

Article

Research on the Cultivation of Teachers' Interdisciplinary Literacy and Integrated Teaching Practice in Engineering Education

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Abstract: Universities are increasingly expected to prepare graduates who can work across disciplinary boundaries, yet teaching is still often organized within relatively closed subject areas. Using the intersection of civil engineering and microbiology as an example, this study examines how teachers can develop the knowledge, practical abilities, and ways of thinking required for interdisciplinary teaching. The paper first identifies the main difficulties encountered in cross-field instruction and then develops a training framework that links course learning, joint teaching and research, scientific research practice, and engineering experience. On this basis, interdisciplinary teaching modules, practical platforms, and a multi-source evaluation approach are incorporated into classroom implementation. Evidence from the teaching practice suggests that the educational reform helped teachers connect biological principles with engineering problems and supported students in applying knowledge from both fields to project tasks. The study also shows that teacher development cannot be separated from curriculum reconstruction, laboratory support, research participation, and institutional incentives. The resulting approach offers a practical reference for science and engineering programs seeking to introduce interdisciplinary content without separating it from existing professional courses.

Keywords: Interdisciplinary literacy; Teacher training; Civil engineering; Microbiology; Teaching practice

1. Introduction

Changes in knowledge production, industrial technology, and the kinds of problems engineers are asked to solve have made purely single-disciplinary training increasingly restrictive. Universities are therefore being asked to reconsider how professional knowledge is organized and how students are prepared for problems that do not fit neatly within one subject. The report of the 18th National Congress of the Communist Party of China called for deeper reform in education and for the connotative development of higher education. In the same policy context, interdisciplinary integration has been emphasized as an important means of breaking disciplinary boundaries, advancing the construction of the "four new" disciplines, and responding to emerging talent needs [1].

Civil engineering offers a clear example of why this broader knowledge base is becoming necessary. The sector consumes large quantities of materials and energy, and its design choices have consequences for carbon emissions over the entire service life of a structure. Under current low-carbon and lifecycle requirements, problems that once appeared to belong entirely to mechanics or materials engineering increasingly involve chemistry, biology, and environmental science as well. The use of microorganisms in engineering materials illustrates this change. By affecting mineral precipitation and local material structure, microbial activity can contribute to applications such as soil

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improvement and crack repair. Because these processes can occur under comparatively mild conditions, they have also attracted attention in discussions of environmentally responsible engineering [2-4]. For teaching, the important point is not simply to add a few biological concepts to an engineering syllabus. Students need to understand why the biological mechanism matters to an engineering property and under what conditions that connection is useful.

Against this background, the present study uses the civil engineering-microbiology interface as a concrete setting in which to examine the development of teachers' interdisciplinary literacy. The central concern is not simply whether teachers know concepts from another field, but whether they can select, reorganize, and teach that knowledge in ways that remain connected to engineering problems. The study therefore combines curriculum development, small teaching modules, pilot implementation, and teaching evaluation. By tracing these activities together, it seeks to identify a workable path for strengthening the interdisciplinary capacity of engineering teachers and for supporting the continuing development of new engineering education.

2. Teaching Demand for Interdisciplinary Integration and Teacher Qualifications

2.1. Pain Points in Cross-Field Teaching

(1) Disciplinary differences can make genuine integration difficult. Civil engineering usually begins from observable engineering objects and constraints: structural safety, material performance, loads, construction conditions, and measurable design indices. Microbiology, by contrast, often explains phenomena through cellular activity, metabolic pathways, microbial communities, and experimental evidence at a much smaller scale. These differences affect not only what is taught, but also the language used to explain a problem and the kinds of evidence considered persuasive. If the two knowledge systems are simply placed side by side, students may remember isolated concepts without understanding how a biological process eventually changes an engineering property.

(2) Suitable teaching materials remain limited. Most established textbooks are written for one discipline and assume a corresponding disciplinary background. A civil engineering textbook rarely explains microbial cultivation or metabolism in the depth needed for biological applications, while a microbiology text generally does not connect those mechanisms to strength, durability, permeability, or other engineering indicators. Teachers therefore have to assemble materials from research papers, experimental manuals, engineering cases, and digital resources. The shortage of mature case collections, laboratory instructions, and virtual simulation materials increases the preparation burden and makes sustained interdisciplinary teaching harder to organize.

(3) Practical teaching is constrained by the way laboratories and training facilities are usually organized. A useful civil engineering-microbiology exercise may require microbial cultivation and detection on one side and specimen preparation, mechanical testing, or engineering simulation on the other. In many universities these facilities belong to separate laboratories and are managed according to different teaching schedules and safety procedures. Students may consequently learn the biological mechanism in one setting and the engineering effect in another, with little opportunity to follow the full process from reaction to material response. This separation weakens the link between theory and problem solving.

2.2. The Composition of Core Competencies for Interdisciplinary Teachers

For this type of teaching, interdisciplinary literacy should be understood as more than a larger stock of knowledge. Teachers must be able to move between two disciplinary perspectives and decide what should be connected, what should remain distinct, and how the connection can be made understandable to students. In the present study, this literacy is considered through three related dimensions: knowledge, application ability, and interdisciplinary thinking.

(1) Interdisciplinary knowledge reserve [5]. Teachers need a reliable foundation in their original discipline as well as enough knowledge of the neighboring discipline to

avoid superficial explanation. For the case discussed here, this includes civil engineering topics such as structures, engineering materials, and construction; basic microbiological concepts such as metabolism, microbial classification, and biological reactions; and knowledge located at the interface of the two fields, including biomineralization, microbial building materials, and environmental bioremediation. The goal is not to turn one teacher into a specialist in every area, but to build a knowledge network that supports correct connections between mechanisms and engineering outcomes.

(2) Cross-application ability [6]. Knowledge becomes useful for teaching only when it can be transferred into a new problem setting. An interdisciplinary teacher should be able to relate microbiological principles to civil engineering questions, design experiments that include both biological and engineering variables, and interpret laboratory findings in terms of engineering performance. The same ability is required when research results are converted into course material: a technically correct experiment still needs to be reorganized into a sequence that students can follow, discuss, and test.

(3) Cross-disciplinary thinking quality. Teachers also need a way of thinking that is comfortable with different disciplinary assumptions. Civil engineering and microbiology do not always use the same scale of observation, terminology, or experimental logic. Effective teaching therefore requires openness to the methods of another field, a systems perspective that connects micro-level processes with macro-level behavior, and the habit of looking for meaningful links rather than forcing every concept into a single framework. This form of thinking is especially important when students are asked to analyze unfamiliar engineering problems.

2.3. The Practical Challenges Faced by Interdisciplinary Teacher Literacy Training

Interdisciplinary teaching has become a visible part of emerging engineering education, but the move from policy intention to routine classroom practice is not automatic. The difficulty lies partly in the fact that teachers were themselves trained within established disciplinary systems. Knowledge structures, research habits, laboratory methods, and evaluation standards have developed along different paths, so the ability to teach across fields has to be cultivated rather than assumed.

A first difficulty concerns the structure of teachers' existing expertise. University teachers usually spend many years building depth in a relatively narrow research area, and that specialization is essential to high-quality professional teaching. At the same time, it can make cross-field work demanding. Civil engineering teachers may be comfortable with structural design, mechanics, and material testing but unfamiliar with microbial metabolism, biomineralization, or biological regulation. Microbiology teachers may understand strains, communities, and reaction processes in detail while having less experience with material service behavior, engineering specifications, and performance requirements. When these knowledge gaps are not addressed, interdisciplinary courses easily become a sequence of separate lectures rather than a genuinely integrated learning experience.

A second challenge is pedagogical rather than purely disciplinary. Teachers have to decide how knowledge from another field changes the way an engineering problem is taught. MICP provides a useful illustration. Explaining urease activity and carbonate formation is only the biological part of the story; students also need to see how precipitation alters pore structure, why those changes affect strength or other properties, and under what conditions the technique could be considered in geotechnical work. The teacher is therefore required to connect mechanism, experiment, engineering index, and application scenario. This is a different task from delivering a complete body of knowledge in one subject and requires a shift toward guiding students through an interdisciplinary problem.

The evaluation environment can create an additional barrier. Existing teacher assessment systems often give clear weight to publications, research projects, and achievements within a recognized discipline, whereas time spent developing interdisciplinary courses, coordinating laboratories, preparing shared resources, or co-

teaching may be less visible. If this work is treated as an extra responsibility rather than part of professional development, sustained participation is difficult. A more appropriate evaluation approach would recognize teaching innovation, collaboration, interdisciplinary research, and the conversion of research or engineering experience into reusable teaching resources.

3. Construction of a Cross-Disciplinary Literacy Training System for Teachers

3.1. Positioning of Training Objectives

The training objective is to help civil engineering teachers develop enough interdisciplinary competence to design and deliver teaching that connects microbial processes with engineering questions. Rather than creating a separate biology course for engineering students, the project emphasizes the integration of selected biological ideas into existing professional contexts. Topics such as material improvement, soil reinforcement, pollutant treatment, and durability provide the main application settings. Training activities are therefore organized around the knowledge needed to explain these applications, the experiments needed to demonstrate them, and the teaching methods needed to make the connections explicit to students.

3.2. Design of Training Path

3.2.1. Specialized Training and Course Learning

The training arrangement combines online study, face-to-face instruction, and practical experience. Civil engineering teachers can use online courses such as Microbiology Basics, Environmental Biological Engineering, and Principles of Biological Building Materials to establish a basic conceptual foundation before entering the laboratory. Offline sessions led by microbiology specialists then focus on issues that are difficult to learn from reading alone, including experimental procedures, microbial metabolism, and the interpretation of biological results. Laboratory practice gives engineering teachers direct experience with cultivation and basic testing. Training also works in the opposite direction: microbiology teachers are introduced to civil engineering fundamentals, material behavior, construction processes, and relevant specifications, and visits to engineering training bases help them see how laboratory mechanisms are translated into engineering requirements. In this way, knowledge exchange is reciprocal rather than one-sided.

3.2.2. Joint Teaching and Research and Team Building

A stable interdisciplinary course requires more than occasional guest lectures, so the project also organizes a joint teaching and research team. Civil engineering teachers, microbiology teachers, and technical personnel from industry participate in activities such as collective lesson preparation, classroom observation, case discussion, and the design of practical projects. These meetings provide a space to resolve problems of terminology, sequence, and technical depth before they appear in class. For younger teachers, a mentoring arrangement is used so that they can participate in curriculum development and teaching research with guidance from colleagues who already have cross-field experience. Team-based preparation reduces the expectation that one teacher should independently master every part of the interdisciplinary content.

3.2.3. Scientific Research Projects and Practical Experience

Research projects provide another route for teacher development because they bring the two disciplines together around a concrete technical question. Teachers are encouraged to participate jointly in projects related to microbial mineralization for soil reinforcement, bio-concrete, and biological treatment in municipal engineering. In these projects, biological variables and engineering performance have to be considered at the same time, which makes knowledge integration a practical necessity rather than an abstract training objective. Cooperation with enterprises extends this experience beyond the university. By observing or participating in real applications, teachers can better

understand engineering constraints and can later convert those experiences into cases, data sets, or problem scenarios for teaching.

3.2.4. Interdisciplinary Training Model Based on Scientific Research Feeding Back to Teaching

Research participation is especially useful because it exposes teachers to the full chain of an interdisciplinary problem. A project on microbial engineering materials may involve strain or culture conditions, mineralization mechanisms, material preparation, property testing, and evaluation of engineering suitability. Each step uses a different kind of knowledge, and the links between the steps are not always obvious at the beginning. Working through the project helps teachers see how a microscopic biological process becomes relevant to a macroscopic engineering response. That experience is difficult to obtain from short-term lectures alone and gives teachers a stronger basis for deciding what to include in class.

MICP research illustrates this process clearly. A civil engineering teacher who studies the method needs to understand how microbial metabolism contributes to carbonate generation, but the analysis cannot stop there. The resulting precipitation must also be discussed in relation to pore structure, bonding, mechanical behavior, and durability. Following these connections during research makes it easier to design a teaching case in which students move from mechanism to measurable engineering effect instead of treating the biological and engineering parts as unrelated topics.

Research can also keep course content closer to current technical developments. Textbooks remain necessary for basic principles, but their revision cycle is usually slower than the development of an emerging interdisciplinary field. Ongoing projects, by contrast, produce experimental observations, data, unsuccessful trials, and engineering cases that can be adapted for teaching. Cases such as MICP-reinforced sand or microbial self-healing concrete allow students to work with a recognizable engineering problem while encountering newer technologies. When teachers use research material in this way, the classroom becomes a place where established theory and recent practice can be compared rather than simply listed.

For this reason, the relationship among research, teaching, and engineering practice should be treated as a continuing cycle. Research gives teachers new problems and evidence; teaching forces those ideas to be reorganized and explained; engineering practice then tests whether the selected knowledge is meaningful outside the laboratory. Repeated movement among these settings can gradually strengthen interdisciplinary literacy.

3.3. Cultivation and Support Mechanism

(1) Institutional support should make interdisciplinary teaching part of normal teacher development rather than an informal extra task. Universities can clarify responsibilities for course construction and team teaching, recognize interdisciplinary curriculum development and teaching-research projects in evaluation, and provide appropriate support in professional assessment and performance arrangements. Such measures matter because interdisciplinary work often requires additional coordination and preparation that is not visible in a conventional single-discipline workload.

(2) Resource support should focus on the points where cross-field teaching is most difficult to sustain. Dedicated funding can be used for teacher training, redevelopment of course materials, experimental manuals, and the improvement of practical facilities. Libraries and laboratories can also coordinate their resources so that teachers can access literature from both fields and use shared instruments more efficiently. An integrated space that links engineering simulation, biological experiments, and data analysis would reduce the fragmentation that currently occurs when students have to move between independent teaching systems.

(3) Regular academic exchange is needed to prevent the training system from becoming closed within one institution. On-campus seminars and teaching salons can be used to discuss specific course problems, while participation in external teaching

workshops, academic forums, and professional training can expose teachers to different approaches. Inter-university cooperation is also useful for sharing cases and experimental resources that are difficult for a single program to develop alone.

4. Design and Implementation of Interdisciplinary Teaching Practice

4.1. Research Design

The teaching practice was organized in three stages. In the first stage, the work began with existing civil engineering courses rather than with a newly created interdisciplinary course. "Soil Mechanics" and "Foundation Engineering" were selected, and topics with a clear biological connection, such as microbial mineralization for soil stabilization and concrete self-repair, were identified. For each topic, a short module of approximately one to two class hours was prepared together with slides, short videos, and case materials. Education and technical experts reviewed the proposed content before it entered the classroom. The second stage involved pilot teaching. One to two teachers and one to two classes used the modules, and information was collected through tests, questionnaires, and interviews to examine both learning effects and practical feasibility. The third stage focused on revision and wider use: feedback from the pilot was used to adjust the way interdisciplinary knowledge was embedded in the professional courses, and the resulting experience was summarized for teaching seminars and project reports.

4.2. Innovation in Teaching Methods

(1) Project-driven teaching method [7]. Project work was used to keep the interdisciplinary content tied to an engineering task rather than treating it as an additional block of theory. Students worked in groups and moved through problem definition, scheme development, experimental work, and presentation. In the "Bio-concrete R&D" task, for instance, the choice of functional microorganisms could not be made independently of the concrete mix or the performance to be tested later. Students had to explain why a biological choice was reasonable, how it was incorporated into the material design, and what the strength and durability results implied. The final report was therefore judged on the connection between the two parts of the project, not on whether the biological and engineering results were simply listed side by side.

(2) Case teaching method. Cases were used when they could expose the conditions and limitations behind an interdisciplinary technology. The materials included examples of microbial self-healing concrete from Delft University of Technology and microbial sand-fixation practice in desert environments in China. During discussion, students were not asked merely to recall the name or principle of a technique. They first identified the engineering problem, then traced the biological mechanism involved and considered the circumstances in which the method could or could not be applied. This made the case useful as a reasoning exercise, especially when a technically attractive idea faced practical constraints.

(3) Virtual-real integration teaching method [8]. Some key processes in this field are either too small, too slow, or too difficult to observe directly during an ordinary class. Virtual simulation was therefore used before or alongside laboratory work to make processes such as microbial mineralization and crack repair easier to follow. The simulated view was not treated as a substitute for experiment. Students still carried out operations including microbial cultivation and material-performance testing in the shared laboratory, where measurement error, sample variation, and procedural constraints became part of the learning process. Combining the two forms of practice allowed a mechanism to be introduced visually and then examined under real experimental conditions.

4.3. Building a Practical Platform

(1) Interdisciplinary laboratory within the university. The teaching platform was built by coordinating, rather than duplicating, the existing Civil Engineering Materials Laboratory and Microbiology Laboratory. Different instruments were needed at different

points in one task: microbial incubators and bacterial community analysis supported the biological stage, while material strength testing was used to examine the engineering response. Arranging these resources around a common teaching task allowed students to follow the sequence from biological preparation to material testing and interpretation, which is difficult when the two laboratories operate as completely separate teaching units.

(2) Off-campus practice base. Campus experiments cannot reproduce every constraint encountered in an engineering project. Cooperation with municipal engineering companies, environmental technology enterprises, and building-material research organizations was therefore used to expose students to issues of scale, construction conditions, cost, and operation. Site visits and participation in research or development activities also generated examples that teachers could bring back into class. In this sense, the off-campus base served both student practice and the continued renewal of teaching cases.

(3) Innovation and entrepreneurship platform. The university's Innovation and Entrepreneurship Center was used for work that extended beyond the time available in a normal course. Students and teachers could continue topics such as biological building materials or environmental bioremediation through project incubation, prototype work, and technical presentation. This setting introduced an additional question that classroom exercises often leave aside: whether an interdisciplinary idea can be turned into a workable engineering solution with a clear user, process, and application context.

4.4. Optimization of Teaching Evaluation System

A single written examination provides only part of the evidence needed to judge interdisciplinary teaching. Knowing the definition of a microbial process, for example, does not show that a student can relate that process to an engineering indicator. The same distinction applies to teachers: familiarity with theory is different from being able to design a task in which knowledge from two fields is used together. Evaluation was therefore treated as a combination of conceptual understanding, practical performance, collaboration, and teaching design rather than as one final score.

For teachers, the evaluation focused on what changed in actual teaching work. Course design, cooperation with colleagues from another discipline, participation in research or engineering projects, and the quality of newly developed materials were all considered relevant evidence. Self-reflection was useful for recording difficulties that might not appear during a classroom observation, while peer review and student comments provided a view of whether the cross-disciplinary connection was understandable in practice. No single source was treated as sufficient on its own.

Student assessment followed the same logic. In the MICP soil-reinforcement module, a student could be asked to justify the choice of microorganism, outline the experiment, interpret the material-performance data, and comment on a possible engineering use. A response of this kind shows whether the student can move from mechanism to design and then from data to application. Written tests were retained for basic concepts, but they were used alongside project and practical evidence rather than standing as the whole assessment.

The evaluation results were also used to revise the course. Teachers and students sometimes identified problems that numerical scores alone did not reveal, such as an explanation that was too compressed, an experiment that consumed more class time than expected, or a weak link between the biological and engineering parts of a task. These observations, together with test results and practical records, informed changes to the content, experimental arrangement, and teaching sequence in the next round.

4.5. Building a Sustainable Interdisciplinary Teaching Ecosystem

Long-term operation is a separate problem from the initial design of an interdisciplinary course. Adding new content once is relatively easy; keeping teachers, laboratories, research activities, and external partners involved over several teaching cycles is more difficult. In the civil engineering-microbiology case, sustainability therefore depends on routines that can survive beyond the first project period. The aim is to make

interdisciplinary work part of normal course operation, so that it does not rely on a few teachers repeatedly taking on extra coordination without institutional support.

Continuity of the teaching team is especially important. Civil engineering and microbiology differ in scale of observation, experimental practice, terminology, and professional judgment, so equal depth in both fields cannot reasonably be expected from every individual teacher. A mixed team allows responsibilities to follow expertise while lesson planning remains shared. In an MICP module, for example, engineering teachers can take the lead on soil structure, mechanical behavior, and application constraints, while microbiology teachers explain strains, metabolism, and mineralization. The key step is the joint preparation between these contributions; without it, students simply receive two adjacent lectures.

Research material should enter the classroom selectively rather than automatically. A rapidly developing field produces more data than a course can use, and some results are too narrow or method-dependent to function well as teaching examples. More useful cases are those that reveal a relationship students can examine, such as the way bacterial concentration, mineralization cycles, or environmental conditions correspond to changes in soil performance. Working with such data also exposes variation and trade-offs that are often hidden in textbook summaries. At the same time, it gives teachers a way to connect the course with questions they are already investigating.

School-enterprise cooperation contributes something that controlled laboratory work cannot provide. An engineering site introduces scale, construction sequencing, equipment limits, cost, and project management, all of which can alter how a promising laboratory method is used. Practice bases established with engineering companies, environmental organizations, or research institutions therefore give students a chance to see what happens between an experimental result and field application. Work related to green building materials, ecological restoration, or geotechnical reinforcement is particularly useful because the biological and engineering considerations remain visible at the same time.

The curriculum should also be revised periodically, but revision does not always mean adding more topics. New materials and techniques may make one example more relevant, while feedback from students or laboratory staff may show that another module is too dense for the available time. Reviewing course content, experimental tasks, and assessment methods against actual teaching experience and industry change can therefore lead to expansion, simplification, or removal. In some cases, teaching fewer interdisciplinary links more clearly is preferable to covering a larger number superficially.

Taken together, these arrangements provide the conditions for continued operation rather than a one-off demonstration. Collaborative teaching keeps expertise available, research supplies current problems and evidence, enterprise participation adds real engineering constraints, and periodic revision prevents the course from becoming fixed around outdated examples. Their common value is practical: the interdisciplinary content remains attached to the people, facilities, and problems through which students encounter it.

5. Analysis of the Effectiveness of Teaching Practice

The practical effect of the reform was examined from three aspects: changes in teachers' interdisciplinary competence, students' learning and application, and the development of teaching resources and support conditions. Information from the pilot and subsequent implementation was considered together so that the reform was not judged by a single classroom indicator.

5.1. Systematic Improvement of Teachers' Interdisciplinary Literacy

The participating teachers showed improvement across the knowledge, ability, and thinking dimensions used in the training framework. In the knowledge-related evaluation, 92% of civil engineering teachers were reported to have mastered core concepts such as microbial metabolic mechanisms, while 85% of microbiology teachers showed an accurate

understanding of key civil engineering material properties; the reported completion rate for interdisciplinary knowledge-network construction was 88%. In terms of teaching and application, 76% of teachers were able to design "engineering + biology" teaching modules independently, and 68% took part in interdisciplinary teaching-research or scientific research projects. The work also produced three characteristic courses and two experimental guides. For interdisciplinary thinking, 83% of teachers were able to identify integration points from a systems perspective, and the number of innovative teaching schemes proposed increased by 65% compared with the situation before the reform. These results indicate that the training influenced not only what teachers knew, but also how they organized and used that knowledge in teaching.

5.2. Significant Improvement in Students' Comprehensive Abilities and Learning Outcomes

Student results were considered from three angles: understanding across the two fields, performance in practical tasks, and engagement with the learning process. The evaluation showed that 91% of students could explain connections between the two disciplinary knowledge areas, while accuracy in understanding technologies such as microbial mineralization for sand fixation rose by 52% compared with the traditional mode. Project work showed a similar pattern. For subgrade microbial reinforcement and related tasks, the reported improvements in feasibility, data accuracy, and technological innovation were 48%, 39%, and 63%, respectively, and students obtained four academic competition awards at provincial level or above. Recognition of the teaching mode reached 89%. Classroom participation, independent exploration, and team collaboration were also higher than in traditional classes, suggesting that the practical tasks gave students reasons to use the interdisciplinary knowledge rather than only remember it.

5.3. The Interdisciplinary Teaching System Is Becoming More and More Perfect, with a Significant Improvement in Its Supporting Capability

The reform left behind a set of resources that could be reused after the pilot stage. Five core knowledge points were developed into 12 micro-teaching modules, with more than 60 supporting items, including presentation materials, videos, and experimental guides. Three modules were subsequently included in the university's high-quality teaching resource library. The shared Civil Engineering-Microbiology laboratory had completed more than 200 teaching experiments and served over 800 students, while three off-campus practice bases were connected with engineering projects. These resources did not remove every difficulty involved in cross-disciplinary teaching, but they made it easier to link classroom explanation with biological experimentation and engineering practice in later teaching cycles.

5.4. The Development Prospects and Further Optimization Directions of Interdisciplinary Teaching Reform

The outcomes reported above should be read as evidence from an ongoing reform, not as a finished model. Some parts of the approach are already usable, but others still depend heavily on local course arrangements, laboratory access, and the availability of teachers from both disciplines. The next stage should therefore pay more attention to how the curriculum is connected internally, how often students can actually use the practical platforms, where digital tools add clear value, and whether the evaluation captures lasting problem-solving ability rather than only short-term learning gains.

Curriculum organization is one issue that remains unresolved. Civil engineering programs are still built mainly around established professional subjects, and content from microbiology, environmental science, or artificial intelligence is often introduced as an isolated topic after the main disciplinary structure has already been set. A more coherent approach would start from an engineering direction and then decide which additional knowledge is needed. In geotechnical engineering, microbial remediation can be discussed together with environmental geotechnics and monitoring technologies; in materials courses, bio-based or self-healing materials can be connected with durability,

performance evaluation, and lifecycle questions. Organizing content in this way makes the reason for including the new material more explicit.

Access to practical platforms also needs improvement. Interdisciplinary ideas are difficult to understand fully when students encounter them only through slides or equations, because the connection between a biological process and an engineering response is partly experimental. A shared platform across civil engineering, microbiology, and environmental engineering could allow one task to continue from microbial cultivation to material preparation and then to performance testing. Virtual simulation is useful when a process is too slow, too small, or otherwise difficult to observe directly, but its role should be complementary. Students still need contact with physical experiments, including the uncertainty and procedural limits that simulations tend to simplify.

Digital tools can support this work, provided that they are chosen for a specific teaching problem. A model that visualizes mineralization or soil-structure change may help students connect microscopic processes with macroscopic behavior. A data-analysis platform can make it easier to compare experimental results or alternative engineering decisions. These uses are valuable because they reveal relationships that are otherwise hard to inspect. By contrast, adding artificial intelligence, big data, or virtual reality simply because the technologies are current does not strengthen interdisciplinary teaching unless they help students reason about the engineering problem.

Evaluation should continue to emphasize whether students can integrate knowledge while solving a problem. Written examinations remain useful for basic concepts, but they do not capture experimental design, interpretation of data, teamwork, or the justification of an engineering decision using information from more than one field. Course projects, practical reports, team performance, and design tasks can provide this additional evidence. The aim is not to replace examinations, but to avoid allowing one type of assessment to dominate a learning process that is broader than recall.

Several practical constraints must also be acknowledged. Teachers need protected time to learn unfamiliar material and prepare it with colleagues from another department. Cross-department coordination becomes difficult when schedules, laboratory rules, and evaluation procedures are different, and reusable experiments or case materials require continued investment rather than a one-time purchase. For this reason, the reform cannot depend entirely on individual enthusiasm. Stable cooperation mechanisms, teacher development support, and appropriate institutional recognition are needed if the work is to continue beyond a pilot project.

The civil engineering-microbiology case suggests that responding to technical change does not require weakening the disciplinary core of engineering education. The more useful question is where another field becomes necessary for understanding an engineering mechanism, interpreting evidence, or choosing a solution. Seen in this way, interdisciplinary teaching extends professional reasoning rather than replacing professional depth. This distinction is likely to matter increasingly as green and low-carbon technologies bring biological and environmental processes into engineering design.

6. Conclusion

This study used the intersection of civil engineering and microbiology to examine how teachers can acquire and use interdisciplinary literacy in actual teaching. The experience from the reform indicates that short-term knowledge training alone is insufficient. Teachers need repeated opportunities to prepare courses with colleagues, participate in research, work in laboratories, and connect what they learn with engineering situations. The project therefore linked teacher training with teaching research and practice, and paired that route with classroom changes in curriculum content, teaching methods, practical platforms, and evaluation. The reported results for teachers, students, and teaching resources show that this combination can be implemented within existing engineering programs rather than only through a separate interdisciplinary course. Even so, continued operation depends on institutional support and regular

revision. Future work should improve the training arrangements, broaden exchange among universities and regions, select new technologies and engineering cases carefully, and make better use of both virtual and physical practical resources. The longer-term objective is for interdisciplinary teaching to become part of routine professional education, supported by stable people and resources rather than by a temporary reform project.

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