

A Progressive Model for Developing Mining Undergraduates' Professional Communication through Industry–Academia–Research Collaboration

Ping Li^{1,2,*}, Linkun Liu¹, Lirong Zhang¹, Min Gao¹, Lin Chen¹, Suisui Qian¹, Zhou Su¹

1. School of Mechanical and Electrical Engineering, Xinjiang University of Technology, Hotan 848000, Xinjiang, China

2. Key Laboratory of Green, Intelligent Development and Efficient Utilization of Strategic Mineral Resources of the Xinjiang Production and Construction Corps, Xinjiang University of Technology, Hotan 848000, Xinjiang, China

*Corresponding author: Ping Li, 13765563003@163.com

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Abstract: This study addresses the disconnect between disciplinary knowledge and communication in complex engineering contexts among mining undergraduates. Professional communication is conceptualized as the capacity to translate knowledge across classroom, research and industry boundaries. We develop a training model integrating boundary-object activation, four-stage task progression and dual-loop feedback, supported by audience switching, evidence restructuring and feedback use. Authentic mining problems, datasets, models and decision documents support four successive tasks: participatory expression, structured explanation, evidence-based argumentation and cross-context decision-making. Work revision and audience transfer are used to promote competence development, alongside a quasi-experimental design, four measurement occasions, a seven-dimensional rubric and multi-stakeholder ratings. The synthetic data illustrate the proposed analytical framework only and do not constitute an empirical test of effectiveness. The model proposes that collaboration becomes educationally productive when authentic resources are converted into revisable boundary objects and embedded in sustained feedback and contextual transfer.

Keywords: Industry–Academia–Research Collaboration; Mining Education; Professional Communication Competence; Boundary Crossing; Authentic Assessment; Feedback Literacy

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1. Introduction

Smart-mine development is changing how mining engineers produce knowledge and make decisions. Engineers must calculate and design, but they must also communicate design boundaries to production managers, justify risks to safety departments, explain data to interdisciplinary teams and discuss environmental impacts with the public. Professional communication is therefore not a peripheral soft skill. It is the interface through which disciplinary knowledge enters collaboration, judgement and action. Employer research in mining likewise links graduate employability to work-integrated learning, reflective experience and sustained university–industry cooperation ^[1]. Studies of university–industry partnerships reveal substantial variation in project aims, organization and assessment, with collaboration in early and middle years remaining underdeveloped ^[2]. The effectiveness of project-based learning also depends on task authenticity, scaffolding,

teacher workload and the stability of industry partners^[3-6]. Inviting companies into the classroom does not, by itself, produce competence. The unresolved question is how external resources can be transformed pedagogically so that they shape students' cognition and revision practices. Feedback-literacy research offers a complementary process account^[7-8]. Multi-draft writing, dialogic feedback and metacognitive interventions can help students interpret standards, seek advice and act on it^[9-13], but receiving feedback is not equivalent to using it. Industry-engaged capstone projects and authentic assessment can increase task relevance by introducing professional audiences, practical constraints and awareness of consequences^[14-16]. Excessive complexity, however, may also increase cognitive load.

Recent research has shifted from asking whether universities and industry collaborate to examining how collaboration enters the curriculum. A systematic review found wide variation in objectives, duration, partner responsibilities and assessment, while most evidence came from capstones and senior projects^[2]. Longitudinal collaboration in earlier courses remains limited. Research on project-based learning similarly shows that authentic problems and industry mentors can strengthen engagement and knowledge application. Their effects nevertheless depend on task structure, scaffolding intensity, teacher workload and partner continuity^[3-6]. External participation is therefore an organizational condition, not direct evidence of student learning.

2. Mechanisms for Developing Professional Communication through Industry–Academia–Research Collaboration

2.1 Contextual Characteristics of Professional Communication in Mining

Professional communication in mining cannot be developed through a single presentation course. Classroom learning emphasizes codified knowledge, research training addresses open questions and uncertain evidence, and mining companies make consequential decisions involving safety and production. Students must repeatedly move from course concepts to research evidence and industrial decisions before they can learn how disciplinary knowledge operates across settings. Their communication tasks have three contextual features. First, they are interdisciplinary and require evidence from geology, mining, mechanical and electrical engineering, safety, environmental science and economics. Second, they are constrained by risk, requiring explicit assumptions, data and consequences. Third, they involve diverse audiences with technical, managerial, regulatory and community concerns. The central challenge is therefore knowledge translation and risk communication under complex engineering constraints, rather than rhetorical fluency alone.

We conceptualize professional communication competence as a hierarchical, multidimensional construct. Its foundation comprises participation and basic organization; the intermediate level includes disciplinary accuracy, evidence selection and argument structure; and the advanced level involves audience adaptation, uncertainty communication and cross-context transfer. Assessment should examine content reliability, argumentative validity and sustained performance after a change of context. It should also distinguish competence, performance and opportunity, thereby avoiding the interpretation of increased participation or team compensation as individual growth. Drawing on boundary-crossing theory, we define the construct as the capacity to reorganize problems, evidence, terminology and uncertainty for a specific audience and decision purpose while maintaining disciplinary accuracy and responding defensibly to questions. This definition encompasses what is communicated, to whom, for what purpose and how the communication supports action.

2.2 Complementary Resources in Collaborative Training

Consider the organization of haulage in an open-pit mine. An industry partner provides de-identified vehicle records, road conditions and production indicators. The course instructor converts these materials into transport-system analysis and graphical communication tasks. A research mentor asks students to compare dispatching schemes, explain model assumptions and examine data uncertainty. Students then produce a technical review report and a production decision brief. Mining content thus becomes the shared source of learning tasks, audiences and assessment criteria rather than a decorative case study.

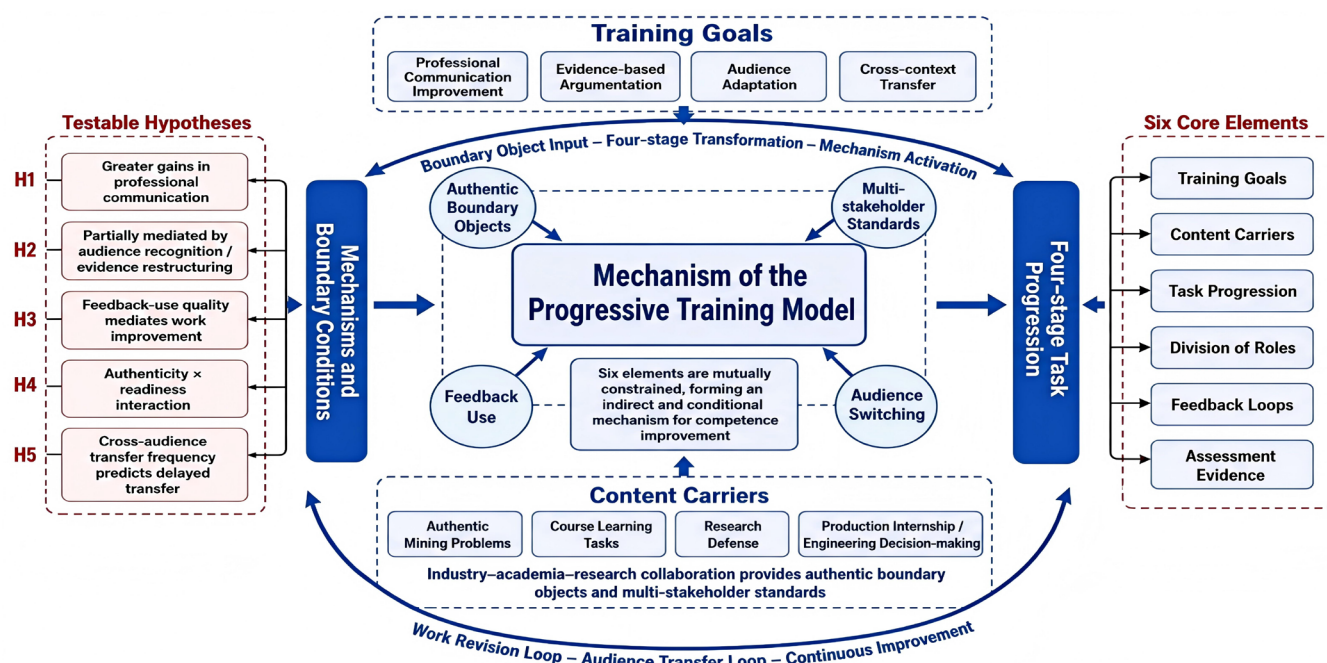
Industry, teaching and research partners contribute authentic engineering constraints, curriculum-ready task design and data-analysis methods, respectively. Together they create a sequence of problem entry, knowledge analysis, solution communication and feedback-informed revision. Boundary objects connect the three parties. These are engineering artefacts

that stakeholders can recognize jointly, interpret locally and revise iteratively, such as haulage data, risk maps and production plans. Companies emphasize safety, efficiency and feasibility; courses emphasize conceptual structure and competence progression; and research training emphasizes methodological appropriateness and evidential credibility. Boundary objects align these standards within a common task and reduce the overload that can arise when partners are merely added together. A collaborative learning loop is unlikely to form when a case lacks data, constraints or a decision problem, or when submitted work is never revised.

2.3 Mechanisms of the Progressive Training Model

The proposed training model comprises six mutually constrained elements: training goals, content carriers, task progression, division of roles, feedback loops and assessment evidence. It is not a list of activities. Without authentic mining problems, collaboration lacks a content carrier. Without four-stage progression, students merely repeat presentations at successive grade levels. Without dual-loop feedback, external comments cannot be converted into competence. Without transfer assessment, classroom performance cannot be connected to research defenses, production placements or engineering decisions. Figure 1 presents the proposed causal relations and supports five testable hypotheses. H1: after adjustment for baseline performance, students receiving progressive training will show greater gains than those receiving conventional instruction in total professional communication, evidence-based argumentation, audience adaptation and cross-context transfer. H2: audience recognition and evidence restructuring will partially mediate the relationship between boundary-object authenticity and learning outcomes. H3: the quantity of multi-source feedback will not directly predict post-test performance; feedback-use quality will mediate the relationship between feedback and improvement in student work. H4: task authenticity will interact with student readiness, and its benefit will diminish when authenticity exceeds available cognitive scaffolding. H5: the frequency of cross-audience transfer will provide incremental prediction of delayed transfer performance.

Figure 1. Proposed mechanism through which industry–academia–research collaboration develops professional communication competence.



The hypotheses distinguish outcomes, mechanisms and boundary conditions rather than attributing every positive change to the broad label of collaboration. Feedback-literacy research shows that receiving comments differs from using them. Feedback can improve subsequent performance only when students understand standards, evaluate advice, manage emotional responses and take action. Feedback use, rather than feedback quantity, is therefore the first mediator. Students submit a revision statement explaining why each suggestion was adopted, rejected or reworked. Audience switching is the second mediator. The same work is successively communicated to peers, course instructors, research mentors and industry mentors, requiring students to reselect evidence and terminology. Feedback use explains how an artefact improves; audience switching

explains how competence transfers. As Figure 1 shows, collaboration first supplies multi-stakeholder standards and authentic boundary objects. Four-stage tasks then activate audience recognition and evidence restructuring. The work-revision loop improves current performance, while the audience-transfer loop supports stability across contexts. Collaborative resources are therefore expected to influence competence indirectly and conditionally, rather than through a simple input–output relationship.

3. Construction of the Progressive Training Model

The model can be summarized as one developmental thread, four stages, tripartite collaboration and dual-loop feedback. The thread is the development of professional communication around mining-engineering problems. The four stages move from participatory expression to structured explanation, evidence-based argumentation and cross-context decision-making. Companies, courses and research teams provide industrial contexts, pedagogical transformation and evidence training, respectively. The two feedback loops concern revision of student work and transfer across audiences. Section 3.1 specifies what is developed, Section 3.2 explains progression, and Section 3.3 defines how the three partners operate together.

3.1 Model Goals and Four-Stage Competence Structure

The four stages are not a grade-by-grade list of activities. Tasks progress according to the complexity of the required cognitive operation. Table 1 aligns each stage with its core operation, boundary objects, audience shift and assessment evidence. Advancement depends on whether students can perform more complex knowledge translation with reduced scaffolding, rather than on completion of an academic year. Progression occurs along three dimensions. Communication moves from experiential description to evidential reasoning; audiences shift from familiar peers to authentic or near-authentic stakeholders with different interests and knowledge; and assessment moves from task completion to defensible judgement under constraints. The stage labels are explanatory devices. Cognitive operation, scaffolding intensity and transfer distance determine whether the curriculum is genuinely progressive.

Table 1. Four-stage progression matrix for professional communication competence among mining undergraduates.

Stage	Core cognitive operation	Typical boundary objects	Audience and task	Evidence for progression
Participatory expression	Identify the topic and audience; develop basic confidence	Mining images, professional narratives and safety incidents	Deliver a three-minute technical explanation to peers	Willingness to communicate and a complete basic structure
Structured explanation	Organize concepts, processes and data into a causal structure	Process diagrams, production data and course models	Explain an engineering process to students outside the course	Accuracy and organization meet rubric standards
Evidence-based argumentation	Compare options, address counterevidence and respond to questions	Research data, competition proposals and industrial problems	Defend a position before teaching, research and industry reviewers	Evidence is cited and limitations are explained
Cross-context decision-making	Reframe evidence for the audience and propose action	Placement problems, capstone projects and decision briefs	Translate content for technical, managerial and public audiences	Accuracy and defensible reasoning are maintained in an unfamiliar task

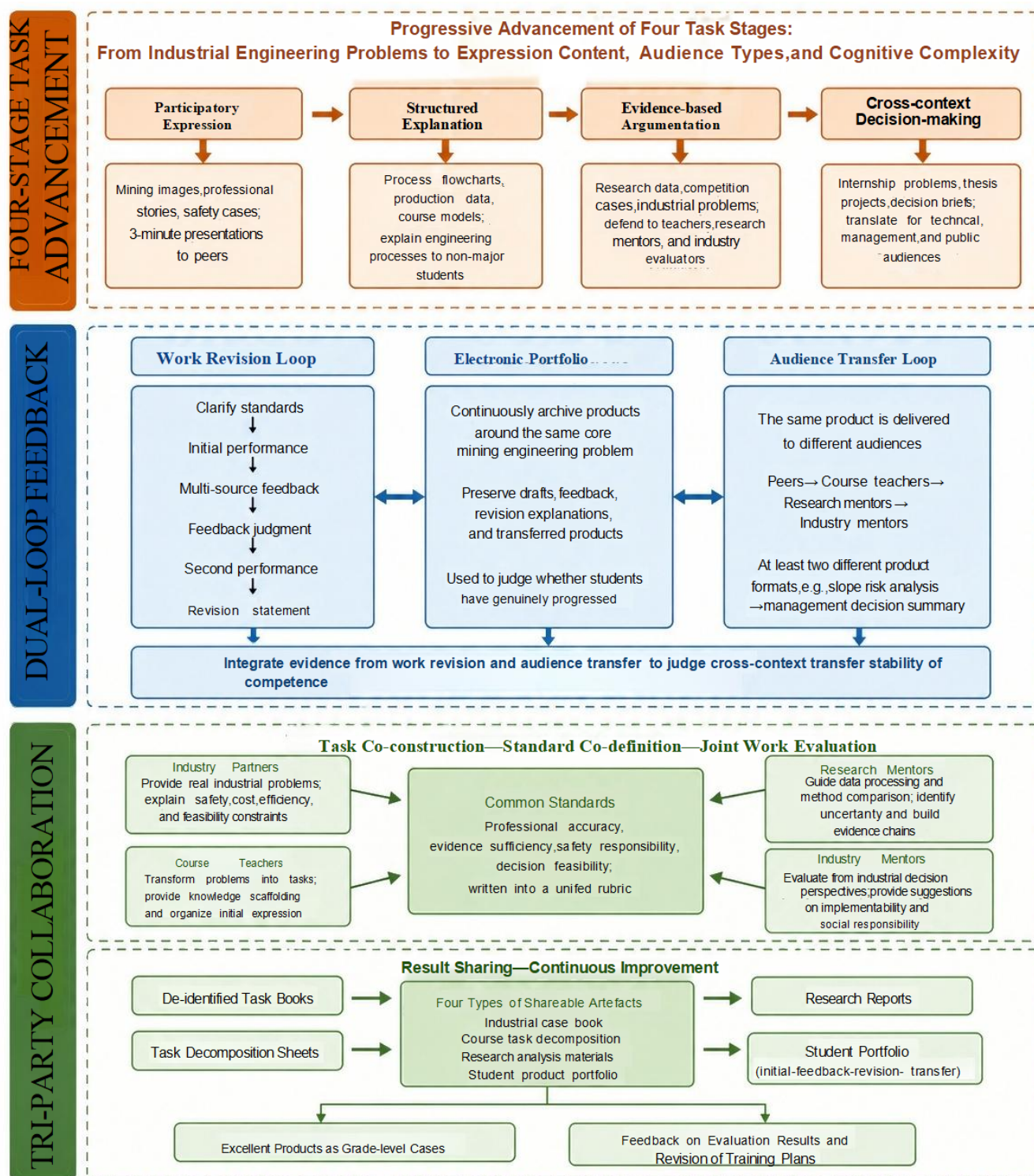
3.2 Training Pathway and Dual-Loop Feedback

The operating pathway is shown in Figure 2. The work-revision loop comprises clarification of standards, initial performance, multi-source feedback, feedback judgement, a second performance and a revision statement. The audience-transfer loop requires students to communicate the same central claim to at least two audiences and convert it into two product forms. For example, a slope-risk analysis may be rewritten as a management decision summary. The loops converge in an electronic portfolio, enabling instructors to judge both improvement and transfer across contexts.

The pathway depends on a complete loop, not on a larger number of activities. Without a second performance, feedback cannot become observable learning action. Without an audience change, repeated practice may reflect familiarity rather than

transfer. Each core task should therefore retain at least two versions of the work, and every academic year should include at least one cross-audience transfer task.

Figure 2. Teaching pathway integrating four-stage tasks with dual-loop feedback.



3.3 Tripartite Operating Mechanism

This mechanism translates collaboration from background context into explicit operating rules. Companies, courses and research teams do not jointly teach a single class; instead, they complete sequential roles around the same mining task. The company defines an authentic problem and specifies safety, cost, efficiency and feasibility constraints. The course instructor converts the problem into an achievable task appropriate to students' stage, provides knowledge scaffolds and organizes the initial performance. The research mentor guides data processing, method comparison, uncertainty identification and evidence-

chain construction. Finally, the industry mentor assesses whether conclusions are understandable, actionable and accountable from a production-decision perspective. Collaboration operates through task co-construction, standard co-definition, joint evaluation of student work and shared use of outcomes. Co-construction ensures that content originates in practice while remaining aligned with course objectives.

Co-defined standards place disciplinary accuracy, evidential sufficiency, safety responsibility and decision feasibility in a common rubric. Joint evaluation preserves differences among teaching, research and industry standards and requires students to explain their trade-offs. Shared use of outcomes converts strong student work into cases for later cohorts and feeds observed knowledge gaps back into courses and research training. Collaboration thus affects students while also informing curriculum improvement. To prevent collaboration from becoming a series of talks and visits, every core task must produce four auditable artefacts: a de-identified brief from an industrial context, a task-decomposition sheet aligned with course outcomes, an analysis record documenting research evidence and method selection, and a student portfolio containing the initial draft, feedback, revision statement and transferred product. Continuous availability of all four artefacts is the operational criterion for collaboration within the model.

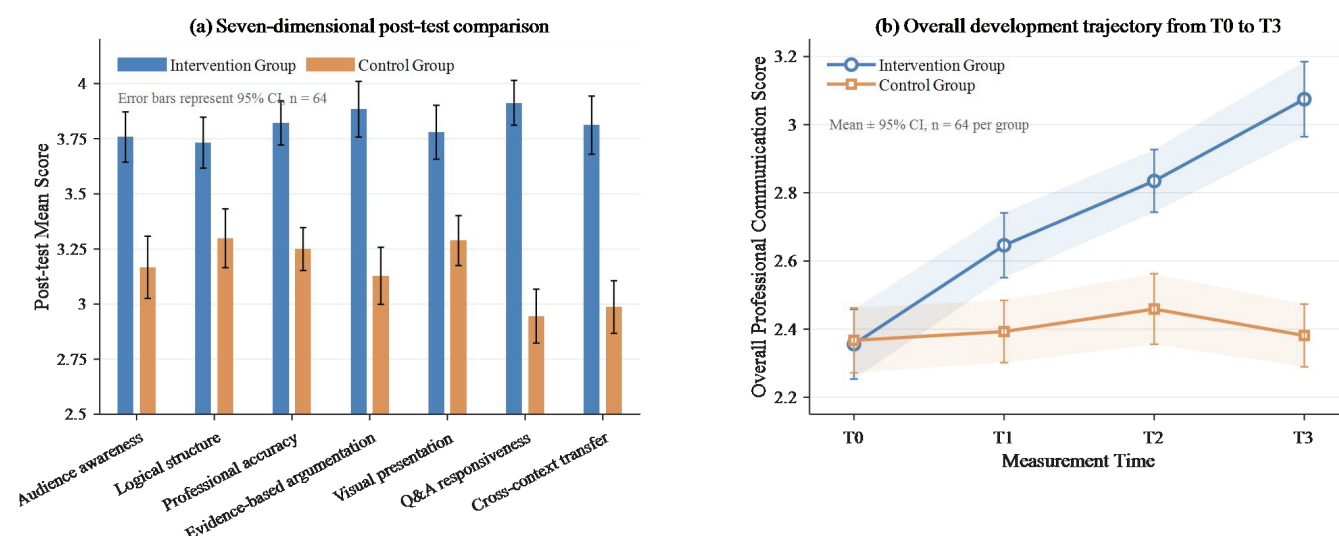
4. Implementation and Evaluation of the Training Model

4.1 Implementation and Evaluation Design

To evaluate implementation, the proposed design includes 128 students from four intact classes over two semesters, with intervention and control groups measured at four occasions from T0 to T3. The intervention group follows the progression from participatory expression through structured explanation and evidence-based argumentation to cross-context decision-making. Tasks include classroom presentations, explanations of disciplinary problems, data-based argumentation, proposal briefings and cross-context communication. Course instructors, research mentors and industry mentors provide feedback on disciplinary knowledge, methodological evidence and engineering constraints, respectively. Students repeatedly revise their work, producing a task–feedback–revision–improvement sequence.

Evaluation examines whether students progress from participation to accurate explanation, evidence-based argumentation and cross-context application. A five-level rubric covers seven dimensions: audience awareness, structural logic, disciplinary accuracy, evidential argumentation, visual presentation, responses to questions and cross-context transfer. Changes from T0 to T3 are compared between intervention and control groups. Classroom tasks, project work, defense performance and revision records provide complementary evidence of implementation and competence development.

Figure 3. Synthetic illustration of the evaluation framework: (a) seven post-test rubric dimensions; (b) competence trajectories from T0 to T3. Error bars and intervals are illustrative only.



4.2 Illustrative Results and Analysis

Synthetic data are used solely to demonstrate how the proposed evaluation would represent changes from T0 to T3. Figure 3a illustrates higher post-test scores for the intervention group across the seven rubric dimensions, with the largest visual

differences in evidential argumentation, responses to questions and cross-context transfer. Figure 3b shows similar initial levels, followed by a widening illustrative difference as structured explanation, evidence-based argumentation and cross-context tasks are introduced. These simulated patterns demonstrate the intended analytical logic; they do not establish intervention effectiveness. If reproduced with empirical data, the framework would allow evaluators to examine whether authentic tasks, multi-stakeholder feedback and iterative revision support movement from general expression to disciplinary argumentation and transfer. The resulting evidence could also guide adjustments to task difficulty, feedback processes and assessment standards in an implementation–evaluation–improvement cycle.

5. Conclusion

This study addresses the separation between disciplinary learning and communication in complex engineering contexts among mining undergraduates. It proposes a model linking boundary objects, progressive tasks, dual-loop feedback and cross-context transfer. The model assumes that collaboration develops competence only after resources have been transformed pedagogically: authentic problems must become workable boundary objects, multi-stakeholder standards must become actionable feedback, and the same content must be reworked for different audiences and decisions. Four stages move from participatory expression to structured explanation, evidence-based argumentation and cross-context decision-making. Work revision and audience transfer provide the two feedback loops. The proposed evidence chain spans participation, performance, transfer and mechanism and combines a quasi-experimental design, four measurement occasions, blind ratings, process logs and multilevel modelling. Current synthetic data illustrate the analytical framework and cannot demonstrate actual effects. Model stability must be examined through ethical review, rubric validation, multi-institution replication, delayed transfer assessment and cost-effectiveness analysis. Professional communication in mining is therefore not simply a willingness or ability to speak. It is the capacity to translate disciplinary knowledge under multiple constraints, for multiple stakeholders and in the presence of uncertain evidence.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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