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RESEARCH-BASED TEACHING FOR AN INTERDISCIPLINARY MATERIALS SCIENCE GENERAL EDUCATION COURSE: A DESIGN FRAMEWORK AND IMPLEMENTATION PATHWAY

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Abstract: General education science courses for non-majors often default to diluted lectures, a problem sharp enough in China to have earned its own label, the shuike (watered-down courses) and pressing enough that reform now targets the design of individual courses. Materials science is an unusually good vehicle for a better course. It is everywhere in daily life, and it is interdisciplinary by construction, joining physics, chemistry, and engineering. Yet materials education research addresses majors, general education science rarely uses materials, and the two have not been joined through research-based teaching. This paper presents a literature-grounded design framework for a materials science general education course built on authentic inquiry, together with an implementation pathway and an evaluation plan. Following the design-based research tradition, it reports the first cycle, the analysis and design, and reports no student data. Synthesizing four literatures, research-based teaching, materials education, general education science for non-majors, and interdisciplinary higher education, the framework derives six design principles and organizes a one-semester course into four interdisciplinary modules on a shared inquiry cycle, culminating in a course-based research capstone scaled for non-majors. The paper sets out a staged rollout that answers the known failure modes of interdisciplinary teaching, and an evaluation plan with predefined revision triggers that would close the design cycle. The framework gives Chinese general education a quality-signaling course model and the Emerging Engineering Education agenda a concrete interdisciplinary instrument, while remaining adaptable beyond that context. Its effectiveness awaits the empirical second cycle.
Keywords: Research-based teaching; Inquiry-based learning; Course-based undergraduate research; Materials science education; General education; Non-majors; Interdisciplinary curriculum; Design-based research; Scientific literacy; Higher education

1 INTRODUCTION

Almost every university asks students outside the sciences to take a science course. General education exists to give the non-specialist a working grasp of how the physical world is understood. The ambition is old and the delivery is often thin. Too many of these courses shrink into a survey lecture, a set of facts to memorize and return on an exam, with the actual practice of science left out. In China the problem is common enough to have a name. Students call the weakest electives shuike (watered-down courses) and the label sticks to much of the general education catalogue. Two decades of expansion have widened access to general education without settling what it should teach or how [1]. The quality gap is now the central complaint, and reformers have begun to treat the design of individual courses, not just the breadth of the menu, as the thing to fix [2].

Pressure for a better model is not only internal to general education. China's Emerging Engineering Education initiative, launched in 2017, calls on universities to produce graduates who can work across disciplinary lines and to rebuild courses toward that end [3-4]. The initiative is aimed at engineering programs, but its logic reaches the general education that surrounds them, and reform cases in that spirit are starting to appear [5]. A general education course that took interdisciplinary thinking seriously, and that let students practice inquiry rather than watch it, would answer both the quality complaint and the reform agenda at once.

Materials science is an unusually good vehicle for such a course. Its subject matter is everywhere. Every manufactured object, from a phone screen to a battery to a plastic bottle, is a materials problem solved, and students already have questions about the things they use. The discipline is also interdisciplinary by construction. It joins physics, chemistry, and engineering through a single organizing idea, the relationship among a material's structure, properties, processing, and performance, and it reaches naturally into economics, environment, and design [6]. A student who follows one everyday material through those lenses has done interdisciplinary work without being told to. Few subjects offer that combination of familiarity and breadth.

The case for teaching such a course through inquiry rather than lecture is by now well supported. A large meta-analysis found that active learning raises student performance across science, engineering, and mathematics, and lowers failure rates, relative to straight lecturing [7]. A more specific and powerful idea has matured alongside it. Course-based undergraduate research experiences, or CUREs, embed authentic investigation into a regular course, so that an entire class, not a hand-picked few, takes part in research whose outcome is not known in advance [8]. Because the research is built into the course, a CURE reaches students who would never be selected for a faculty member's laboratory, which makes it a tool for inclusion as much as for learning [9]. That inclusive reach is exactly what a general education course needs.

These threads have not been drawn together. Research on materials education is real but aimed almost entirely at majors, concerned with how to teach the engineering curriculum better. Research on general education science for non-majors is rich but rarely touches materials. The closest published work we have found is a single online materials chemistry course built for general education students, designed to raise their scientific literacy [10]. It shows the audience is reachable, but it delivers content rather than research. We are aware of no published course design that combines materials science, general education for non-majors, and research-based teaching in one framework. That absence is the opening this paper addresses.

This paper offers a literature-grounded design for such a course, together with the pathway to put it into practice and the plan to evaluate it. It is deliberately a design contribution. Following the design-based research tradition, in which usable educational knowledge is built through cycles of theory-grounded design and testing [11], the paper reports the first cycle: the analysis of what the evidence recommends and the design that follows from it. No implementation data are presented, and none are implied. What we present is a framework that others can build, critique, adapt, or refute, with the empirical test set out as the next step.

The paper makes four contributions. First, it synthesizes four normally separate literatures, namely research-based teaching, materials education, general education science for non-majors, and interdisciplinary higher education, and locates the gap where they fail to meet. Second, it derives a set of design principles from that synthesis and assembles them into a concrete course framework built around interdisciplinary inquiry. Third, it sets out a staged implementation pathway that anticipates the known failure modes of interdisciplinary and general education teaching. Fourth, it specifies an evaluation plan that would close the design cycle and turn the framework into tested knowledge. The remainder proceeds as follows. Section 2 reviews the four literatures. Section 3 states the design methodology. Section 4 presents the framework. Section 5 gives the implementation pathway, Section 6 the evaluation plan, and Section 7 discusses significance, limitations, and next steps.

2 LITERATURE REVIEW

This section reviews the four bodies of work the design draws on. Each has matured on its own. The point of reading them together is to show that their intersection, a research-based interdisciplinary materials course for non-majors, remains unoccupied, and to extract from each what a sound design would need.

2.1 Research-Based Teaching and Inquiry-Based Learning

The idea that teaching and research belong together at the undergraduate level has a settled vocabulary. Healey distinguishes four ways a course can relate to research [12]. Research-led teaching conveys current findings; research-oriented teaching conveys the methods; research-tutored teaching has students discuss research in small groups; and research-based teaching has students themselves act as producers of knowledge rather than its audience. The last of these is the most demanding and the most valuable, and it names the target of this paper. Research-based teaching sits within a wider family of inductive methods, in which students meet a problem or observation before the governing principle, and build the principle from the encounter [13].

The evidence that such methods work is strong. The most cited synthesis compared active learning with traditional lecturing across hundreds of studies in science, engineering, and mathematics, and found active learning improved examination performance and cut failure rates [7]. A meta-analysis focused specifically on inquiry-based learning confirmed its benefit, and showed that the effect depends on guidance [14]. Students given appropriate support learn more than those left to inquire on their own. That finding matters for design. That finding speaks to an old debate. One influential critique argued that minimally guided instruction ignores how human memory works and burdens novices past the point of learning [15]. The reply was not that guidance is unnecessary but that good inquiry teaching is guided, with scaffolding that supports students through investigations they could not yet run alone [16]. The lesson for a course serving beginners is to choose guided inquiry, not open inquiry, and to withdraw support gradually.

Inquiry also has a usable structure. Pedaste and colleagues synthesized many models into a single cycle with five phases, orientation, conceptualization, investigation, conclusion, and discussion, that can be arranged and repeated to fit a given task [17]. This cycle gives a course a repeatable grammar for activity design. The course-based research experience, or CURE, supplies the authenticity. A consensus report defined the CURE by five features [8]. Students use the practices of science; the work involves discovery of genuinely unknown answers; the questions are broadly relevant beyond the classroom; students collaborate; and the work iterates. A companion model theorized how these features produce their effects on students [18]. A separate argument established their equity value: building research into a required course reaches every enrolled student rather than a selected minority [9]. Broader syntheses of undergraduate research report gains in learning, persistence, and confidence, while cautioning that quality of design matters [19-20]. A systematic review of which scientific practices CUREs actually implement found the practice of "asking questions" often underdeveloped, a gap a new design should attend to [21]. Evidence that research-based learning benefits students reaches beyond the sciences [22], and inquiry has been shown to improve the science literacy and confidence of non-majors specifically [23]. For structuring an undergraduate research curriculum, Brew offers a decision framework linking the scope of the research to the level of the students [24]. One caution frames all of this. The CURE literature is concentrated in the life sciences and in courses for majors, so its transfer to a non-majors materials course cannot be assumed, and is itself part of the design problem.

2.2 Materials science education

Research on teaching materials science is aimed overwhelmingly at students who are becoming materials engineers. Its recent energy has gone into changing how the existing curriculum is delivered. Studies have tested flipped and highly interactive classroom formats for introductory materials courses [25-26]. Others have built online laboratory teaching with augmented reality for topics such as crystal structure [27], and active-learning workshops tied to sustainability outcomes [28]. Perspectives on the future of the field point toward artificial intelligence and product-based learning [29]. At the level of the discipline as a whole, there is now an explicit argument that materials education should be integrated across its contributing fields rather than taught as separate silos [6]. That argument supports interdisciplinary design but is pitched at the training of specialists.

For non-majors, the record thins to a handful of cases. The clearest is an online materials chemistry course built for general education students, whose aim was scientific literacy rather than disciplinary depth [10]. A course-based research experience in materials chemistry has been reported, but for chemistry majors in a laboratory sequence [30]. Adjacent non-majors science courses show that unfamiliar material can be made accessible through everyday and applied contexts. They use nanotechnology, the chemistry of food and cooking, and human health as entry points [31-33]. These are encouraging analogues. None combines materials content, a non-majors audience, and authentic inquiry, which is the combination this paper designs for.

2.3 General Education Science for Non-Majors

Teaching science to non-majors has its own well-developed literature, and it begins with a different goal. The aim is not to produce a junior scientist but a capable citizen who can deal with science as an outsider, drawing on expertise without possessing it [34]. A national consensus report framed scientific literacy along these lines, distinguishing what individuals and communities need from science in ordinary life [35]. Concrete redesigns exist. A widely noted rebuild of a general education science course reorganized it around critical thinking and scientific reasoning rather than content coverage, with encouraging results [36].

The literature also warns about the audience. Non-majors bring affective barriers that majors often do not, and science anxiety is a documented obstacle in general education science courses [37]. Non-majors respond differently to the same pedagogy. A comparison of clicker use found the tool changed learning and retention differently for non-majors than for majors [38]. Active learning, too, has been shown to shift the attitudes and self-efficacy of non-majors, not only their scores [39]. Because of these barriers, engagement strategies matter, and even unconventional media such as comics have been tested as ways to draw non-majors toward science [40]. Assessment must also suit the audience; low-stakes probes of how students organize concepts, such as word-association methods, have been used to track non-majors' changing knowledge structures [41]. The structural precedent closest to our design is a problem-based, interdisciplinary science course built expressly for non-science majors [42]. This literature supplies both the goals and the cautions a materials course for non-majors must respect. It matters all the more in the Chinese context, where general education has grown fast but is dogged by the quality problems described earlier [1-2].

2.4 Interdisciplinary Teaching in Higher Education

The final strand concerns what it takes to teach across disciplines well. A systematic review established the conditions that support interdisciplinary higher education and the outcomes it seeks [43]. Chief among those outcomes is the capacity for interdisciplinary thinking, the integration of insights from more than one discipline into a coherent understanding. A prominent framework, the Connected Curriculum, proposes organizing an entire degree around research and around the connections between disciplines, which makes it a natural reference for a research-based interdisciplinary course [44]. But the literature is candid about difficulty. A review of interdisciplinary teaching activities found them different, difficult, and local, meaning they resist standardization and rarely transfer intact from one setting to another [45]. Within engineering education specifically, sustaining interdisciplinary work has been shown to require aligned vision, teaching practice, and institutional support [46].

Two further cautions bear directly on design. Problem-based and project-based methods are often assumed to deliver interdisciplinarity automatically, but they do not; the interdisciplinary outcome has to be designed for, not left to the format [47-48]. And interdisciplinary breadth can come at the cost of disciplinary depth, a trade-off that curriculum designers must weigh openly [49]. Sustaining such courses over time depends on governance that crosses the usual departmental boundaries [50]. Assessing them requires tools built for the purpose, able to judge whether a student has genuinely integrated disciplines rather than merely placed them side by side [51].

Read together, the four strands tell a consistent story. Research-based teaching and the CURE model offer a validated way to give whole classes authentic research, but almost entirely in the sciences and for majors. Materials education knows its subject is interdisciplinary but teaches it to specialists. General education science knows its audience and its goals but seldom uses materials or authentic inquiry. Interdisciplinary higher education supplies the theory of integration and a stern warning that it must be designed deliberately and supported institutionally. The design task, then, is defined by these gaps. It is to transfer CURE-style authentic inquiry to a general education audience, anchored in the interdisciplinary structure of materials science, scaffolded for novices, and kept within reach of students who arrive wary of science.

3 DESIGN METHODOLOGY

This paper is a work of design, and it uses the methodology built for design in education. Design-based research develops usable knowledge by creating an intervention, grounding it in theory, and refining it through cycles of enactment and study [11]. Its purpose is dual. It aims to solve a real instructional problem and, at the same time, to produce knowledge about how and why the solution works [52]. Wang and Hannafin describe the approach through five characteristics: it is pragmatic, grounded in theory and context, interactive and iterative, integrative of methods, and contextual in its findings [53]. Over the following decade design-based research matured from a promising idea into a recognized methodology with an accumulated record [54]. Its generic form moves through phases of analysis, design, and evaluation, repeated as understanding improves [55].

A full design-based research program runs several such cycles. This paper reports the first two phases of the first cycle, the analysis and the design. The analysis is the synthesis of Section 2, which establishes what the evidence recommends and what remains undone. The design is the framework, pathway, and evaluation plan that follow. Enactment with real students, and the empirical evaluation that would test the design, belong to the next cycle and are not reported here. We state this plainly rather than apologize for it. A documented, theory-grounded design is itself a contribution of design-based research, and it is the necessary first move when the literature offers no prior design to iterate upon. In a space this empty, the responsible step is to build the design carefully, make its reasoning explicit, and set out the terms on which it can be tested.

Four inputs govern the design. The first is the set of design principles distilled from the four literature strands of Section 2; these are stated and warranted in Section 4. The second is constructive alignment, the course-design theory holding that intended learning outcomes, the teaching and learning activities, and the assessment tasks must all be designed as a single, mutually consistent system [56]. We read constructive alignment in the course-level, design-first sense its authors intended, as a way to build a course rather than a checklist to audit one after the fact [57]. The third input is the inquiry cycle, which supplies the grammar for the course's activities, its repeatable sequence of orientation, conceptualization, investigation, conclusion, and discussion [17]. The fourth is the CURE feature set, which serves as the benchmark of authenticity against which the course's research component is measured [8].

Figure 1 shows how these pieces fit. Four literature strands feed six design principles. Those principles combine with constructive alignment to produce the course framework, whose activities are structured by the inquiry cycle and whose research capstone is held to the CURE standard. An evaluation plan closes the loop, defining the evidence that the next design cycle would gather.

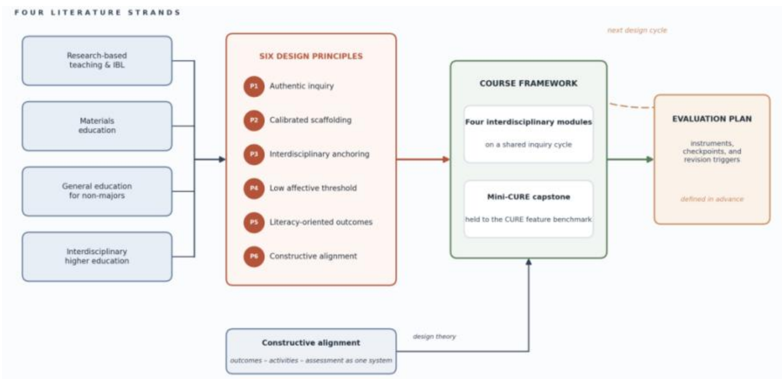

Figure 1 The Design Methodology as a First Cycle of Design-Based Research

Note: Four literature strands are distilled into six design principles that, together with constructive alignment, yield the course framework, implementation pathway, and evaluation plan; the plan feeds the next cycle.

4 THE DESIGN FRAMEWORK

The framework turns the evidence of Section 2 into a course. It has four parts: the design principles that constrain every choice, the course architecture that organizes the semester, the research capstone that supplies authentic inquiry, and the alignment matrix that ties outcomes to activities and assessment.

4.1 Design Principles

Six principles follow from the literature. Each is a rule the design must obey, and each carries a warrant.

P1. Authentic inquiry at general education scale. Students should do real investigation, however small, not watch demonstrations of it. This is the move from research-led to research-based teaching [12], and the CURE literature shows that authentic, unknown-answer research can be built into a whole course rather than reserved for a few [8]. The principle commits the course to genuine inquiry as its spine, not as a garnish.

P2. Calibrated scaffolding. Beginners need guided inquiry, not open inquiry, with support that fades as competence grows. The evidence is that inquiry works best when guided [14], that unsupported novices are easily overloaded [15], and that good inquiry teaching scaffolds rather than abandons the learner [16]. The course therefore starts with tightly structured tasks and loosens its grip module by module.

P3. Interdisciplinary anchoring. Every unit reads one material through several disciplinary lenses, aiming at integration rather than a parade of separate viewpoints. Interdisciplinary understanding, the coherent joining of insights from more than one discipline, is the stated goal of interdisciplinary higher education [43], and materials science offers it naturally through the structure-property-processing-performance chain [6]. The principle demands questions that no single discipline can answer alone.

P4. Low affective threshold. The course must lower the barriers that keep non-majors anxious about science. Science anxiety is a real obstacle in general education courses [37], and everyday, applied contexts make unfamiliar science approachable [32]. The design uses familiar objects as entry points and keeps mathematical formalism to the minimum the ideas require.

P5. Literacy-oriented outcomes. The goal is the competent outsider, a citizen who can reason about materials in daily life, not a junior materials scientist [34]. The national framing of scientific literacy sets the same target [35]. Outcomes are written in those terms, and content is chosen for its power to build judgment rather than for coverage.

P6. Constructive alignment throughout. Outcomes, activities, and assessment are designed as one system, so that what students do and how they are judged both serve what they are meant to learn [56]. The principle governs the whole framework and is made concrete in the alignment matrix of Section 4.4.

4.2 Course Architecture

The framework specifies a one-semester general education course of two credits and roughly thirty-two contact hours, open to students from any major, with no prerequisites and no assumed mathematics beyond secondary school. A class size of thirty to sixty is assumed. The semester is built from four interdisciplinary modules. Each module takes one familiar class of materials and one guiding question that cannot be answered from a single discipline. The questions do the interdisciplinary work, because answering them forces students across the boundaries between physics, chemistry, engineering, and society.

Module 1, "Why doesn't the phone screen scratch?" studies glass and ceramics. Students meet the physics of hardness, the chemistry of composition and ion exchange, the engineering of chemical strengthening, and the design trade-offs between durability, weight, and cost. The everyday object is in every pocket, which is the point.

Module 2, "What makes a battery age?" studies energy-storage materials. It reaches into electrochemistry, the degradation of materials over cycles of use, the engineering of the cell and its management, and the environmental questions of supply and recycling. Battery decline is something every student has experienced, which gives the inquiry an immediate hook.

Module 3, "Can plastic be sustainable?" studies polymers. Students examine molecular structure, the chemistry of degradation and biodegradation, the life-cycle engineering of materials, and the policy and ethics of plastic use. The module joins a technical account to a public controversy, which is where materials literacy earns its keep.

Module 4, "What should replace it?" is a synthesis module in which teams choose a material problem and run a small investigation of their own. It is the course's research capstone, described in Section 4.3. The overall course architecture is summarized in Figure 2.

Each module runs the inquiry cycle [17]. Orientation begins with the everyday puzzle. Conceptualization turns the puzzle into a question and a testable expectation. Investigation is a hands-on or data-based activity. Conclusion interprets what was found, and Discussion widens the frame to the societal lens the guiding question opened. Across Modules 1 to 3 the inquiry is structured, with guidance deliberately withdrawn as the semester proceeds, so that by Module 4 students are ready for the more open capstone. This staged release of responsibility is P2 made operational.

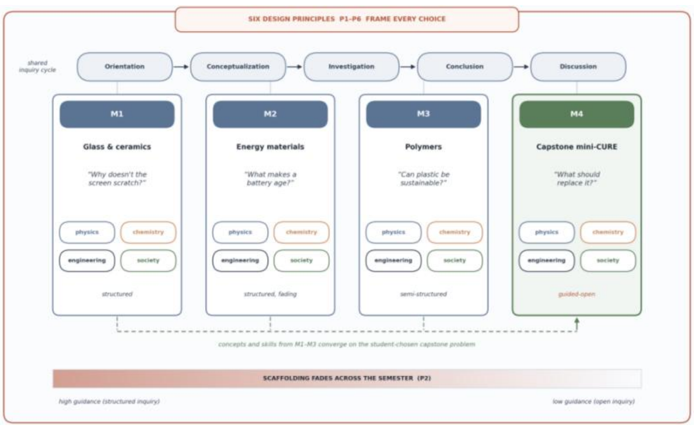

Figure 2 The Course Framework

Note: Four interdisciplinary modules sit on a shared inquiry-cycle spine, bounded by the six design principles, with guidance fading from the structured early modules toward the open capstone where the disciplinary lenses converge on a student-chosen problem.

4.3 The Mini-CURE Capstone

Module 4 carries the authentic-research weight of the course, and it is designed against the five CURE features, honestly scaled for non-majors [8]. Scientific practices are present but bounded. Teams pose a question, gather or find data, and argue a conclusion from evidence. The practice of asking a good question is given explicit attention, since reviews find it the most neglected [21]. Discovery is real at the level of the class, because the specific comparisons students make have no answer key and are unknown to the instructor in advance. Relevance is built in, because the problems are drawn from students' own lives. Collaboration is structured into teams of four or five. Iteration is guaranteed by a required revision round, in which teams act on feedback before their final account.

The investigations must be feasible for beginners with modest equipment, so the framework offers a menu of tractable types rather than open-ended laboratory work. These include kitchen-scale materials testing, such as comparing how everyday plastics respond to heat or how coatings resist abrasion. Others are the comparative teardown of consumer products to gather structured observations, the use of citizen-science and public datasets on materials and recycling, and simple property measurement using the sensors already in a smartphone. None of these requires a specialist laboratory, and all can yield data a team can defend. Two precedents establish that this level of research belongs in a course: a materials chemistry CURE for majors and the broader record of course-based research in chemistry [21,30]. Its viability for non-majors specifically rests on the problem-based interdisciplinary courses already built for that audience [42]. Figure 3 summarizes the mapping, feature by feature.

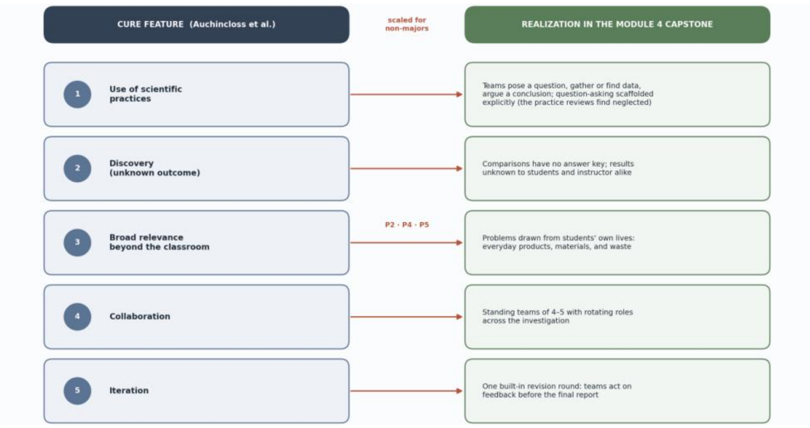

Figure 3 Mapping the Five CURE Features to Their Realization in the Module 4 Capstone

Note: Each feature is retained in a form scaled for non-majors, with the scaling governed by principles P2, P4, and P5.

4.4 Alignment Matrix

Constructive alignment requires that outcomes, activities, and assessment form one system [56]. Table 1 makes that system explicit. The course sets three intended learning outcomes, all written in the literacy-oriented terms of P5. ILO1 is to explain the behavior of an everyday material through more than one disciplinary lens. ILO2 is to evaluate a public claim about materials using evidence. ILO3 is to plan, carry out, and communicate a small investigation. The rows of the table are the four modules; the columns show which outcomes each module serves, the teaching and learning activities it uses, and the assessment tasks that judge it.

Table 1 Constructive-Alignment Matrix for the Course

Module	ILOs served	Teaching–learning activities	Assessment
M1 Glass & ceramics ("Why doesn't the screen scratch?")	ILO1, ILO2	Structured inquiry cycle; hardness demonstration and guided data activity; four-lens discussion	Short multi-lens explanation of a chosen product; participation in structured investigation
M2 Energy materials ("What makes a battery age?")	ILO1, ILO2	Guided inquiry with fading scaffolds; degradation data interpretation; debate on supply and recycling	Evidence-based brief evaluating a public claim about batteries
M3 Polymers ("Can plastic be sustainable?")	ILO1, ILO2	Semi-structured inquiry; life-cycle activity; policy-and-ethics discussion	Individual analysis joining a technical account to a societal judgment
M4 Capstone ("What should replace it?")	ILO1, ILO2, ILO3	Open guided inquiry; team mini-CURE with one revision round	Team investigation report and presentation, graded for disciplinary grounding and integration

Note: ILO1: explain a material across disciplinary lenses; ILO2: evaluate materials claims with evidence; ILO3: conduct and communicate a small investigation.

Read through constructive alignment, the matrix shows each outcome taught and assessed by activities suited to it, with the demand rising across the semester. The early modules build the two literacy outcomes through structured tasks and judge them with focused writing. The capstone adds the investigation outcome and assesses it through a research product graded, following the interdisciplinary-assessment literature, for whether students have genuinely integrated their disciplinary lenses rather than merely listed them [51]. The fading of guidance from M1 to M4 is visible in the activity column, which is P2 realized as a sequence rather than a slogan.

5 IMPLEMENTATION PATHWAY

A framework is only as good as the route to putting it in place. This section proposes that route. It is written as a plan, not a report; the course has not yet been taught, and what follows describes what the design calls for rather than what has happened.

5.1 Staged Rollout

The pathway runs in three stages, each a step in the design-based research cycle.

Stage 1 is preparation, spanning roughly one semester before the course opens. Its central task is to assemble a small cross-disciplinary teaching team, three or four people covering materials science, physics or chemistry, and at least one colleague from the humanities, policy, or design who can carry the societal lens with authority. The team would develop the module kits: activity protocols, sets of everyday-material samples, and data templates for each inquiry cycle. It would also pilot the Module 4 investigation menu internally, running the candidate mini-projects itself to confirm they are feasible with modest equipment and that they yield defensible data. This internal trial catches the practical failures before students meet them.

Stage 2 is the first offering. The framework would run in a single section of thirty to forty students, taught as designed and documented in full. The documentation is not incidental; it is the empirical material of the design-based research cycle, capturing what happened in each module, where scaffolding held or failed, and how the capstone investigations unfolded. This is the point at which the evaluation plan of Section 6 comes into force.

Stage 3 is revision and scale. Guided by the evaluation evidence, the team would revise the modules, the scaffolding, and the capstone menu, then extend the course to further sections or to other institutions. Each enlargement is treated as a further iteration rather than a finished rollout, in keeping with the iterative logic of design research [54-55]. Scale is earned by evidence, not assumed. The implementation pathway and iterative feedback structure are summarized in Figure 4.

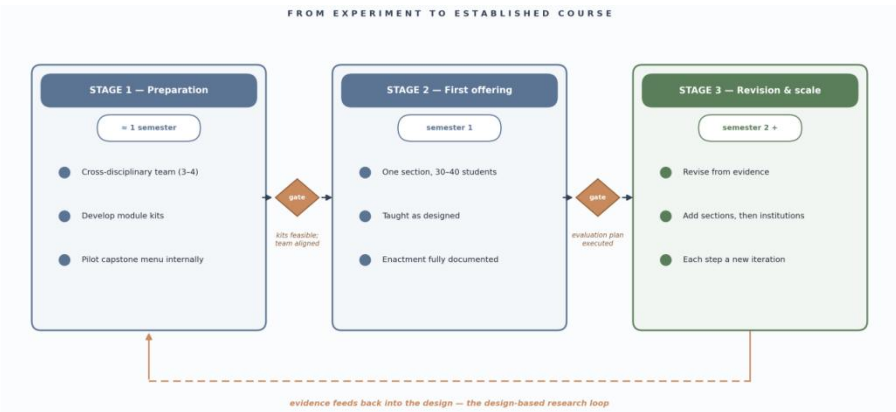

Figure 4 The Three-Stage Implementation Pathway

Note: Preparation, first offering, and revision-and-scale each pass through a gate, and the evidence gathered at each stage feeds back into the design, closing the design-based research loop.

5.2 What can Go Wrong, and the Design's Answers

The literature on interdisciplinary and general education teaching is a catalogue of ways such courses fail. The pathway is built to answer each known risk rather than to hope it away.

The first risk is that interdisciplinary teaching does not travel. Reviews find it different, difficult, and local, resistant to being lifted from one setting into another [45]. The answer is the full publication of the design, its kits, and its reasoning, so that a team elsewhere adapts it knowingly instead of copying it blindly. Deliberate adaptation is the realistic goal, and it requires the design to be transparent, which is part of the purpose of this paper.

The second risk is that team teaching fractures. Sustaining interdisciplinary work in engineering education depends on aligning the team's vision, its teaching practice, and its institutional support [46]. The answer is to budget the co-planning time explicitly in Stage 1, so that shared design happens before the course opens rather than being improvised once it is running.

The third risk is that active methods produce activity without integration. Problem-based and project-based formats do not deliver interdisciplinarity on their own [47]. The answer is designed into the architecture: the guiding questions cannot be answered from one discipline, and the capstone is graded for integration rather than for effort [51]. The interdisciplinary outcome is required by the tasks, not left to chance.

The fourth risk is the loss of disciplinary depth that interdisciplinary breadth can bring [49]. The answer is the course's literacy orientation. Because the goal is judgment rather than coverage, the course does not pretend to teach a materials major's depth, and it is honest that it does not. The fifth risk is specific to the setting: a general education elective may be dismissed as a shuike, a low-effort shuike (watered-down courses) [1]. The answer is visible workload parity with credit-bearing courses and a tangible research product from every student, which is hard to reconcile with the water-course reputation.

5.3 Institutional Conditions

Some conditions lie beyond the teaching team and must be secured at the institutional level. Sustaining a course that crosses departments requires governance that also crosses them: a clear home unit, recognition of team teaching in workload accounting, a modest budget for consumable materials, and access to a room that can host hands-on work [50]. In the Chinese setting, these needs align with the incentives of the Emerging Engineering Education initiative, which rewards exactly this kind of interdisciplinary course reform [3], and with the appetite for general education renewal that reform cases have begun to show [5]. Finally, the course benefits from deliberate quality signaling, the public markers, in its outcomes, workload, and research deliverables, that separate it from the electives students have learned to dismiss [2]. None of these conditions is exotic, but the course will not last without them.

6 EVALUATION PLAN

This section specifies what would be measured once the course runs. It is a plan, and no data exist yet. Stating the evaluation in advance serves two purposes. It makes the design falsifiable, by fixing the evidence that would confirm or challenge it, and it prepares the empirical second cycle of the design-based research program.

6.1 What to Measure

The plan measures three outcome families, each tied to an intended learning outcome from Table 1.

The first is interdisciplinary understanding, the target of ILO1. It would be assessed with a rubric adapted from the targeted assessment of interdisciplinary work [51]. The rubric scores a student product for the quality of its disciplinary grounding, the degree to which insights are genuinely integrated, and the presence of critical awareness about the integration itself. The capstone reports from Module 4 are the natural site for this assessment, since they ask students to bring several lenses to one problem.

The second is scientific literacy in the competent-outsider sense, the target of ILO2. It would be measured with performance tasks that present a public claim about a material and ask students to evaluate it with evidence, following the literacy framings that define the goal [34-35]. Alongside these tasks, low-stakes knowledge-structure probes, such as word association administered before and after the course, would track how students' mental organization of materials concepts changes [41]. The pairing gives both a performance measure and a structural one.

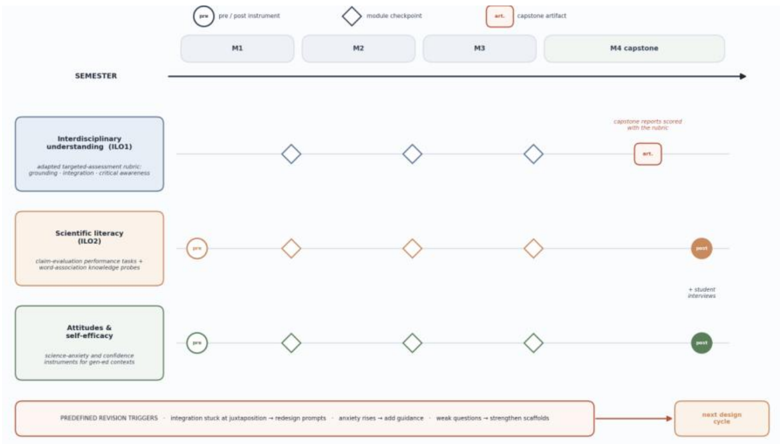

Figure 5 The Evaluation Plan across the Semester

Note: Three outcome families run as parallel lanes, with pre and post instruments, checkpoints after each module's inquiry cycle, and the capstone artifacts as the summative evidence; predefined revision triggers feed the next design cycle.

The third is attitude and self-efficacy, which the non-majors literature marks as decisive for this audience. Because science anxiety is a known barrier and active methods are known to shift confidence, the plan includes established measures of science anxiety and of confidence in the general education context [23,37]. A course that raised competence while leaving students more anxious would have failed at something the design cares about, so the affective measures are not an afterthought. Figure 5 places the three families on the semester timeline.

6.2 How to Interpret the Evidence

The design would be evaluated within a single offering, using a pre and post comparison on the literacy and attitude instruments, module-level checkpoints after each inquiry cycle, and the capstone artifacts as the summative evidence of integration. The quantitative instruments would be triangulated with a sample of student interviews, so that scores are read alongside students' own accounts of what changed. Expectations should be set honestly. Published redesigns of general education science courses report gains in reasoning and attitude [36,39], and models of CURE outcomes describe the kinds of effect authentic research tends to produce [18]. But a first offering of a new design should be judged against those qualitative patterns rather than against a promised effect size. The point of the first empirical cycle is to learn where the design works and where it breaks, not to declare a victory.

6.3 Feeding the Next Cycle

Because this is design-based research, the evaluation is built to inform revision, and the revision triggers are defined in advance rather than chosen after the fact. If integration scores cluster at the level of juxtaposition, with disciplines listed but not joined, the module prompts would be redesigned to force deeper connection. If anxiety measures rise over the semester, the openness of the capstone would be rebalanced toward more guidance, in line with the finding that inquiry needs appropriate support [14]. If the question-asking practice stays weak, the scaffolds around it would be strengthened, addressing the gap the CURE literature has flagged. Setting these triggers before the data arrive guards against reading whatever happens as success. It closes the design-based research loop [11,55] and defines the second design cycle, the enactment and empirical study, as the direct follow-up to this paper.

7 DISCUSSION AND CONCLUSION

The framework is best understood by what it adds to the work closest to it. The nearest precedent delivered materials chemistry to general education students online, with scientific literacy as its aim [10]. That course showed the audience is reachable and the content teachable, but it worked in a research-led mode, conveying findings to students. The present framework moves further along Healey's spectrum, from research-led toward research-based teaching, by giving students structured inquiry cycles, a four-lens interdisciplinary architecture, and a capstone in which they conduct a small investigation of their own [12]. In the other direction, a materials chemistry CURE has shown that authentic course-based research succeeds with chemistry majors [30]. What the framework contributes there is the logic of scaling that research down to non-majors, through calibrated scaffolding, a low affective threshold, and literacy-oriented outcomes rather than disciplinary depth. The design occupies the space between these precedents, which the literature had left open.

The framework speaks to two reform agendas at once. For Chinese general education, it offers a documented course model with the quality signals that the shuike problem demands, a concrete answer to the complaint that general education electives ask too little of students [1-2]. For the Emerging Engineering Education initiative, it supplies a specific interdisciplinary course that the reform can adopt, one built to produce the cross-boundary thinking the initiative seeks [3]. Neither application is parochial. The inputs to the design are general, drawn from an international evidence base, so the framework can be adapted well beyond the setting that motivates it.

The limitations are real and should be stated without hedging. This is a conceptual contribution. The framework has not been enacted, and no claim about its effectiveness can be made until it has. Any judgment about learning gains awaits the next design cycle and the evaluation set out in Section 6. The scope is a single course, and the design leans on a capable, well-supported teaching team, which not every department can field. And as the interdisciplinary literature insists, a design like this does not transfer intact; it must be adapted locally, with the understanding and the institutional support that adaptation requires [45]. These are constraints on the claim, not flaws in it, but they mark the boundary of what a first design cycle can assert.

The work ahead is clear. The immediate next step is to enact the first offering, run the evaluation plan, and report the empirical cycle, converting a designed framework into tested knowledge. Beyond that first study lie natural variants worth exploring: different classes of material as the module anchors, larger sections, and a fully online delivery of the kind the nearest precedent used [10]. Each variant is a further turn of the design-based research cycle.

Materials science, read through the objects students already hold, is a natural place to give every general education student one genuine experience of research. The pieces needed to do this have each been validated on their own: authentic course-based inquiry, guided scaffolding, interdisciplinary integration, and a literacy-first approach to non-majors. What has been missing is a design that puts them together for this audience and this subject. This paper offers that design, and the terms on which it can now be tested.

COMPETING INTERESTS

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REFERENCES

[1] Wang H, Xie D. Twenty Years of General Education in China: Progress, Problems, and Solutions. Chinese Education & Society, 2018, 51(1): 9-20.
[2] Pang H, Cheng M, Yu J, et al. Suzhi Education and General Education in China. ECNU Review of Education, 2020, 3(2): 380-395.
[3] Zhuang T, Xu X. 'New Engineering Education' in Chinese Higher Education: Prospects and challenges. Tuning Journal for Higher Education, 2018, 6(1): 69-109.
[4] Wei S, Ohland M, Zheng L. New Engineering Education initiative of China: A Policy Debrief. 2022 ASEE Annual Conference & Exposition Proceedings, 2022.
[5] Li X, Li Y. Individualized and Innovation-Centered General Education in a Chinese STEM University. Education Sciences, 2023, 13(8): 846.
[6] Khan MS, Wells MA. Integrating interdisciplinary education in materials science and engineering. Nature Reviews Materials, 2023, 8(8): 491-493.
[7] Freeman S, Eddy SL, McDonough M, et al. Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 2014, 111(23): 8410-8415.
[8] Auchincloss LC, Laursen SL, Branchaw JL, et al. Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report. CBE—Life Sciences Education, 2014, 13(1): 29-40.
[9] Bangera G, Brownell SE. Course-Based Undergraduate Research Experiences Can Make Scientific Research More Inclusive. CBE—Life Sciences Education, 2014, 13(4): 602-606.
[10] Ramachandran R, Bernier NA, Mavilian CM, et al. Imparting Scientific Literacy through an Online Materials Chemistry General Education Course. Journal of Chemical Education, 2021, 98(5): 1594-1601.
[11] Design-Based Research Collective. Design-Based Research: An Emerging Paradigm for Educational Inquiry. Educational Researcher, 2003, 32(1): 5-8.
[12] Healey M. Linking Research and Teaching to Benefit Student Learning. Journal of Geography in Higher Education, 2005, 29(2): 183-201.
[13] Prince MJ, Felder RM. Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. Journal of Engineering Education, 2006, 95(2): 123-138.
[14] Lazonder AW, Harmsen R. Meta-Analysis of Inquiry-Based Learning: Effects of Guidance. Review of Educational Research, 2016, 86(3): 681-718.
[15] Kirschner PA, Sweller J, Clark RE. Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. Educational Psychologist, 2006, 41(2): 75-86.
[16] Hmelo-Silver CE, Duncan RG, Chinn CA. Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). Educational Psychologist, 2007, 42(2): 99-107.
[17] Pedaste M, Mäeots M, Siiman LA, et al. Phases of inquiry-based learning: Definitions and the inquiry cycle. Educational Research Review, 2015, 14: 47-61.
[18] Corwin LA, Graham MJ, Dolan EL. Modeling Course-Based Undergraduate Research Experiences: An Agenda for Future Research and Evaluation. CBE—Life Sciences Education, 2015, 14(1): es1.
[19] Linn MC, Palmer E, Baranger A, et al. Undergraduate research experiences: Impacts and opportunities. Science, 2015, 347(6222).
[20] Krim JS, Coté LE, Schwartz ReS, et al. Models and Impacts of Science Research Experiences: A Review of the Literature of CUREs, UREs, and TREs. CBE—Life Sciences Education, 2019, 18(4): ar65.
[21] Buchanan AJ, Fisher GR. Current Status and Implementation of Science Practices in Course-Based Undergraduate Research Experiences (CUREs): A Systematic Literature Review. CBE—Life Sciences Education, 2022, 21(4).
[22] Wessels I, Rueß J, Gess C, et al. Is research-based learning effective? Evidence from a pre–post analysis in the social sciences. Studies in Higher Education, 2020, 46(12): 2595-2609.
[23] Gormally C, Brickman P, Hallar B, et al. Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence. International Journal for the Scholarship of Teaching and Learning, 2009, 3(2).
[24] Brew A. Understanding the scope of undergraduate research: a framework for curricular and pedagogical decision-making. Higher Education, 2013, 66(5): 603-618.
[25] Liou WK, Bhagat KK, Chang CY. Beyond the Flipped Classroom: A Highly Interactive Cloud-Classroom (HIC) Embedded into Basic Materials Science Courses. Journal of Science Education and Technology, 2016, 25(3): 460-473.
[26] Merrett C. Analysis of Flipped Classroom Techniques and Case Study Based Learning in an Introduction to Engineering Materials Course. Advances in Engineering Education, 2023, 11(1).
[27] Müssig J, Clark S, Hoermann K, et al. Imparting Materials Science Knowledge in the Field of the Crystal Structure of Metals in Times of Online Teaching: A Novel Online Laboratory Teaching Concept with an Augmented Reality Application. Journal of Chemical Education, 2020, 97(9): 2643-2650.

[28] Kioupi V, Vakhitova TV, Whalen KA. Active learning as enabler of sustainability learning outcomes: Capturing the perceptions of learners during a materials education workshop. MRS Energy & Sustainability, 2021, 9(1): 64-78.
[29] Marquez R, Barrios N, Vera RE, et al. A perspective on the synergistic potential of artificial intelligence and product-based learning strategies in biobased materials education. Education for Chemical Engineers, 2023, 44: 164-180.
[30] Bell M, Dierlam EK, Smith C, et al. Synthesis and Characterization of Functionalized Silica Particles: A Course-Based Undergraduate Research Experience in Materials Chemistry. ACS Omega, 2025, 10(40): 47095-47102.
[31] Park EJ. Nanotechnology Course Designed for Non-Science Majors To Promote Critical Thinking and Integrative Learning Skills. Journal of Chemical Education, 2019, 96(6): 1278-1282.
[32] Cheng SC, Ziffle VE, King RC. Innovative Food Laboratory for a Chemistry of Food and Cooking Course. Journal of Chemical Education, 2020, 97(3): 659-667.
[33] Armstrong D, Poë JC. The Science of Human Health—A Context-Based Chemistry Course for Non-Science Majors Incorporating Systems Thinking. Journal of Chemical Education, 2020, 97(11): 3957-3965.
[34] Feinstein N. Salvaging science literacy. Science Education, 2010, 95(1): 168-185.
[35] National Academies of Sciences, Engineering, and Medicine. Science Literacy: Concepts, Contexts, and Consequences. National Academies Press, 2016.
[36] Rowe MP, Gillespie BM, Harris KR, et al. Redesigning a General Education Science Course to Promote Critical Thinking. CBE—Life Sciences Education, 2015, 14(3): ar30.
[37] Udo MK, Ramsey GP, Mallow JV. Science Anxiety and Gender in Students Taking General Education Science Courses. Journal of Science Education and Technology, 2004, 13(4): 435-446.
[38] Crossgrove K, Curran KL. Using Clickers in Nonmajors- and Majors-Level Biology Courses: Student Opinion, Learning, and Long-Term Retention of Course Material. CBE—Life Sciences Education, 2008, 7(1): 146-154.
[39] Wilke RR. The Effect of Active Learning on Student Characteristics in a Human Physiology Course for Nonmajors. Advances in Physiology Education, 2003, 27(4): 207-223.
[40] Hosler J, Boomer KB. Are Comic Books an Effective Way to Engage Nonmajors in Learning and Appreciating Science? CBE—Life Sciences Education, 2011, 10(3): 309-317.
[41] Nakiboglu C. Using word associations for assessing non major science students' knowledge structure before and after general chemistry instruction: the case of atomic structure. Chemistry Education Research and Practice, 2008, 9(4): 309-322.
[42] Keller GE. Using Problem-Based and Active Learning in an Interdisciplinary Science Course for Non-Science Majors. The Journal of General Education, 2002, 51(4): 272-281.
[43] Spelt EJH, Biemans HJA, Tobi H, et al. Teaching and Learning in Interdisciplinary Higher Education: A Systematic Review. Educational Psychology Review, 2009, 21(4): 365-378.
[44] Fung D. A Connected Curriculum for Higher Education. UCL Press, 2017.
[45] Lindvig K, Ulriksen L. Different, Difficult, and Local: A Review of Interdisciplinary Teaching Activities. The Review of Higher Education, 2019, 43(2): 697-725.
[46] Van den Beemt A, MacLeod M, Van der Veen J, et al. Interdisciplinary engineering education: A review of vision, teaching, and support. Journal of Engineering Education, 2020, 109(3): 508-555.
[47] Stentoft D. From saying to doing interdisciplinary learning: Is problem-based learning the answer?. Active Learning in Higher Education, 2017, 18(1): 51-61.
[48] Brassler M, Dettmers J. How to Enhance Interdisciplinary Competence—Interdisciplinary Problem-Based Learning versus Interdisciplinary Project-Based Learning. Interdisciplinary Journal of Problem-Based Learning, 2017, 11(2).
[49] Millar V. Interdisciplinary curriculum reform in the changing university. Teaching in Higher Education, 2016, 21(4): 471-483.
[50] Hannon J, Hocking C, Legge K, et al. Sustaining interdisciplinary education: developing boundary crossing governance. Higher Education Research & Development, 2018, 37(7): 1424-1438.
[51] Boix Mansilla V, Duraisingh ED. Targeted Assessment of Students' Interdisciplinary Work: An Empirically Grounded Framework Proposed. The Journal of Higher Education, 2007, 78(2): 215-237.
[52] Barab S, Squire K. Design-Based Research: Putting a Stake in the Ground. Journal of the Learning Sciences, 2004, 13(1): 1-14.
[53] Wang F, Hannafin MJ. Design-based research and technology-enhanced learning environments. Educational Technology Research and Development, 2005, 53(4): 5-23.
[54] Anderson T, Shattuck J. Design-Based Research: A Decade of Progress in Education Research?. Educational Researcher, 2012, 41(1): 16-25.
[55] McKenney S, Reeves TC. Conducting Educational Design Research. Routledge, 2018.
[56] Biggs J. Enhancing teaching through constructive alignment. Higher Education, 1996, 32(3): 347-364.
[57] Loughlin C, Lygo-Baker S, Lindberg-Sand Å. Reclaiming constructive alignment. European Journal of Higher Education, 2020, 11(2): 119-136.