moment where the immediate sensory feedback of the material corrected her theoretical assumptions about cooling:

"The bronze immediately started to harden... it was helpful to see... that it wasn't perfect."

She emphasized that this multisensory engagement was critical for her retention, acting as a cognitive anchor for the theory: *"I need to physically experience something before I can really grasp it... when I have all of the senses involved, it's much easier for me to recall it later."*

Multimedia: Structuring Knowledge via Dual Coding

The student's decision to document her via a video, effectively engaging in "learning by teaching." Mechanism. The process of creating the video compelled her to organize her intuitive physical knowledge into a logical narrative structure (Dual coding). The analysis reveals that the video editing process was not merely technical but deeply cognitive, requiring the logical organization of information:

"I also had to figure out chronologically which things to show first... showing the phase diagram for copper before tin."

This process of selection and arrangement functioned as a mechanism for Reflective Observation, pushing her to identify and fill gaps in her own knowledge:

"I had to explain it deeper and understand it further when I was looking for extra visuals."

Meaning: Bridging the Abstraction Gap

The most significant cognitive breakthrough occurred in the Meaning phase, where the student successfully bridged the gap between 2D theoretical models and 3D physical reality. The act of visualizing the data for the video led to a profound realization regarding the nature of phase diagrams:

"I didn't know that there were three-dimensional phase diagrams until I made this video. And I was like, oh, my God, I get it now."

She directly attributed this breakthrough to the combination of hands-on work and mathematical theory: *"I understand the math once I see something physically... [this project] helped a lot to understand the math part of it for me."*

Metacognition: Mental Models and Identity

The project facilitated a shift in professional identity and a heightened awareness of her own cognitive processes (Metacognition). The student articulated her internal "mental model" with a vivid metaphor, describing herself as having a *"CAD simulator in my head"* that requires physical data to function. Furthermore, the process of sharing her work helped her transition from feeling like an academic outsider to a contributor:

"I never really felt like I fit in anywhere... But having the opportunity to share this experience... has made me feel unique... I have something to contribute."

Mastery: Confidence and Transfer

Finally, the student reported a level of confidence and retention superior to traditional lecture-based learning. She stated,

"I felt more confident... I was able to grasp... a more real understanding... instead of the theoretical understanding."

Crucially, the study demonstrates Transfer of Learning. The student reported applying this exact strategy—visualizing abstract concepts to build mental models—in a subsequent Calculus course. This suggests that the 6M Framework does not just teach materials science; it equips students with an enduring, AI-resilient strategy for mastering complex domains.

Discussion

The 6M Framework offers a pedagogical solution to the historical dissociation of theory from practice and the modern threat of Generative AI. While previous instructional models often rely on a single theoretical lens, this case study demonstrates that engineering identity and conceptual mastery require the synthesis of multiple learning domains. By structurally coupling intrinsic motivation (Self-Determination Theory) with physical execution (Kolb’s Experiential Learning) and digital articulation (Mayer’s Multimedia Learning Theory), the 6M model forces a cognitive integration that none of these activities achieve in isolation.

The primary pedagogical contribution of this framework is the operationalization of Kolb's *Reflective Observation*. Traditional "cookbook" labs often short-circuit Kolb’s cycle, allowing students to generate physical data without genuine contemplation. In the 6M Framework, the "Multimedia" requirement disrupts this passivity. The video production process acts as a cognitive forcing function akin to the Feynman Technique [24]; students cannot deeply understand a concept unless they can explain it simply to a lay audience. In this framework, the camera acts as the "unblinking audience," and the video editor becomes a secondary laboratory where students must reconcile "messy" physical data with "clean" theoretical models. This transforms reflection from an abstract ideal into a tangible, gradable deliverable, ensuring students identify gaps in their own understanding before submission.

Critics of experiential and multimedia learning often cite resource constraints as barriers to implementation [7]. However, the logistical feasibility of the 6M Framework rests on leveraging a resource that is already ubiquitous: the student’s smartphone. Current undergraduates are digital natives, possessing universal literacy in video creation. This dramatically lowers the technical barrier to entry; students do not need to be taught how to film or edit, they only need to be guided on *what* to document. This democratization of production means the framework requires near zero institutional capital investment, meeting students where they are and converting their recreational digital habits into rigorous, AI-resilient academic skills.

Conclusion

This exploratory case study serves as a proof-of-concept for the 6M Framework, illustrating how the integration of physical fabrication with digital storytelling can deepen conceptual understanding and foster professional engineering identity. While the findings are derived from a single-subject collaborative autoethnography (N=1) and cannot yet be generalized to the broader engineering student population, the qualitative data provides a critical, granular look at the internal cognitive shifts that occur when students bridge theory and practice. The study indicates that when students act as autonomous "makers" and multimedia "narrators," they are less likely to rely on passive rote memorization or Generative AI shortcuts. Instead, the requirement to document physical phenomena creates a learning artifact that is inherently personal, process-oriented, and resistant to algorithmic generation.

Future research will focus on scaling this intervention to larger cohort sizes to empirically evaluate its logistical feasibility and statistical impact on student retention and identity formation. For practitioners, this study offers a preliminary roadmap: by shifting the instructor's role from a traditional lecturer to a facilitator of experiential and multimedia learning, engineering programs may find a viable pathway to reconcile the historic divide between abstract theory and physical practice. Ultimately, the 6M Framework proposes a comprehensive pedagogical blueprint for the future of engineering education—one that fosters graduates who are as confident in the physical workshop as they are in the theoretical classroom, while equipping them with the AI-resilient cognitive strategies necessary to thrive in an increasingly automated world.

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