From Externally Regulated Participation to Intrinsic Motivation and Adaptability: The ICARE Pathway in Early-Year Engineering Education

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Abstract

Rapid socio-economic and technological transformation is reshaping expectations of future engineers, elevating not only technical competence but also interdisciplinary thinking, creativity, collaboration, and responsible professional judgment. These shifts foreground the need for educational models that develop not only knowledge and skills but also motivation and adaptability, particularly in the early years when students are forming initial professional identities and deciding whether to persist in the major.

Yet early-year engineering students often enter university with externally regulated participation, uneven tolerance for ambiguity, and limited readiness to navigate critique, setbacks, and collaborative demands. Although emotional and motivational factors are increasingly recognized as consequential, early-year curricula and widely used frameworks (e.g., CDIO 3.0, KEEN 3Cs, PBL/TBL, maker-centered learning) still only partially address the comprehensive and progressive nature of Emotional Readiness.

A central challenge is that Emotional Readiness is both developmental and heterogeneous: students' emotional demands shift across interest exploration, technical challenge, teamwork, and professional meaning-making, while cohorts show uneven readiness profiles. This yields three design implications: instruction should be organized around evolving learner needs, emotional empowerment should be treated as an explicit learning goal, and supports should be differentiated across emotion awareness, stress management, resilience, and self-efficacy.

Guided by a reverse developmental analysis of stage-based psychological needs, we articulate a trajectory from safe exploration of interests and future selves, through individual and collaborative challenge engagement, to professional self-authorship and sustained intrinsic motivation and adaptivity. To operationalize this trajectory within existing curricula, we propose ICARE, a staged instructional architecture (Inspire–Challenge–Accompany–Redefine–Empower), that sequences instructor facilitation to progressively cultivate Emotional Readiness and guide students' role transition from compliance-driven participation toward value-led engagement and adaptive professional growth.

We demonstrate ICARE in a first-year Engineering Graphics course using an artifact-based Double Diamond workflow, and frame assessment through triangulated evidence from deliverable traces, cohort patterns, continuity beyond the course, authentic-audience outcomes, and student-reported perceptions. Collectively, the paper contributes a curriculum-compatible pathway model and an evidence-oriented implementation approach that make early-year emotional motivational development explicit, staged, and assessable, positioning gateway courses as a leverage point for cultivating the readiness conditions that sustain motivation and adaptability over time.

1. Introduction

The industrial landscape is undergoing a profound paradigm shift driven by the convergence of information, communication, and artificial intelligence technologies. Industry 4.0 integrates cyber–physical systems, pervasive sensing, and data-driven automation to transform industrial production models [1–4], while Industry 5.0 complements this by emphasizing a sustainable, human-centric, and resilient industrial transition [5], [6]. Together, these developments move industrial practice beyond efficiency and profit maximization toward broader societal value creation, resilience, and human well-being.

This shift reshapes expectations for engineering graduates. Beyond strong disciplinary foundations, industry and policy reports consistently highlight four core competency demands. First, interdisciplinary understanding is essential, as complex real-world problems increasingly span mechanical, electrical, computing, and social domains, and rely on cyber–physical system integration [2], [3]. Second, creativity is required to generate novel solutions to unmet industrial and societal needs and is frequently cited as a key human advantage relative to intelligent machines [2]. Third, effective collaboration is needed for engineers to work productively in cross-disciplinary, intercultural, and multi-stakeholder teams, where diverse perspectives can enhance innovation and performance [4]. Fourth, social responsibility has become a central expectation, aligned with Industry 5.0's emphasis on the Sustainable Development Goals (SDGs) and the imperative that technologies contribute to societal well-being [2], [5], [9], [10].

However, consistently developing and applying these four competencies depends on two upstream, domain-general attributes: intrinsic motivation and adaptability. Rooted in Self-Determination Theory (SDT), intrinsic motivation refers to the drive to learn and act based on autonomy, competence, and relatedness rather than external rewards or pressures [5–8]. In engineering contexts, intrinsic motivation supports deeper conceptual understanding, exploratory thinking, and the internalization of ethical and professional values, thereby fueling interdisciplinary learning, creative problem solving, collaborative engagement, and social responsibility [5], [6], [8]. Adaptability, defined as the capacity to adjust cognitions, behaviors, and emotions in response to novelty, uncertainty, and change [11–13], is increasingly critical amid rapid technological evolution and projected large-scale needs for reskilling and upskilling [2], [7]. Adaptability enables engineers to update mental models, revise strategies under new constraints, modify communication and role behaviors in dynamic teams, and address competing stakeholder needs in ways that sustain responsible practice [2], [11–13], [27].

The cultivation of intrinsic motivation and adaptability is therefore not a peripheral concern, but a central design goal for modern engineering education. Yet, even technically well-constructed curricula do not automatically foster these attributes. Students' willingness and capacity to sustain effort, learn from difficulty, and respond adaptively to uncertainty depend on underlying psychological conditions, particularly how they perceive demands, regulate emotions, and interpret success and failure. The remainder of this paper addresses two questions: (1) what psychological foundations support the development of intrinsic motivation and adaptability in engineering students, and (2) how can early curricular experiences be structured to deliberately cultivate these foundations in ways that are compatible with existing program constraints?

2. Literature Review and Research Gaps

2.1 Emotional Readiness as a Cross-Cutting Psychological Foundation

To capture the psychological foundations that enable intrinsic motivation and adaptability in engineering students, we adopt Emotional Readiness as a custom, integrative construct tailored to engineering education. Rather than a single, clearly bounded "skill", Emotional Readiness is conceptualized as a dynamic state of psychological preparedness: a readiness to encounter, make sense of, and work constructively with the emotional demands that arise at different stages of the engineering learning trajectory. Drawing on work in social–emotional learning, developmental psychobiology, resilience theory, and achievement emotions [2–4], [7], [10], [15], we define Emotional Readiness as the degree to which students are prepared to notice and interpret their learning-related emotions, tolerate and manage the associated stress, recover from setbacks, and sustain a sense of competence as they move from interest exploration to technical challenge, collaboration, public evaluation, and long-term self-growth. This preparedness is underpinned by four interrelated dimensions:

- Emotion awareness: the ability to recognize and label learning-related emotions in engineering contexts (e.g., anxiety when using unfamiliar CAD tools, frustration in team conflict, pride after resolving a design impasse) [1], [23].
- Stress management: the use of context-appropriate strategies to cope with academic and project-related pressure, such as iterating on failed prototypes or balancing technical tasks with coordination duties [10], [15], [21].
- Psychological resilience: the capacity to maintain effort and reframe setbacks as part of iterative optimization rather than as evidence of fixed inability [15], [18], [23].
- Self-efficacy: confidence in one's ability to master engineering content, use new technologies, and contribute meaningfully to projects and teams [1], [19], [22].

These four dimensions do not exhaust Emotional Readiness, nor are they isolated competencies. Instead, they function as core ingredients and indicators of a broader readiness-to-learn state. Developmental and school readiness research shows that such self-regulatory capacities constitute a "readiness to learn," especially at transition points such as entry to university [2–4]. When students are psychologically prepared in this sense, able to monitor and regulate their emotions, manage stress, and sustain self-belief, they are more willing to engage with demanding coursework, persist through difficulty, and benefit from challenging learning environments [2], [7], [11–13].

In 21st-century skills frameworks, adaptability and self-regulation, including emotional regulation during monitoring and reflection, are similarly identified as foundational to sustained learning and performance in complex, uncertain environments [2], [7], [11–13]. Emotional Readiness thus operates as a cross-cutting foundation for intrinsic motivation and adaptability rather than as an additional outcome layered on top of them. SDT-based supports (e.g., autonomy-supportive teaching, authentic projects) are more likely to foster intrinsic motivation when students are emotionally prepared to tolerate ambiguity and manage the anxiety or frustration that often accompany autonomy and challenge [5], [6], [8]. Similarly, adaptability depends not only on exposure to novelty but also on students' readiness to update appraisals and emotional responses when demands shift [11–13], [39]. Students with higher Emotional Readiness can better reinterpret challenging tasks as opportunities for growth, modulate their effort and strategies, and maintain constructive engagement with peers and technologies.

Existing frameworks in engineering education implicitly address components of Emotional Readiness. Project-based and maker-centered curricula normalize iteration and failure [14], [24]; the KEEN 3Cs framework (Curiosity, Connections, Creating Value) encourages curiosity-driven, value-oriented work that can buffer frustration [9]; and SEL (Social and Emotional Learning) seminars can reduce distress and support student adjustment [10]. However, these efforts are typically fragmented: they rarely treat Emotional Readiness as a coherent developmental preparedness built across the learning trajectory or explicitly link stage-specific emotional demands (e.g., anxiety in open-ended tasks versus coping with critique in public evaluation) to the corresponding forms of readiness. To address this gap, the next subsection synthesizes stage-based psychological needs via a reverse analysis that traces from advanced outcomes back to foundational conditions, clarifying Emotional Readiness as preparedness across stages.

2.2 Stage-Based Psychological Needs in Engineering Learning: A Reverse Developmental Analysis

To clarify how Emotional Readiness supports intrinsic motivation and adaptability, we conducted a reverse developmental analysis by starting from the target outcome (sustained intrinsic motivation and adaptivity) and identifying the prerequisite capacities that enable it; we then present the resulting stage-based sequence in forward order for readability, highlighting how emotional demands evolve from initial participation through technical challenge engagement, collaboration, public evaluation, and professional meaning-making.

2.2.1 Proactive Self and Future Exploration

Learners often begin with compliance-driven participation, so the primary need is psychological safety to explore interests and possible future selves, build early self-efficacy through low-stakes action, and sustain curiosity despite uncertainty or imperfect ideas [8], [15], [16], [19], [25], [33], [40], [44].

2.2.2 Individual Technical Challenge Engagement

As learners encounter unfamiliar tools and open-ended problems, the primary need is to manage technical anxiety, normalize trial-and-error as expected learning, and interpret feedback as actionable input that builds competence rather than signals inability [2], [12], [17-19], [31].

2.2.3 Collaborative Challenge Engagement

When work becomes team-based, the primary need is to sustain agency and belonging while navigating idea down-selection, disagreement, uneven contributions, and role ambiguity, using emotion awareness and stress management to maintain shared ownership under social and task pressure [6-7], [16], [21], [28] [30], [42].

2.2.4 Professional Self-Authorship

As learners communicate work to wider audiences and face critique, the primary need is meaning-making support to reframe the vision–reality gap as legitimate trade-offs under constraints and to articulate decisions and limitations as justified professional judgment rather than personal success or failure [21-23], [27], [45], [49].

2.2.5 Intrinsic Motivation and Adaptivity

The desired outcome is a durable growth orientation in which learners integrate setbacks into a coherent learning narrative and flexibly adjust strategies, roles, and goals under novelty and change, sustaining self-directed learning over time [1], [18-20], [26], [29], [50].

2.3 Why early-year engineering students are a priority

The stage-based needs trajectory above implies that Emotional Readiness is progressively constructed and that weaknesses in early stages can propagate forward, shaping how learners respond to later technical, social, and evaluative demands. This progression is particularly consequential for early-year (Year 1–2) engineering students, who are simultaneously adjusting to new academic norms, forming initial professional identities, and deciding whether to persist in the major [18], [22]. Foundational "gateway" course performance strongly predicts subsequent academic progression [18], [20], while negative early experiences, such as perceived overload, repeated failure, or misalignment with engineering culture, are associated with attrition [19], [21].

During this transition, intrinsic motivation and adaptability function as protective factors: students with higher autonomous motivation and adaptability show greater persistence, well-being, and more constructive responses to failure and uncertainty [5–8], [11–13], [39]. Emotional Readiness, through emotion awareness, stress management, resilience, and self-efficacy, supports more favorable control–value appraisals, adaptive coping, and achievement emotions that sustain engagement under challenge [2–4], [7], [10], [11], [15], [21]. Importantly, Emotional Readiness is malleable; studies of entry-level design experiences and resilience profiling of university inductees suggest that targeted supports can strengthen self-efficacy, resilience, and adjustment with longer-term implications for persistence [1], [15], [21–23].

Early-year engineering education is therefore a high-leverage period for systematically cultivating Emotional Readiness as a foundation for intrinsic motivation and adaptability[35], [36], [48].

2.4 Implications for Instructional Design and Transition to a Staged Framework

Sections 2.2–2.3 suggest that Emotional Readiness is not a static trait but a progressively constructed preparedness that evolves as learners move from interest exploration to technical challenge, collaboration, public evaluation, and professional meaning-making. For early-year students, who are simultaneously adapting to university norms and deciding whether to persist, this implies that motivational and adaptive outcomes depend on whether curricula intentionally build the prerequisites needed at each stage, rather than assuming students already possess them.

Three instructional implications follow. First, instruction should be organized around stage-specific learner needs (e.g., safety for exploration, calibrated challenge, supported persistence, and meaning-making), so that autonomy and challenge become developmentally workable rather than prematurely overwhelming. Second, emotional empowerment should be treated as an explicit design target: major learning activities should intentionally cultivate emotion awareness, stress management, resilience, and self-efficacy as psychological conditions that enable students to persist, collaborate, and learn from difficulty. Third, because early cohorts show heterogeneous readiness profiles, supports should be differentiated and sequenced, shifting from stronger guidance and co-regulation toward greater student ownership as readiness strengthens[13].

Existing engineering education frameworks and pedagogies incorporate elements of these ideas, but they rarely specify a coherent staged architecture that links evolving emotional demands to corresponding instructor moves and observable transition outputs. To operationalize the reverse-derived trajectory in a curriculum-compatible form, we therefore propose ICARE (Inspire–Challenge–Accompany–Redefine–Empower): a staged instructional framework that translates the psychological pathway in Section 2.2 into a concrete sequence of facilitation functions, guiding students' role transition from externally regulated participation toward value-led engagement, professional self-authorship, and sustained intrinsic motivation and adaptability.

3. ICARE Framework: Conceptual Pathway and Instructional Architecture

3.1 Conceptual pathway: the intended student trajectory (Figure 1)

ICARE specifies a staged developmental progression culminating in intrinsic motivation and adaptability. Students typically begin as task-assigned learners characterized by compliance and limited perceived autonomy. Through staged support, ICARE is designed to foster (i) emerging personal agency and interest ownership, (ii) socially situated engagement and shared commitment, (iii) challenge-oriented persistence and adaptive help-seeking, (iv) professional self-authorship through meaning-making and trade-off justification, and (v) continuity planning that sustains motivated learning beyond the course context [25], [38], [39].

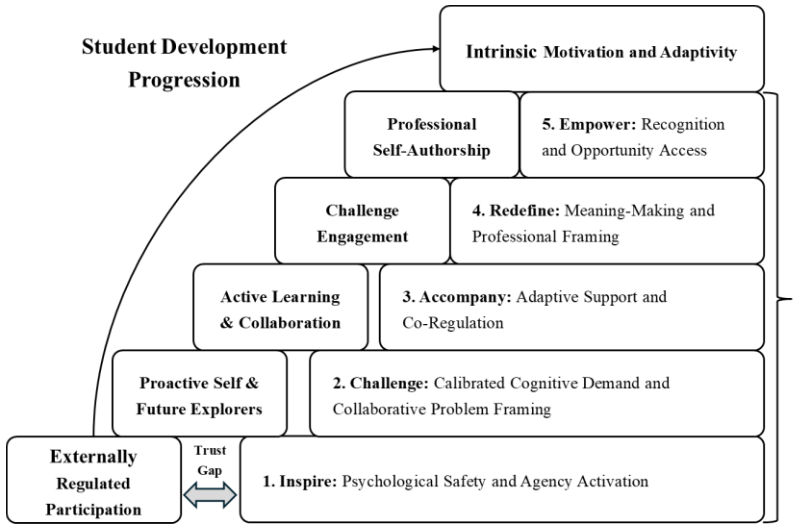

Fig. 1 Trajectory of Student Agency and Emotional Readiness

3.2 Instructional architecture: the ICARE blueprint (Figure 2)

ICARE aligns student development with stage-specific instructor facilitation through five stages, Inspire, Challenge, Accompany, Redefine, and Empower, each defined by a distinct instructional function. Inspire activates agency by establishing psychological safety and a respectful, growth-first environment. Challenge introduces calibrated cognitive demand through collaborative problem framing and vision-to-deliverables guidance. Accompany provides adaptive support and co-regulation through aligned resources, multi-tier technical/peer support, and real-time feedback. Redefine enables meaning-making and professional framing through structured reflection and explicit links to real-world contexts and longer-term learning pathways. Empower extends development through recognition and opportunity access, supporting visibility, growth tracking, and continuity beyond the course. Collectively, this architecture specifies how facilitation is sequenced to support progressive student role transition toward intrinsic motivation and adaptability.

3.3 Stage-by-stage operationalization and implementation narrative

ICARE is operationalized through five stage-specific narrative–table pairs (Tables 1–5). To maintain concision, the narrative does not restate what is already explicit in the tables; instead, it foregrounds each stage's instructional function and provides one or two representative implementation moves that illustrate how instructor facilitation produces the transition outputs.

3.3.1 Inspire: creating the conditions for students to choose to engage

At course entry, many students participate primarily because the course is required and thus tend to wait for instructions or seek the "correct answer." Inspire establishes psychological safety and a growth-first climate so it becomes legitimate to explore interests and possible selves through engineering, supported by curated inspirational resources that broaden plausible directions without prescribing a "right" path. A representative move is to institutionalize "error-free questioning/no-judgment" norms and separate early idea expression from evaluation, enabling broad ideation and interest-driven teaming before feasibility critique.

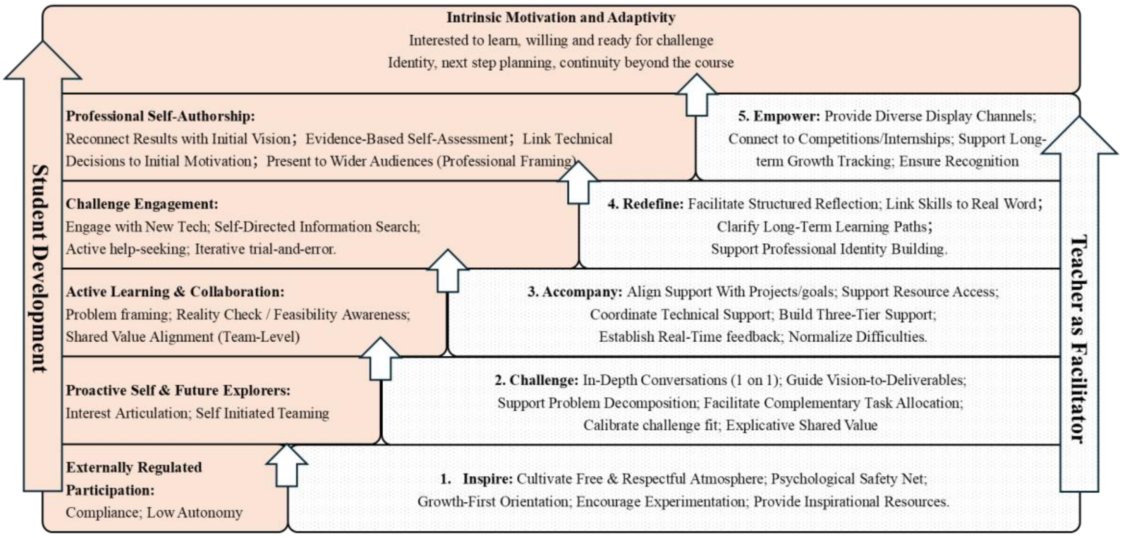

Fig. 2 Trajectory of Student Agency and Emotional Readiness

Table 1 Inspiration Phase Operationalization

Student's Track	Dominant Needs	Instructor Facilitation Actions	Transition Output
Open-Ended Brainstorming	Cultivate a free & respectful atmosphere for idea generation	Establish "error-free questioning" and "no-judgment" norms; prioritize quantity over quality; model curiosity-driven prompts	Generate a diverse idea bank, laying a solid foundation for students to select their top 5 ideas and initiate team matching
Idea Proposal & Teammate Matching	Psychological safety to share ideas and find aligned collaborators	Separate idea expression from evaluation; suspend feasibility critique; legitimize solo participation; make instructor matching rules transparent	Complete top 5 idea sharing and potential teammate connections, creating a clear interest matching list to focus ideas in the next phase
Reflect on top 5 & Keep Options Open	A growth-first mindset that embraces uncertainty	Reframe uncertainty as developmental; normalize iteration; delay commitment; provide reflection prompts to clarify interest-value alignment	Refine top 5 ideas with articulated uncertainties, offering a focused lens to draw inspiration from past projects
Explore Curated Inspirational Resources	Expanded imagination; direction without premature commitment	Curate diverse past-year projects; provide exploration websites/platforms; frame examples as inspiration (no templates)	Refine project visions with insights from past work, building a clear, inspired foundation for team formation
Interest-Driven Teaming	Autonomy with support; reduced identity friction in collaboration	Announce clear timeline and deadline; safeguard inclusion; review top 5 and instructor-match teams; confirm teams with students	Form stable, interest-aligned teams, accumulating insights to inform the next round of brainstorming and continuous learning loops

3.3.2 Challenge: turning interest into a shared, workable team commitment

Once interests are activated, a common barrier is translation: teams overscope, underestimate feasibility gaps, or split tasks without a shared purpose, weakening collaboration before technical work begins. Challenge structures convergence from vision to deliverables through focused 1:1/team check-ins (one-on-one consultations with individual students and with project teams) and explicit vision-to-output alignment (e.g., requiring teams to specify what they will show at the end and justify choices with criteria), then decomposes the project to calibrate a "stretch but doable" scope. A representative move is to surface hidden disagreement and force specificity by requiring a decision matrix and refined alternatives before commitment, so consensus is evidence-based rather than implicit compromise.

Table 2 Challenge Phase Operationalization

Student's Track	Dominant Needs	Instructor Facilitation Actions	Transition Output
In-Depth 1:1/Team Conversations	Psychological safety to voice preferences; equitable participation	Run 1:1/team check-ins; ensure every member speaks; probe quieter members; surface hidden disagreements	Generate individual rationale notes, building consensus for aligning on priority ideas
Align Vision-to-Deliverable Alignment	Shared understanding of "success"; ability to translate vision into actionable outputs	Require end-of-course outputs (prototype/report/demo); ask "what will you show at the end?"; push beyond vague slogans	Produce a decision matrix and 3 refined idea posters, translating vision into measurable success metrics
Decompose Project	Clarity on boundaries/goals; ability to break vision into sub-problems	Prompt: "What must be true for this to work?"; guide teams to split visions into technical/resource/collaborator sub-problems	Create a challenge or unknowns map, surfacing critical constraints to inform scope calibration
Calibrate Challenge Fit	A "stretch but doable" target; legitimacy to revise scope	Detect "1 real + 2 filler" patterns; require cross-idea discussion; run instant top 2 votes; mandate dissent with rationale	Generate a revised priority matrix, ensuring the challenge is appropriately ambitious to anchor team value alignment
Explicate Shared Team Value	Shared commitment; safe space to negotiate differences	Coach pitching; explicitly check commitment ("Are you willing to support this choice?"); assign "do more work and re-pitch" if no consensus	Finalize a Team Value Statement and conflict resolution plan, uniting the team to define bounded problem scope
Draft Bounded Problem Definition Report	Clear problem requirements; ownership with actionable boundaries	Provide a problem-definition template; prompt boundary questions (users, context, constraints); ensure the problem is non-trivial but achievable	Submit a Problem Definition Report, establishing clear scope to guide design decomposition
Decompose Vision to Design Specs & Tasks	Competence building; a path from vision to measurable progress	Coach translation from vision to requirements; push for measurable specs; identify technical/resource risks	Generate a draft Concept Report, breaking vision into actionable specs and tasks to frame task allocation
Allocate	Fair role division;	Prevent siloed ownership; mandate	Finalize a task

Complementary Task	ownership without fragmentation	cross-ownership checkpoints; assign complementary roles; define integration milestones	allocation table and team workflow plan, ensuring clear role alignment to support collaborative execution

3.3.3 Accompany: supporting persistence when technical difficulty becomes real

During execution, uncertainty can trigger avoidance, stagnation, or over-reliance on instructors (or tools such as generative AI) to bypass cognitively demanding steps. The issue is not only skill gaps but limited experience with productive struggle and recovery. Accompany retains student ownership while tightening the support ecosystem via aligned resources, a multi-tier support ladder (experts for direction, mentors for operations, peers for mutual learning), and short-cycle feedback routines that reduce "stuck time." A representative move is a post-checkpoint team meeting to diagnose over-simple versus over-ambitious goals and recalibrate scope, coupled with explicit normalization of difficulty as expected iteration and coached help-seeking.

Table 3 Accompany Phase Operationalization

Student's Track	Dominant Needs	Instructor Facilitation Actions	Transition Output
Refine Project Goals	Clear direction: calibrated ambition ("stretch but doable")	Hold post-concept report 1 on 1 team meetings; diagnose over-simple vs. over-ambitious goals; prompt scope refinement	Deliver revised goal/scope statements and action plans, providing clear direction for resource access and technical coordination
Access learning resources	Credible learning materials; reduced friction to learn new tech	Provide scaffolded resource packs (basic to advanced); point to databases/standards; tailor resources to team specs	Deliver a Curated Resource Pack and learning roadmap, equipping teams to tackle technical challenges
Seek Support	Timely feedback and targeted guidance to address execution gaps quickly	Establish a 3-tier support ladder: teachers/ lab technicians/domain experts (direction), seniors/mentors (operations), peers (mutual learning); publish "where to go for what" guidance; coordinate off-campus resources; Build dedicated Slack/WhatsApp channels; set response expectations; run short check-ins; require micro-updates	An efficient feedback mechanism (defined response norms + micro-update protocols) to address technical and execution issues promptly A student deep-linking network (3-tier support roster + peer collaboration channels) to foster sustained connections between learners, mentors, and experts
Normalize Difficulties	Emotional safety during setbacks; willingness to persist; resilience framing	Acknowledge anxiety as normal; validate effort; reframe setbacks as iteration; reinforce controllable next steps	Embed reflection prompts and resilience-focused feedback notes, building team grit to inform reflection

3.3.4 Redefine: developing professional self-authorship through meaning-making

After substantial technical work, many students experience a vision–reality gap and may interpret constraints and trade-offs as shortcomings, undermining their ability to explain professional significance. Redefine addresses this by facilitating structured reflection that reconnects outcomes to initial motivation and frames decisions as legitimate engineering judgment, supported by explicit links to real-world contexts, longer-term learning paths, and professional identity language. A representative move is a post-technical reflection and narrative-building session that makes trade-offs explicit and guides translation from technical features to an audience-appropriate value story.

Table 4 Redefine Phase Operationalization

Student's Track	Dominant Needs	Instructor Facilitation Actions	Transition Output
Facilitate Structured Reflection	Make sense of the vision-reality gap without self-blame; regain perspective beyond technical details	Run a reflection meeting post-technical completion; surface expectation vs. reality; support evidence-based reframing	Integrate reflection notes into the project report, creating a Lessons Learned module for future iteration
Link Skills to Real Engineering Expression (Trade-offs & Constraints)	Reframe struggle as authentic engineering; understand trade-offs of time/resources/skills	Make trade-offs explicit; connect CAD/analysis/prototyping to industry constraints; coach professional justification	Write trade-off rationale statements, building engineering literacy to inform long-term learning paths
Clarify Long-Term Learning Paths	Confidence gaps are addressable; a roadmap for "what to learn next"	Help students label current status (know/don't know/ready next); recommend targeted learning paths/resources	Generate a Next-Step Learning Plan with resource pointers, empowering students to grow beyond the project
Professional Identity Building	Objective self-assessment; ownership of achievements; ability to present as an emerging engineer	Coach accurate self-assessment language; link decisions to safety/cost/user needs/social impact; help students claim professional legitimacy	Produce Professional Identity Statements and Achievement Summaries, strengthening confidence for public communication
Prepare Wide-Audience Deliverable (Reconnection & Expression)	Ability to "zoom out" from details; reconnect outcomes to initial inspiration; confidence to communicate with depth and breadth	Hold a post-technical narrative-building meeting; prompt restating the initial spark; guide translation from features to value story	Finalize a Public Presentation Plan and demo script, laying the groundwork for multi-channel showcase
Coordinate Technical Debugging Support (Embedded)	Relief from being stuck; confidence through expert-backed troubleshooting	Connect discipline experts/mentors; structure debugging sessions); ensure understanding, not copying	Generate debug logs and issue status lists, resolving technical blockers to inform reflection on engineering trade-offs

3.3.5 Empower: extending motivation and adaptability beyond the course

Even when students do meaningful work, motivation can fade if the course ends at submission without continuation pathways or mechanisms to translate achievement into next opportunities.

Empower creates visibility and continuity through showcasing channels, recognition via structured feedback and public acknowledgment, and scaffolds that connect students to opportunities (e.g., competitions and internships) while making growth legible over time. A representative move is a cross-year exhibition paired with multimodal storytelling coaching and an opportunity and portfolio bridge, so students leave with a concrete next-step plan that sustains intrinsic motivation and adaptability beyond the course context.

Table 5 Empower Phase Operationalization

Empower Phase			
Student's Track	Dominant Needs	Instructor Facilitation Actions	Transition Output
Diverse Display Channels	Legitimate platforms to be seen; confidence to communicate publicly; audience-appropriate expression	Deliver a cross-year course exhibition; offer internal + external display channels; coach multimodal storytelling	Finalize an Exhibition Program and online showcase, creating visible platforms for recognition and external opportunities
Gain Recognition	Appreciation + belonging; confidence from being taken seriously; motivation through social acknowledgement	Arrange peer review + expert appraisal + public feedback; structure feedback prompts; recognize growth and contribution	Produce a Feedback Summary and Recognition Highlights, boosting confidence to pursue external opportunities
Connect to Competitions / Internships	Pathways from coursework to external opportunities; transferable formats	Recommend opportunities; coach adapting artifacts to external formats (pitch, portfolio, industry-style presentation); connect to contacts/mentors	Provide an Opportunity List and portfolio guidance, helping students translate coursework into competition/internship applications
Long-Term Growth Pathways (Advanced-Course Integration)	Continuity beyond the course; legitimacy to build further; clear next technical steps	Design bridge-to-curriculum mapping; link project needs to advanced courses/modules/labs; encourage carrying forward artifacts; suggest "next-tech stack" tools	Deliver a Project Continuation Package and course-mapping notes, creating a clear trajectory for extending projects in advanced courses

3.4 Summary

Taken together, ICARE sequences instructional support to enable progressive student role transition from externally regulated participation toward intrinsic motivation and adaptability. The design establishes psychological safety and agency, structures calibrated challenge and shared commitment, supports productive struggle through timely scaffolding, and consolidates professional self-authorship through reflection and professional framing; it then extends learning through recognition and continuity pathways beyond the course. The following section illustrates implementation and presents assessment evidence.

4. Example Implementation and Assessment Evidence

4.1 Linking ICARE to Observable Evidence

Section 3 described ICARE as a staged instructional support logic that develops students' emotional readiness for motivated learning, adaptive help-seeking, professional judgment, and sustained engagement. This section demonstrates how ICARE can be instantiated and assessed in a first-year CAD and Engineering Drawing (Engineering Graphics) course by embedding stage-specific deliverables along a Double Diamond workflow and triangulating evidence from course artifacts and authentic-audience outcomes.

4.2 Course Context: Engineering Graphics as the First Engineering Gateway

CAD and Engineering Drawing is typically students' first discipline-specific engineering course and a foundational experience for engineering identity formation. Engineering graphics is not only a drafting skill but a core engineering language for expressing initial ideas, defining requirements, developing technical solutions, and communicating design intent to stakeholders. In contrast to traditional graphics courses that emphasize standards and 2D documentation as an endpoint, this course positions graphics as an end-to-end communication medium within a concurrent engineering process, where ideation, technical development, and communication evolve together.

4.3 Implementation Backbone: Double Diamond deliverables as ICARE Scaffolds

We implement ICARE through an artifact-based Double Diamond that structures a diverge–converge rhythm across problem framing and solution development (Fig. 3). In the problem-space diamond, students move from broad exploration to convergence in a problem-definition report with feasibility reasoning; in the solution-space diamond, teams iterate from initial to revised concept reports through feedback, trade-offs, and troubleshooting, culminating in a poster and short video for exhibition and reflection. ICARE aligns with these transitions by sequencing support from early autonomy and psychological safety (Inspire) to calibrated rigor (Challenge), just-in-time scaffolding during iteration (Accompany), professional reframing and justification (Redefine), and public-facing recognition and continuity (Empower). Circles in Fig. 3 denote evolving idea/artifact representations rather than a fixed count.

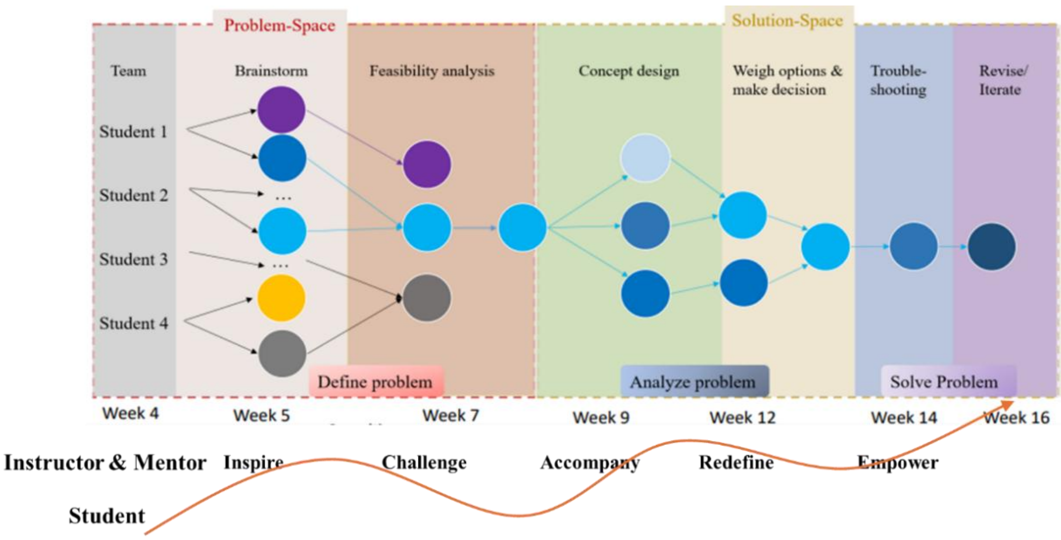

Fig. 3 Double Diamond Deliverables as ICARE Scaffolds

4.4 Micro Vignettes Motivating the Assessment Logic

To illustrate how the ICARE-aligned indicators in Table 6 are evidenced in authentic coursework, we use one end-to-end "backbone" case (coffee machine) and a contrasting-pair comparison (high-part-count integration versus deep iterative refinement on a smaller assembly), selected from a six-year archive of course projects (approximately 70 projects per year; 400+ projects total). The purpose of these vignettes is not to document project narratives in detail, but to show how assessment prioritizes developmental evidence (iteration quality, decision justification, and professional judgment) rather than artifact size or part count alone.

Backbone case (coffee machine) (Figure 4)

The coffee-machine case provides a compact evidence chain across stages: early interest ownership and psychologically safe participation are visible in ideation logs, "three ideas" posters, and peer critique traces (I2–I3). Convergence and calibrated challenge are evidenced by iterative problem definition and feasibility reasoning that revise scope, criteria, and decisions in response to critique (C2–C3). During execution, productive struggle is evidenced by targeted help-seeking and beyond syllabus learning tied to project needs, together with troubleshoot revise cycles in evolving CAD assemblies (A1–A3). Finally, professional reframing is evidenced by explicit trade-offs and scope control, with justification embedded in technical artifacts and translated into audience-aware communication (poster and video) that sustains clarity and engagement (R1–R4/E1).

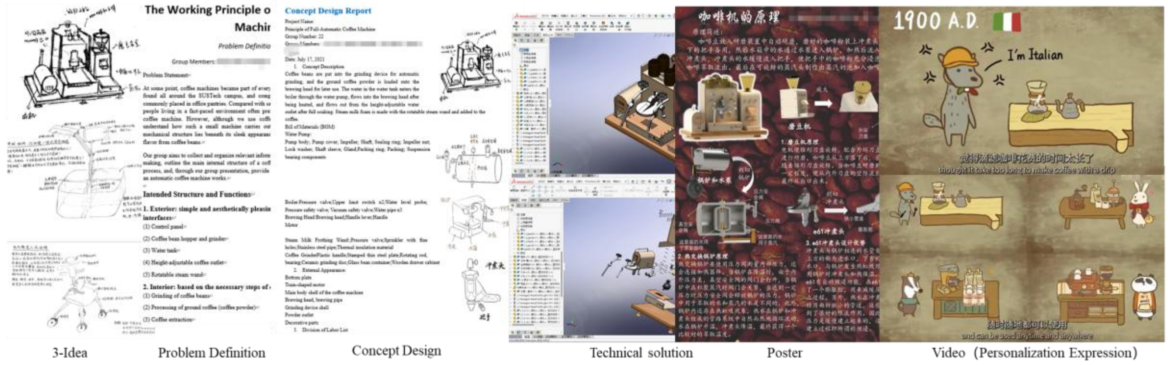

Figure 4 Coffee machine case: staged deliverables

Contrasting-pair logic (growth-first principle)

To avoid conflating learning with artifact scale, grading applies a 30-point rubric that foregrounds developmental evidence over part count, integrating interest/ownership, calibrated challenge building, technical implementation (including persistence and learning uptake), and presentation coherence.

Two high-scoring projects with very different scales illustrate this assessment logic (Figure 5). The Curta calculator team pursued a high-complexity assembly (600+ parts) and earned 29.5/30 because their work documented sustained ownership, calibrated challenge, and iterative learning across the CAD-to-fabrication gap (e.g., troubleshoot–revise cycles, scope adjustment, and evidence-based decision-making), even though the final prototype did not fully achieve the initial vision. In contrast, the Swiss Army knife team worked with a smaller assembly (~20 parts) and also earned 29.5/30 by demonstrating depth rather than scale, including rigorous investigation to justify redesign choices and a coherent, audience-ready communication narrative. Together, the pair supports a growth-first principle: project scale alone does not determine evaluation, and comparable developmental evidence can yield comparable outcomes.

Project	Team Interest (4.5)	Concept Design (4.5)	Technical Implementation(12)	Comprehensive Presentation (9)	Total (30)
Curta Calculator 600+ parts	4.5	4.5	12	8.5	29.5
The Swiss Army Knife ~20 parts	4.5	4.5	12	8.5	29.5

Fig. 5 Contrasting pair cases: comparable scores under a growth first rubric

Table 6 ICARE-aligned assessment indicators and evidence sources

Stage	Indicator	Operational definition	Evidence artifact(s) collected
I1	Topic diversity (interest-driven exploration)	Breadth of student-selected themes providing diverse entry points (e.g., mechanical devices, robotics, architecture, crafts/arts).	Project topics in case library (400+)
I2	Autonomy & ownership (purposeful topic justification)	Teams articulate why the topic matters and translate curiosity/needs into a feasible direction, and document rationale for selecting from multiple options.	Individual ideation logs; Three Ideas topic rationale in problem-definition report.
I3	Psychological safety for early participation	Willingness to share incomplete ideas, accept critique, and iterate early, shown via early participation and constructive peer feedback.	Peer-review comments; checkpoint participation; instructor observation notes of participation and iteration behaviors.
C1	Voluntary stretch beyond minimum requirements	Teams exceed the baseline (each member models ≥1 part) via multiple modeled components per member, complex assemblies; interpreted as motivation-driven stretch, while scoring emphasizes coherence and justification rather than part count alone.	Model complexity, CAD assembly, Advanced techniques exploration.
C2	Problem reframing through iteration	Substantive refinement of problem framing and specification based on feasibility checks and critique;	Problem definition report, concept design report; response to feedback memo.
C3	Feasibility reasoning & decision justification	Decisions are linked to constraints, criteria, and evidence; assumptions are surfaced and used in justification.	Feasibility analysis sections; decision matrices; milestone plans and rationale paragraphs.
C4	Self-imposed challenge goals	Teams deliberately raise difficulty (added constraints and functions; “do better than prior-year theme”) rather than merely meeting	Revised goals; documented stretch decisions; elevated targets for familiar themes.

		minima.	
A1	Productive help-seeking & scaffolding uptake	Timely and targeted use of support channels (peer, TA, instructor and mentor) with observable improvement following support.	Office-hour and TA clinic participation; consultation notes; change evidence linked to feedback.
A2	Beyond-syllabus active learning	Self-directed learning of tools/knowledge not explicitly taught (e.g., advanced rendering, motion study, mechanism analysis, simulation attempts) driven by project needs.	CAD artifacts with advanced features; workflow notes; poster and video method explanations.
A3	Iteration, troubleshooting, and persistence	Repeated diagnosis and revise cycles addressing modeling issues rather than one-shot completion.	CAD version history; issue iteration notes; progress check-ins.
A4	Resource use beyond minimum	Teams leverage additional resources (labs/equipment, specialist consultation) even when not required; interpreted as challenge engagement under interest.	Lab/equipment access records (when applicable); specialist consultation traces; optional prototyping attempts and documented learning.
R1	Engineering judgment and trade-offs	Explicit trade-offs among time, skill readiness, ambition, manufacturability, and scope; evidenced by defensible architecture/scope revision.	Trade-off statements; feasibility-driven architecture revisions; before and after decisions.
R2	Professional reframing of vision and reality gap	Setbacks are interpreted as constraints to manage; plans are revised accordingly (design vs. realization distinction).	Reflection prompts; redesign rationales; scoped implementation and revised structure.
R3	Justification embedded in technical artifacts	Artifacts communicate mechanism logic and constraints, not only geometry (annotated assemblies/exploded views/motion).	Annotated assemblies and exploded views; motion sequences for explanation; drawing packages linked to decisions.
R4	Audience-aware multimodal communication	Poster and video translate technical work for diverse audiences using multimodal choices (rendering, motion pacing, captions/narration, music); evaluated for coherence and technical alignment, not production polish.	Poster; short video with storyboard or script; exhibition presentation artifacts; clarity-focused feedback when available.
E1	Visibility beyond classroom	Work is presented to authentic audiences through campus exhibition and public dissemination channels.	Cross-year exhibition records; course website/case library; public posting records
E2	External feedback uptake and recognition	Feedback and recognition from peers, faculty, industry, and public audiences is received and reflected upon or incorporated where feasible;	Exhibition qualitative comment themes; online comments and engagement; reflection statements referencing feedback; awards or competition outcomes (when applicable).
E3	Continuation pathways	Projects extend beyond course submission (continued development, advanced-course continuation, competitions, students returning as TAs/mentors).	Follow-on project records; continuation examples after course; TA/mentor return records.
E4	Identity/self-efficacy growth	Increased confidence, ownership, and sustained motivation evidenced through reflections and continuation behaviors; supported where available by survey measures of confidence/satisfaction/interest.	Reflection/testimonials; continuation behaviors; engagement survey.

4.5 Evidence Reporting and Triangulation

Building on the artifact-based evidence reported above, we now synthesize Section 4 evidence across four complementary streams: cohort patterns, authentic audience communication, empower stage continuity beyond the course, and survey measures, to triangulate open-ended participation, extension beyond minimum requirements, recognition, and student reported perceptions.

Cohort patterns (Inspire–Challenge–Accompany) (Figure 6)
Cohort-level artifact patterns from the accumulated project archive (400+ projects; Figure 6) indicate an open, interest-driven topic space (Inspire: I1–I2) and frequent self-escalated challenge beyond baseline requirements (Challenge/Accompany: C1/C4), evidenced by autonomy-grounded topic justification and voluntary stretch such as modeling multiple components per member and high-part-count assemblies (often >100 parts), interpreted as markers of self-directed advanced learning rather than a ranking of project complexity.

Fig. 6 Cohort-Level Project Diversity and Voluntary Stretch Beyond Minimum Requirements

Authentic-audience communication (Redefine → Empower) (Figure 7)
Two authentic-audience channels extend communication beyond the classroom and triangulate redefine-stage evidence of audience-aware multimodal storytelling (R4), while also providing secondary empower signals of visibility and recognition (E1–E3): a cross-year on-campus exhibition (Year 1–Year 4) where teams present posters/videos and receive qualitative feedback, and a curated course case website that teams may voluntarily share more broadly, generating external interaction signals (e.g., views, comments, awards). These interactions are interpreted as motivation to communicate and translate technical work for wider audiences, rather than a scored outcome or a direct proxy for learning.

Empower: continuity and transfer beyond the course (Figure 8)
Beyond end-of-course performance, downstream continuation signals provide empower-stage evidence: a subset of teams carried CAD concepts, component designs, and drawings into later professional courses, where artifacts were further refined and increasingly realized as physical or mechatronics prototypes (Figure 7). These trajectories treat early course artifacts as transferable inputs to subsequent work, offering trace-based evidence of sustained ownership, continued skill development, and forward planning beyond the initial course context.

Fig. 7 On-Campus Cross-Year Exhibition: Poster and Video Presentations to Mixed Audiences

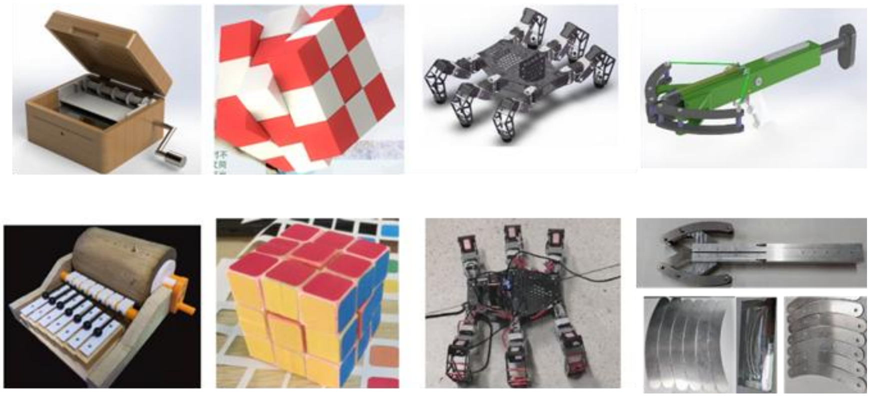

Fig. 8 From Engineering Expression to Engineering Realization

Survey measures

Student self-reports provide a secondary quantitative lens from two offerings using a 1–10 Likert scale: Fall 2019 (n = 90 of 166 students; 56.25%) and Spring 2020 (n = 65 of 98 students; 67.35%). End-of-semester means are uniformly positive (≈8–9/10) and increase across attitude, teamwork impact, confidence in graphics-based communication, satisfaction, and perceived relevance, while perceived ease decreases slightly, indicating a more demanding experience (Table 7). Pre/post interest distributions shift upward, with a larger share selecting the highest ratings (9–10, especially 10) after the course (Figure 9). These descriptive patterns contextualize Empower-related perception signals (E4) and triangulate with artifact traces and continuation evidence.

Table 7: End-of-semester survey ratings by construct

Construct	2019 fall	2020 spring	2020 spring-2019 fall
General attitude toward subject matter	8.38	9.11	0.73
Ease of learning subject matter	5.39	4.96	-0.43
Impact on team working	8.08	8.93	0.85
Confidence building in communication skills with	8.39	9.20	0.81

graphics			
Satisfaction	8.27	8.92	0.65
Relevance of subject matter to future study	8.26	8.76	0.5

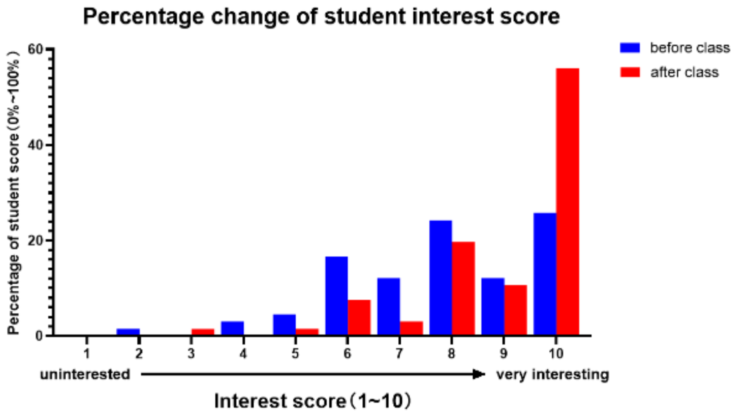

Fig. 9 Distribution of Student Interest Scores Before and After the Course

4.6 Limitations and scope

ICARE is presently evidenced through a single early-year virtual design course within one institutional context. Implementation in hands-on gateway courses may entail higher technical barriers and different uncertainty profiles, requiring adaptation of stage supports. Learner characteristics and psychological needs may also vary across institutional orientations (e.g., research-intensive vs. practice-oriented) and cultural contexts, which could shift stage salience and calibration. In addition, the current evidence is primarily qualitative and trace-based. Further multi-institutional quantitative studies are needed to test effectiveness and boundary conditions.

5. Conclusion

This paper advances the claim that intrinsic motivation and adaptability, widely recognized as core attributes for engineers in contemporary socio-technical contexts, are enabled by a progressively constructed psychological substrate, conceptualized here as Emotional Readiness. Based on a reverse developmental analysis, we propose ICARE as a staged instructional architecture (Inspire–Challenge–Accompany–Redefine–Empower) that sequences facilitation to support students' role transition from externally regulated participation toward value-led engagement, professional self-authorship, and adaptive professional growth. The framework is instantiated in a first-year Engineering Graphics course through a Double Diamond, artifact-based workflow, and examined via triangulated evidence from staged deliverables, cohort patterns, authentic-audience communication, continuity beyond the course, and student reported perceptions. Taken together, the findings suggest that early-year gateway courses can be intentionally structured to cultivate Emotional Readiness as a prerequisite for sustained motivation and adaptability, motivating future work to strengthen measurement validity and evaluate transferability across cohorts, courses, and institutional contexts.

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