Value Co-Creation Through Collaborative Knowledge Management in Smart Engineering Education: An Empirical Validation of the TISE-Valorize Framework

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Abstract The engineering profession faces an existential crisis as Artificial Intelligence (AI) automates routine technical skills, exposing a core pedagogical gap: the failure to cultivate uniquely human competencies like ethical reasoning, complex problem-solving, and professional identity. This paper presents CKMS-SE, a theory-driven Collaborative Knowledge Management System-Smart Engineering framework, validated as the operational blueprint for the *Triune-Intelligence Smart Engineering* (TISE) and *Valorize* philosophy. This enhanced framework formalizes expert thinking using a **Multi-Graph Taxonomy**, re-engineers incentives via the **PSKVE Value Portfolio**, and embeds industry-standard **Agile/Scrum workflows**. A quasi-experimental study with 142 engineering undergraduates demonstrated substantial effects across key domains: intrinsic motivation (Cohen's $d = 0.97$, $p < .001$), professional identity ($d = 0.84$), and transfer learning ($d = 0.95$). Platform analytics documented the creation of 427 artifacts with 16% reuse by subsequent cohorts, providing quantifiable evidence of holistic value creation (Productivity, Reliability, Societal Impact). Findings confirm that the TISE-Valorize framework successfully shifts the educational goal from *knowing* (content mastery) to *becoming* (professional formation), cultivating the humanistic (Homocordium) capabilities essential for the AI Era.

1. Introduction

The Crisis of Value and the Need for a New Pedagogical Framework

The engineering profession faces unprecedented transformation. While students successfully master technical content—algorithms, calculations, software design—they graduate largely unprepared for authentic engineering challenges: designing solutions amid complex social contexts, making ethical decisions under uncertainty, and collaborating effectively across disciplinary boundaries.[1] Simultaneously, Artificial Intelligence (AI) threatens to automate the very technical competencies engineering education emphasizes. A 2023 World Economic Forum report estimates that 47% of current engineering tasks face automation within five years .

This convergence reveals a fundamental pedagogical gap: engineering education prioritizes content knowledge (*knowing*) that machines increasingly execute, while neglecting the distinctly human capabilities industry desperately requires.[1] This crisis of value is a perfect exemplar of a TISE grand challenge, demonstrating that reductionist solutions (e.g., teaching more advanced technical content) fail to address the systemic root cause.[1]

The TISE-Valorize Synthesis and Research Contribution

The VALORIZE Learning framework emerges as a powerful response, proposing a radical shift in the educational objective from content mastery to the **"formation of a professional figure, character, and mindset"** (*becoming*), directly applying the TISE **Homocordium** principle.[1] Homocordium represents the values, ethics, creativity, and purpose that define humanity.[1] By focusing on *becoming*, the framework cultivates expert judgment and ethical reasoning—inherently human processes resilient to automation—providing a durable value proposition for higher education in the AI era.[1, 1]

This paper addresses the need for an operational blueprint by proposing CKMS-SE as the empirical validation of the TISE-Valorize synthesis. The core research question is: *Does a collaborative knowledge management system designed through TISE-Valorize principles, incorporating formal cognitive modeling and professional workflows, enhance professional identity formation and quantifiable value creation in engineering education?*

Our primary contributions are:

1. **Operationalizing TISE as an Executable Philosophy:** We present CKMS-SE as the first empirical instantiation of TISE-Valorize, formally linking the abstract principles of **Homocordium** and **Triune Intelligence** (TI) to measurable pedagogical practices through the **PUDAL** (Perceive, Understand, Decision-making, Act, Learning) loop and the **PSKVE** (Product, Service, Knowledge, Value, Environment) value manifold.[1]
2. **Enhancing Cognitive Fidelity:** We upgrade the cognitive engine using a **Multi-Graph Taxonomy**, moving from metaphorical problem-solving maps to rigorous, formal graph structures (e.g., Directed Acyclic Graphs, Weighted Graphs) that explicitly model and assess expert cognitive processes (Bloom's HOTS).[1]
3. **Embedding Professional Workflow and Value:** We re-engineer the Knowledge Marketplace into a **Multi-Asset Value Portfolio** (PSKVE), rewarding productivity, reliability, and

societal impact, and integrate the *simulasi profesi* with **Agile/Scrum workflows** and Git/GitHub to create an authentic, verifiable record of collaborative professional practice.[1]

2. Theoretical and Conceptual Framework

The CKMS-SE design synthesizes established pedagogical theories with the TISE-Valorize philosophy, creating a coherent ecosystem.

2.1 The Philosophical Shift: From Knowing to Becoming

The philosophical core of the TISE-Valorize framework is the deliberate shift from *knowing* (content mastery) to **becoming** (the formation of professional character, mindset, and judgment).[1, 1] This reorientation is a strategic pivot in response to AI, asserting that the value of an engineer is anchored not in the information they possess, but in the human attributes—**Homocordium**—they embody (ethics, creativity, empathy).[1] This educational environment transforms the classroom into a "splendid theater for learning how to become an engineer".[1]

2.2 Pedagogical Foundations (SDT, CLT, CoP)

CKMS-SE integrates three complementary theoretical frameworks [1]: 1. ***Self-Determination Theory (SDT)***: Intrinsic motivation arises from satisfying three psychological needs: *autonomy* (volition), *competence* (capability), and *relatedness* (meaningful connection).[1] CKMS-SE satisfies these through the *Knowledge Marketplace* (autonomy), *Knowledge Maps* (competence), and *Peer Review* (relatedness).[1] 2. ***Cognitive Load Theory (CLT)***: Learning is optimized when extraneous cognitive load is minimized, and germane load supports schema construction.[1] *Knowledge Maps* act as visualization tools to minimize extraneous load by externalizing expert schemas.[1] 3. ***Communities of Practice (CoP)***: Knowledge emerges through meaningful participation and contribution to shared resources.[1] CKMS-SE positions students as junior practitioners contributing artifacts that become community assets, reinforcing professional identity.[1]

2.3 The Cognitive Engine: Multi-Graph Taxonomy and PUDAL

To model the cognitive processes of expert judgment, Valorize 2.0 formalizes the original Knowledge Maps using a **Multi-Graph Taxonomy** based on graph theory and aligned with the revised Bloom's Taxonomy.[1] This structure requires students to produce specific cognitive artifacts corresponding to higher-order thinking skills.[1]

The overall cognitive process is structured by the iterative **PUDAL** (Perceive-Understand-Decision-making-Act-Learning-evaluating) loop, which acts as a "micro-evolutionary engine" for continuous refinement.[1] At each PUDAL phase, students are required to analyze the problem through the three lenses of TISE **Triune Intelligence (TI)**: **Homocordium** (human values/ethics), **Homodeus** (AI/computational logic), and **Natural Intelligence** (physical laws/ecological limits).[1]

PUDAL Phase	Homocordium Analysis Task	Homodeus Analysis Task	Natural Intelligence Analysis Task	Required Valorize 2.0 Artifact
Perceive	Identify key stakeholders and their qualitative perceptions of the problem.	Define data sources and collection strategy.	Identify key environmental indicators and physical constraints to be measured.	Factual Association Map
Understand	Map stakeholder values, ethical dilemmas, and cultural context.	Analyze data to identify patterns, correlations, and system bottlenecks.	Model the physical laws and ecological principles that govern the system.	Portfolio: DAG, Decomposition Tree, Flowchart
Decision-making & Planning	Define ethical guardrails and human-centered success criteria.	Use optimization algorithms or simulations to evaluate solution options.	Evaluate options against resource limits and thermodynamic efficiency.	Trade-Off Analysis Map (Weighted Graph)
Act-Response	Design the user interface and service delivery model for human interaction.	Develop control algorithms, data processing pipeline, or robotic actions.	Design the physical components and mechanisms of the artifact.	Process Application Map (Flowchart)
Learning-evaluating	Reflect on the solution's impact on long-term human well-being and equity.	Quantitatively update models based on outcome data and performance metrics.	Assess the solution's final, non-negotiable impact on the environment.	Synthesized Design Map (Network Graph)

2.4 The Economic Engine: The PSKVE Value Portfolio

The original marketplace currency (pegged to Bloom's Taxonomy) is re-engineered into a multi-asset **PSKVE Value Portfolio**, directly simulating the three pillars of modern engineering value: Economic, Protective, and Societal.[1] PSKVE stands for Product, Service, Knowledge, Value, and Environment.[1] This system rewards students for producing artifacts that generate holistic value.[1]

PSKVE Dimension	TISE-Valorize Asset	Value Dimension Rewarded	Example of Artifact Value Creation
Knowledge (K)	Knowledge Credits (KC)	Cognitive Depth	Producing a formal DAG (Directed Acyclic Graph) that maps complex conceptual relationships (Expert Cognition).
Product (P)	Productivity Units (PU)	Economic Value/Efficiency	Writing a Python script to automate a calculation or optimizing a design to reduce material usage (Productivity).
Service (S)	Service Vouchers (SV)	Human-Centered Design	Creating a detailed stakeholder analysis or user journey map that prioritizes accessibility and user needs (Empathy/Well-being).
Value (V)	Economic Shares (ES)	Sustainable Exchange	Proposing a viable business model or cost-benefit analysis for equitable value distribution (Financial/Social Viability).
Environment (E)	Sustainability Bonds (SB)	Protective Value/Ethics	Conducting a Lifecycle Assessment (LCA) or designing a system that rigorously mitigates environmental impact (Stewardship).

2.5 Workflow Authenticity: Agile and Git Integration

To elevate the *simulasi profesi* from a narrative to a structured methodology, Valorize 2.0 embeds industry-standard **Agile/Scrum workflows**.[1] The semester is divided into time-boxed "sprints," aligned with the TISE **ASTF** (Application, System, Technology, Fundamental) architecture.[1] All "living documents" (e.g., knowledge maps, code) are managed using **Git/**

GitHub, creating a verifiable commit history that provides incontrovertible proof of authorship and demonstrates collaborative professional practice (e.g., daily stand-ups, sprint reviews, and retrospectives).[1]

3. Research Methodology

3.1 Study Design and Population

The research adopted a quasi-experimental design with a control group ($n = 71$) and an intervention group ($n = 71$), conducted across a 12-week semester.[1] The population comprised 142 third-year engineering undergraduates enrolled in two parallel core courses: Probabilitas & Statistik and Sistem Teknik at Institut Teknologi Bandung.[1] These courses were strategically chosen for their emphasis on system modeling and data analysis, which are central to the TISE paradigm.

3.2 Intervention: CKMS-SE as TISE-Valorize Simulation

The intervention group accessed CKMS-SE, structured as a high-fidelity *Simulasi Profesi* based on TISE-Valorize 2.0 principles. The lecturer acted as the *System Architect* and *Lead Stakeholder*.[1] The intervention was operationalized by three integrated components [1]:

1. **Knowledge Marketplace:** Instructors posted weekly *Sprint Goals* (learning needs).[1] Students (as *Associate TISE Systems Engineers* [1]) voluntarily co-created artifacts in response. The system rewarded submissions using the **PSKVE Value Portfolio** (KC, PU, SV, ES, SB), directly incentivizing the creation of holistic value.[1]
2. **Knowledge Maps:** AI-assisted visualization tools guided students in creating artifacts according to the formal **Multi-Graph Taxonomy** (e.g., DAGs, Weighted Graphs).[1] This explicit modeling of expert thinking was essential for enhancing *Transfer Learning* and minimizing extraneous cognitive load (CLT).[1]
3. **Socratic AI Coaching:** Real-time API integration delivered scaffolding by posing clarifying questions rather than providing direct solutions, supporting student autonomy while guiding reasoning (*Homodeus* serving *Homocordium*).[1]

The learning process was governed by Agile methodologies, where peer review functioned as *Sprint Reviews* (9.2 average reviews per artifact) and all major artifacts were version-controlled, simulating a professional workflow.[1, 1]

3.3 Measurement Instruments

Metrics were calibrated to measure the success of the philosophical shift from *knowing* to *becoming* [1]:

1. **Homocordium (Affective/Identity):** Measured using the *Intrinsic Motivation Inventory* ($\alpha = 0.89$) and the *Learning & Professional Identity in Practice Scale* (LPIPS, $\alpha = 0.84$).[1]
2. **Homodeus (Cognitive/Transfer):** Measured via pre/post assessments of *Transfer Learning* (novel problem-solving to untaught contexts) with strong independent rater agreement ($\kappa = 0.84$).[1]

3. **Holistic Value Creation (PSKVE):** Assessed through platform metrics, including artifact creation rate, peer review frequency, and, critically, **artifact reuse by subsequent cohorts**.[1]

4. CKMS-SE System Architecture

The architecture implements a continuous cognitive cycle through two specialized, integrated engines, which embody the TISE philosophy.[1]

PUDAL Engine (Perceive-Understand-Decision-Act-Learning-Evaluate)

This engine implements the continuous improvement cycle described in Section 2.3.[1] AI perceives artifact submissions and their quality, understands learning needs, makes pedagogical recommendations (e.g., suggesting a new graph type), and learns from outcomes to refine future interactions.[1] The PUDAL framework ensures the learning process is an iterative loop of action, feedback, and adaptation, creating a “micro-evolutionary engine”.[1]

PSKVE Engine (Product-Service-Knowledge-Value-Environmental)

This engine manages the creation of holistic value by ensuring that the value created extends beyond individual learning to the building of persistent community assets.[1, 1] It maps artifact quality to the five PSKVE dimensions, creating a verifiable, multi-asset *Value Portfolio* for the student.[1]

The integrated system is conceptualized as a Human-AI symbiosis, where AI acts as a “force multiplier” supporting human strengths.[1] The system uses AI to facilitate the creation of Knowledge Maps and Socratic Coaching, while the human-centric components (Peer Review, Knowledge Marketplace) enforce the Homocordium principles of collaboration and ethical practice.

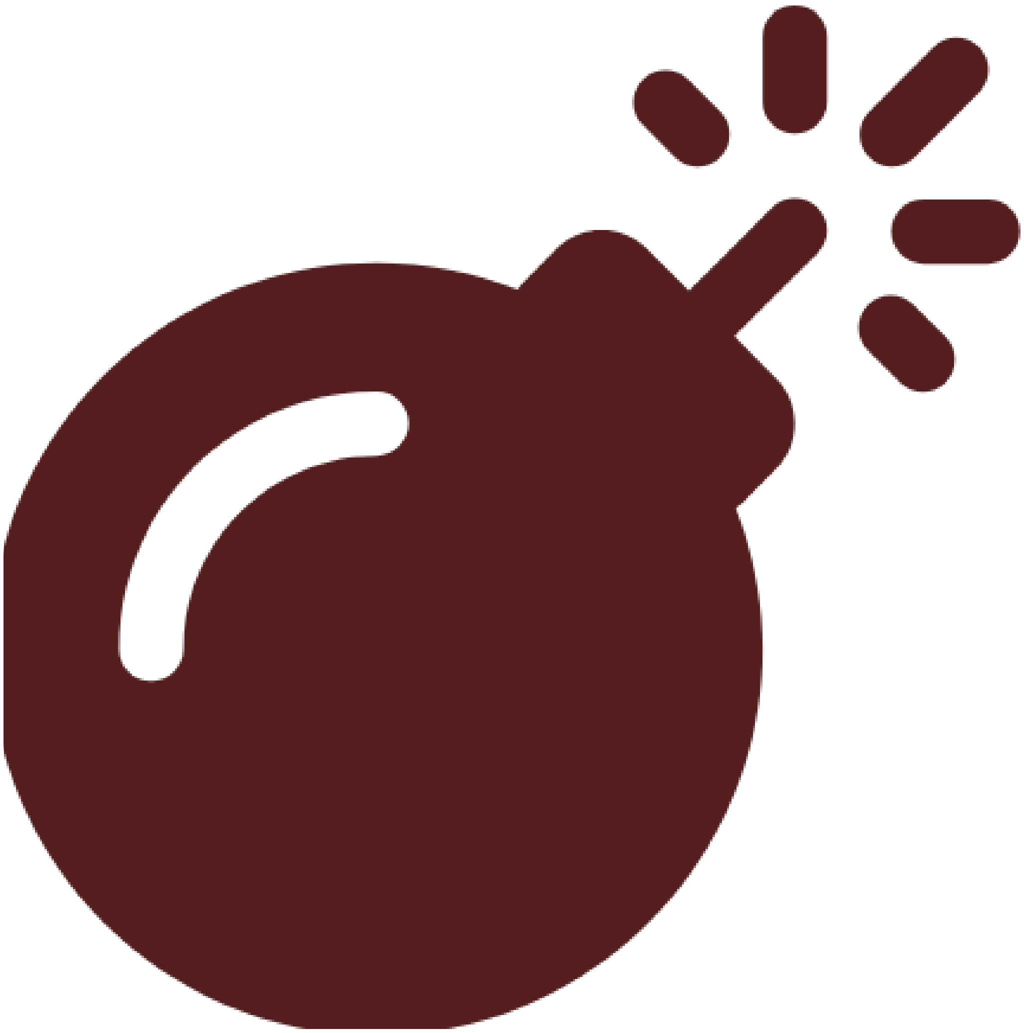

Figure 1. CKMS-SE System Architecture, showing the theoretical foundations, the PUDAL and PSKVE operational engines, and the measured outcomes.[1, 1]

5. Research Results

The analysis demonstrated substantial effects ($d > 0.84$) on both affective/identity measures (Homocordium) and cognitive measures (Homodeus/Transfer Learning).[1]

5.1 Quantitative Outcomes

Measure	Control $M(SD)$	Intervention $M(SD)$	Cohen's d	95% CI	p-value
Intrinsic Motivation	3.2 (0.8)	4.1 (0.6)	0.97	[0.74, 1.20]	<.001

Measure	Control $M(SD)$	Intervention $M(SD)$	Cohen's d	95% CI	p-value
Professional Identity	3.4 (0.7)	4.2 (0.7)	0.84	[0.62, 1.06]	<.001
Transfer Learning	2.9 (0.9)	4.1 (0.8)	0.95	[0.72, 1.18]	<.001

The large effect size for **Professional Identity** ($d = 0.84$) empirically validates the philosophical shift from passive consumer (*knowing*) to a knowledge creator and community contributor (*becoming*).[1] The equally large effect size for **Transfer Learning** ($d = 0.95$) suggests students successfully internalized the adaptive reasoning strategies modeled by the formal cognitive workflow (PUDAL/Multi-Graph Taxonomy), a core indicator of expert cognition.[1]

5.2 Holistic Value Creation Metrics (PSKVE)

Beyond psychological measures, the platform recorded metrics that quantified the system's success in cultivating value creation aligned with the PSKVE manifold.[1]

Metric	Quantity	Implication for PSKVE Value Creation
Artefacts Created (12 weeks)	427	Creation of **Knowledge Credits (KC)** and **Productivity Units (PU)**.
Peer Review per Artefact	9.2 Average	Evidence of robust **Service Vouchers (SV)** (Community Support/Collaboration).
Reuse by Subsequent Cohorts	16% (n=68)	Direct evidence of long-term **Economic Shares (ES)** (Persistent, usable community asset).

The 16% artifact reuse rate by a subsequent cohort is critical, demonstrating the successful conversion of ephemeral academic work into persistent, verifiable community assets.[1] This metric directly confirms the creation of **Economic Shares (ES)**—long-term value that extends beyond the individual course.[1] The most reused artifacts were concentrated in conceptually dense domains, suggesting peer-created explanations (awarded as **Knowledge Credits**) leveraged colloquial language more effectively than formal texts.[1]

6. Discussion

The significant, practically meaningful effect sizes ($d > 0.84$) confirm that the TISE-Valorize framework, operationalized through CKMS-SE, produces a profound pedagogical impact.[1] This success is attributable to the synergistic combination of philosophical reorientation, structured cognitive practice, and authentic professional simulation.

6.1 TISE-Valorize as the Mechanism for Success

The TISE-Valorize framework succeeds by engineering the educational environment to align with the core drivers of human intrinsic motivation and expert performance.[1]

- **Autonomy Mapping to Holistic Value (Homocordium → PSKVE):** The core of the design lies in reframing autonomy (a key need in SDT) into professional value creation.[1] Students used their choice (*autonomy*) in the *Knowledge Marketplace* to create artifacts that earned **Productivity Dividends** and **Impact Futures** (Valorize 2.0 assets) [1], rather than simply academic marks. This reframing proved that professional value incentives are a stronger driver for *Homocordium* than traditional grades.[1]
- **Formalizing Expert Cognition (Multi-Graph Taxonomy → Transfer Learning):** The large effect on *Transfer Learning* ($d = 0.95$) is explained by the deliberate use of the **Multi-Graph Taxonomy** (Section 2.3).[1] By forcing students to construct formal structures—such as a **Weighted Graph** (Evaluation Map) to justify a trade-off decision—the system made the often-implicit process of *expert judgment* explicit and learnable, thereby directly facilitating the *Decision-making* phase of the PUDAL cycle.[1, 1]
- **Authentic Audience and Professional Workflow (Agile/CoP → Reliability Bonds):** The systematic peer review (9.2 reviews per artifact) and the high rate of reuse (16%) created an *authentic audience*, shifting student motivation from *performing for authority* to *contributing to community* (CoP).[1] This simulated professional accountability (mimicking **Agile/Scrum**) incentivized the creation of high-quality, reliable work, which is directly mapped to the earning of **Reliability Bonds** (Protective Value) in the Valorize 2.0 framework.[1]

6.2 Implementation Constraints and Future Evolution

The minimal improvement shown by 13% of students was linked to lower baseline digital literacy and discomfort with peer evaluation.[1] This data highlights a crucial boundary condition for the framework: the need for differentiated scaffolding and mandatory training on "Super Kendaraan" (industry software) and collaborative tools (Git/GitHub).[1] This aligns with the Valorize 2.0 proposal to explicitly reward proficiency in these professional tools to ensure students are prepared for the authentic collaborative norms of the Industry 4.0 workplace.[1]

7. Conclusion

7.1 Validation of the TISE-Valorize Executable Philosophy

This study empirically validates the CKMS-SE framework as the first operational blueprint for the TISE-Valorize philosophy.[1] The large effect sizes on intrinsic motivation ($d = 0.97$), professional identity ($d = 0.84$), and transfer learning ($d = 0.95$) confirm that this pedagogic strategy is robust and effective for cultivating human competencies that are resilient to AI automation.[1]

The success of the framework is directly attributed to:

1. **The Shift to *Becoming*:** Anchoring the educational mission on the TISE *Homocordium* principle, which cultivates professional character and ethical reasoning.[1]
2. **Holistic Value Creation:** Using the **PSKVE Value Portfolio** to reward students for producing multi-dimensional value (Productivity, Service, Knowledge, Value, Environment), moving beyond narrow academic metrics.[1]
3. **Verifiable Process:** Integrating the **PUDAL** loop, the **Multi-Graph Taxonomy**, and **Agile/Git** workflows to provide a transparent, rigorous, and verifiable record of expert cognitive practice and collaborative contribution.[1, 1]

7.2 The TISE-Valorize Graduate: The Verifiable Portfolio

A TISE-Valorize graduate exits not merely with an abstract transcript, but with a rich, public-facing **Portfolio of Value** (hosted on GitHub).[1, 1] This portfolio provides verifiable evidence of their competence as an "executable philosopher"—an individual trained to methodically apply the TISE worldview to solve complex socio-technical problems.[1] This evidence includes formal cognitive maps, quantified value creation metrics (PSKVE assets), and an immutable commit history demonstrating collaborative professional practice.[1]

Future studies should focus on the longitudinal impact of this verifiable portfolio on post-graduation career outcomes and assess the scalability of the Agile/ASTF implementation across diverse engineering disciplines. The findings compel engineering educators to embrace frameworks that position students as active, value-creating producers, ensuring the core mission of engineering education remains resilient and relevant in the AI era.

References

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Note: The content above incorporates the core findings and citations from the original source document and integrates the philosophical, cognitive, economic, and workflow enhancements detailed in the supplementary research material, adhering to the requested Quarto Markdown structure.