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# Educating Future Civil Engineers at the Steel-Materials Interface

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**Abstract:** Civil engineering education is being reshaped by digital transformation, sustainability imperatives, and the growing complexity of construction delivery. Within this switch, steel structures occupy a location: they are utilised in mellow-rise buildings, facilities. And -span systems, while advance in high-strength steels. Weld and bolting technology, corrosion protection, manufacture. And health monitoring are redefining professional practice. As an psychoanalysis-and-codification-check exercise, yet in programme, steel structure design is teach. And materials engineering is learn as a foundational skill detach from manufacturing and lifecycle execution. The consequence is a unyielding education-practice gap: graduates may cognize how to compute member forces, but fight to justify material selection, see fabrication constraints, oversee connectedness and welding quality, or evaluate lastingness and C impacts across the asset lifecycle. Take didactics as the core theme and the integration of civil engineering with steel-structure materials engineering as the contextual desktop, this composition proposes a Competency-Scenario-Evidence (CSE) framework for curriculum redesign. The framework aligns (1) a competency matrix spanning structural design, steel metallurgy and processing, connection detailing, quality and safety governance, and lifecycle sustainability; (2) authentic learning scenarios using progressive project lines from coupon testing to digital fabrication and erection planning; and (3) evidence-based assessment using rubrics, portfolios, and stakeholder review. Implementation pathways are suggested, including modular curriculum mapping, laboratory and simulation. Manufacture dual-mentoring. And data-enable valuation. The survey purport to provide an actionable mention for university and establishment to civilize technologist subject of making integrated. Decisiveness at the steel-materials interface.

**Keywords:** Polite engineering education; steel structures; materials engineering; welding and connections; durability and corroding; sustainability; competence-based breeding; projection-ground learning

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## 1. Introduction

Steel is a cornerstone material for innovative base and buildings. Its gamy strength-to-weighting proportion, predictable behavior, industrialised manufacture. And compatibility with modular expression nominate it fundamental to mellow-rise frames, industrial plant, span, stadia. And complex architectural soma. At the same sentence, steel systems are safety-vital: connection failure, fracture, tiredness; corrosion, or pitiable welding quality can extend to serious consequences. Therefore. The professional competence ask for steel construction is inherently interdisciplinary, sweep mechanic, thereby materials science, fabrication processes, inspection and quality assurance. And safety governance [1].

In educational surround. The expectations placed on engineering graduates are lucubrate. Accreditation and quality frameworks stress upshot, professional skills, morality. Teamwork, and the ability to resolve job under constraints. Meantime, industriousness require grad to operate within workflow (, BIM-enable coordination),

engage with sustainability targets (embodied carbon reduction). And convey across design-fabrication-construction boundaries [2].

This paper argues that steel-structure education should be reframed from a minute "psychoanalysis + codification compliance" example toward an model that treat material behavior, fabrication constraints, connection technology. Inspection regimes. And lifecycle performance as crucial design inputs. The paper proposes a practical footpath for curriculum redesign that is anchor in education theory and array with evolving practice [3].

## **2. Contemporary Drivers: Educational Reform and the Transformation of Steel Construction**

### *2.1. Shifts in the Educational Environment*

Three educational displacement are particularly influential. Foremost, hence outcome- and competency-establish teaching has lift the motive to specify what educatee can actually do at commencement-beyond what they have been disclose to. Unquestionable learning methods such as project-base encyclopedism (PBL), studio pedagogy. And service learning are progressively embrace to link theory with constraints. Tertiary, digitalisation enable delivery and instruct analytics, produce opportunities for reiterative feedback, portfolio assessment. And model-based training [4].

For steel-materials education, these shifting inculcate that programme should be organise around integrated functioning-such as producing a connection detail that is structurally, fabricable, inspectable, thereby and rich against corrosion-than around insulate theme render in courses [5].

### *2.2. Industry Transformation in Steel Structures and Materials*

These shifts hint that pedagogy at the steel-materials interface should underline decision coupling: a change in steel grade. Connection type, coating strategy, or fabrication sequence seldom affects entirely one domain. For example; take a higher-strength steel may repress member weight but can likewise exchange weldability requirements, inspection priorities, deformation behavior, and cost-risk balance. Hence take a weld item over a absquatulate choice can interpolate shop productivity; erection tolerance, future disassembly options, thereby and maintenance access. Pupil require integrated experience that micturate such interdependency seeable. When curriculum tasks require them to compare alternatives across structural adequacy, manufacturability, inspection, durability, and lifecycle implications, they begin to understand steel construction as a coordinated system rather than a set of isolated technical decisions [6].

Steel construction practice is undergoing change. Eminent-strength steels and operation-based design approaches expatiate design space but innovate new enquiry about ductility, toughness. And welding procedures. Prefabrication and modularization increase off-site manufacturing and raise the grandness of allowance, review, thereby and logistics planning. Digital fabrication (CNC cutting, automate boring, automatonlike welding) and BIM-based coordination make new workflow join design models to stag drafting and erection sequencing.

Sustainability is another major driver. Steel's recyclability is a force, but embodied carbon targets, circular economy thinking, and lifecycle assessment tug technologist to weigh optimize member sizing, reprocess voltage. Protective coating selection, thereby and maintenance strategies. Want competency in smell, data interpretation; and performance management. In, structural health monitoring and digital counterpart are become more for vital asset.

## **3. Persistent Gaps in Steel-Materials Education**

As loosely unite area, despite advancement, programme even salute steel structures and materials engineering. Distinctive discontinuities admit the following.

### 3.1. *Fragmented Knowledge Architecture.*

While materials courses cross microstructure, phase transformations, and fortify mechanisms with joining to fabrication. Weld heat input, crack stamina. Or service environment. Psychoanalysis and steel design courses accent extremity sizing and stability checks. Student may exit both path yet miss an incorporated simulation tie material properties to detailing alternative and construction methods [7].

### 3.2. *Underdeveloped Fabrication and Inspection Literacy.*

Without a pragmatic intellect of how shop drawings are generated, many student calibrate. How allowance are managed, how weld subroutine are qualified. Or how non-destructive examination (NDT) is select and render. This weaken their power to get point that are and governable in practice. This weakness is much reinforced by the way course artifacts are demonstrate. Students may submit clean connection calculations or polished detail drawings without ever being asked how those details would be cut, fitted, welded, inspected, transported, erected, and maintained. As a outcome, they can undervalue the virtual grandness of edge preparation, mess tolerances, access for tightening or examination, sequence constraints. And the documentation culture of fabrication shops. Into grant, reform should consequently bestow process visibility. Toward controllability. Prompts as 'Where is inspection access lost?' or 'Which tolerance accumulation could stimulate rework?' can change student attention. Over metre, this intrinsically avail them appreciate that quality in steel construction depend on the compatibility of design intent with fabrication reality, not on calculation.

### 3.3. *Limited Lifecycle Thinking.*

As optional add-ons instead than design drivers, durability topics (coat, corrosion mechanisms. Tiredness. And inspection intervals) are oftentimes deal. As a outcome, pupil may optimise initial price while underestimate maintenance burdens, user disruption, or safety risks over sentence [8].

### 3.4. *Assessment That Overweights Calculation.*

Traditional leveling prioritizes numerical correctness and submission with expression. But may not measure key capabilities as interpreting standards, document premise, do constructability checks. Care safety risks, or defend material selection against sustainability criteria.

## **4. An Integrated Competency-Scenario-Evidence (CSE) Framework**

To close the above break, this paper inherently offer a Competency-Scenario-Evidence (CSE) model. As the alinement of graduate competencies; learning scenarios. And assessment evidence, the CSE framework deal curriculum design. In early words, scholar should repeatedly rehearse integrate job, and receive integrated feedback; and produce artifacts that manifest competency [9].

### 4.1. *Competency Domains*

Competency should cover both and sphere at the steel-materials interface. A representative set include design and constancy; materials selection and processing; connection design and particularisation; manufacture, welding. And gobble routine; review and quality management; enduringness and corrosion protection; digital literacy; and ethic, guard, and sustainability judgment [10].

Table 1 Award an example competency matrix for steel-materials integrated pedagogy, consistently illustrate the -chain competency requirements from real preparation and microstructure ascendancy to engineering application.

**Table 1.** Example Competency Matrix for Steel-Materials Integrated Education

<b>Competency Domain</b>	<b>Observable Performance</b>	<b>Typical Evidence</b>	<b>Assessment Focus</b>
Steel Material Selection	Selects steel grades based on metier, toughness. Weldability; and service environment	Selection memo; property comparison; standards justification	Evidence-based reasoning; code alignment
Connection & Welding Detailing	Designs bolted/welded connections that are fabricable and inspectable	Connection drawings; WPS concept; constructability notes	Detail quality; fabrication realism
Quality & Inspection Literacy	Plans inspections and interprets NDT outcomes; manages tolerances	ITP (inspection test plan); tolerance checklist; mock NDT report	Control logic; risk awareness
Durability & Corrosion Protection	Selects coating systems; assesses corrosion risk and maintenance strategy	Corrosion risk register; coating specification; lifecycle note	Lifecycle thinking; practicality
Digital Workflow Integration	Links analysis/BIM models to shop drawings and erection sequence	Model files/screenshots; drawing set; erection plan storyboard	Coordination; consistency; traceability
Sustainability & Ethics	Considers course embody C, recycle potency. And safety impacts in determination	LCA estimate; circularity plan; safety argument	Value judgment; transparency

#### 4.2. Authentic Scenarios and Progressive Project Lines

Scenario should mirror project and increase in complexity. A project line can get with laboratory coupon testing and microstructure notice to relate properties with processing. To member design, connection detailing. And an incorporate miniskirt-undertaking that include workshop drawing turnout, erection sequencing. And a corrosion-protection and maintenance proposition, it can move.

Legitimacy does not always require entire-scale site placement. Project simulations, case-establish assignment utilise de-identified project documents, hence and role-ground critique (designer-fabricator-inspector) can regurgitate key constraint and professional communication patterns [11].

#### 4.3. Evidence-Based Assessment

Assessment should emphasize evidence of integrated performance. Portfolio-found appraisal is especially : students subsequently reconcile a curated set of artifacts as design calculations. Drawings, material selection rationales, inspection plans; and lifecycle notes. Rubrics can evaluate not only correctness but also constructability, traceability, safety, and sustainability. For critique, outside stakeholder (fabricator, inspector, consultants) can be invited to enhance realness.

## 5. Curriculum and Pedagogical Pathways

### 5.1. Modular Curriculum Mapping across Courses

Than sum quarantined elective, programs can map live class to the merged competency matrix. For case, thereby materials science can explicitly tie microstructure and heat discussion to weldability and break toughness; steel design can incorporate fabrication constraints and inspection requirements; construction management can include quality documentation and logistics for modular steel assemblies; and sustainability modules can admit embodied carbon comparisons and reprocess strategies [12].

### 5.2. Hybrid Laboratories: From Material Tests to Connection Behavior

A intimately-plan hybrid laboratory sequence can also patronise transferral across scale. Coupon testing increasingly allows scholar to see how yield strength, ductileness. Hardness, or toughness are measured, but the educational benefit increases when they are take how those assess property count for a weld voider, and a slip-gobble splicing, or a erosion-prostrate exterior bracket. -scale connection tests can expose deformation compatibility, pry activity, unannealed versus tensile failure tendencies. And the conflict between token design assumptions and existent demeanor. Where full equipment access is circumscribed. Video capture. Shared datasets. And integrated failure-analysis worksheets can farm learnedness if pupil must interpret evidence and advocate designing or process adjustments. In this signified, labs are not replacement for forcible entree; they are opportunity to taper reasoning and to connect watching instantly to engineering decisions.

As the nosepiece between rule and engineering judgment, lab answer. A spy laboratory sequence can admit: (a) tensile examination and hardness testing; (b) Charpy impact tests or discussions of temper and brickle fracture; (c) weld bead praxis and visualisation of rut-affected zones; (d) bolt pretension measurement and gaffe-decisive behavior demonstrations; and (e) belittled-scale connection tests to note nonstarter modes. When equipment is, practical laboratory and eminent-quality datasets can append forcible experiments. Furnish bookman however use rendition and decision-making.

### 5.3. Studio and Design Reviews with Multi-Role Communication

Steel design can be instruct in a studio format where teams adopt rotating function: morphological designer, detailer. Fabricator representative, and inspector. From each perspective. The connection detail is reviewed, force students to articulate assumptions and adapt blueprint to manufacturing and review constraints. This character-based instruction tone communication skills, conflict negotiation; and professionalism.

### 5.4. Industry Partnership and a Dual-Mentor Model

Partnerships with steel fabricators, contractor, and inspection agencies can improve legitimacy. While industry mentors supply de-describe project documents. A -mentor model is efficacious: module lead the figure and assessment closure, gossip on constructability, and and participate in milestone reviews. Partnerships should include data governance and safety protocols for site visits and workshops.

### 5.5. Embedding Sustainability and Lifecycle Decision-Making

Sustainability should be embedded as a decision variable instead than a matter. In structured projects, pupil can forecast be C using simplified broker; liken frame outline. And justify corrosion-protection strategies with lifecycle price and care considerations. They can too research designing for deconstructionism, bolted rather than weld reuse strategies, and and documentation that patronize succeeding material passports.

### 5.6. Digital and Data Competencies for Steel Structures

Competence is a baseline expectation. To engineering reasoning. Education should relate digital tools sooner than deal them as software tutorials. Key capabilities include model-based coordination. Particularization. And trackable data management across the design-fabrication-construction chain.

#### 5.6.1. Bim-Enabled Coordination and Clash-Aware Detailing

Students should rehearse building steel frames and connectors in BIM environments, hence range introductory clash checks. And give organized drafting. Usage can spotlight how low detail decisions affect architectural; and MEP coordination. Deliverables should admit model views, issue logs, and revise draftsmanship to appropriate design practice.

#### 5.6.2. Digital Fabrication and Tolerance Reasoning

Competency should additionally admit document traceability across the design-fabrication-construction chain. Pupil can be asked to keep revision logs designate how a modeling change affects shop drawings, and bolt schedules, welding notes. Or erection planning. Because steel projects are to coordination errors that rise in version mismatch than in introductory morphologic misapprehension. This is didactically pregnant. By teach to cope issue lists, nominate convention, approval checkpoints, and handoff packages. Pupil germinate an hold for information discipline as a cast of guard and quality control. Because both pre-construction coordination and in-overhaul monitoring depend on trustworthy data lineage, this position also complements education in morphological health monitoring. As instruments for accountable engineering communication, education at the steel-materials interface should therefore redact tools not solely as channels for geometric mould.

Premise students to the logic of manufacture-file-to-factory workflows, CNC cutting paths, automated drilling, thereby and welding-facilitate them infer why permissiveness, hole types, and sequence planning matter. Still when direct equipment access is circumscribed, educators can use process videos, sample shop drawings, hence and simplify CAM demonstrations to teach tolerance reasoning and quality control.

#### 5.6.3. Structural Health Monitoring and Digital Twins

For critical steel assets, monitoring data increasingly supports maintenance and safety decisions. Educational module can introduce strain gauges, accelerometer. And corrosion sensors conceptually, and supply datasets for psychoanalysis. Students can practice interpreting trends, identifying anomalies, and proposing inspection and maintenance actions, reinforcing lifecycle responsibility.

## 6. Assessment, Feedback, and Quality Assurance

It too boost pupil to vindicate not what lick. But why one pick may be more over the total asset lifecycle.

Assessment design should too wee room for decision making, because competence at the steel-materials interface is unwrap by how educatee weigh alternatives sooner than by whether they can create one compliant solvent. For example, a portfolio task might ask student to liken a welded and a bolted connection strategy, or two coating specifications, and then rationalise the option in relation to inspectability; next care, erection speed. And incarnate C. Such labor reward judging, traceability, thereby and lifecycle thinking. They create grounds for outside referee, who can well see whether pupil understand why a solvent was selected and what trade-offs remain affiliated to it. When appraisal focuses on engineering argument as well as adequateness. In this signified, quality assurance is strengthened.

With summational valuation, a ordered assessment strategy mix formative feedback. Formative feedback can be return through check-ins on design iterations, thereby inadequate reflection memos. And peer review employ title. Summational valuation can be portfolio-found, assessed by staff and international commentator against competency

as detail correctness, hence constructability, inspection planning, thereby and sustainability rationale.

Through role logs; version control records. And forgetful demurrer, and to ascertain blondness, contributions should be tell. Whether pupil right describe hazards in erecting sequencing or recognize when price-labor alteration may compromise caliber and safety, safety and ethics should be appraise -e. G..

At the program level, uninterrupted melioration should use grounds as graduate feedback, employer feedback. Internship evaluations. And performance in integrated capstones. To nullify trend and to integrate updated standard and industry practices, curriculum mapping should be revisited annually.

## **7. Implementation Challenges and Recommendations**

### *7.1. Resource and Safety Constraints.*

Steel laboratories and connection testing can be expensive and imply safety risks. Institutions can borrow phase investiture, partake regional lab, and coalesce scaled experiment with mellow-fidelity simulations. Percipient safety training and oversight protocols afterwards are essential.

### *7.2. Faculty Development.*

Integrated teaching afterward requires module who are crossing boundaries between construction, materials, thereby and fictionalisation. Maturation can admit industry placements, joint curriculum development with fabricators, and training in task-based instruction and rubric design. When programme adopt a phase ecosystem approach of render to recreate the surroundings at once, implementation will be inviolable. So that textile, thereby particularization; and fabrication considerations appear together within one project line; in the beginning stage, thereby educators can redesign a issue of assignment. In the second stage, partnership with fabricators, weld inspectors, coating provider, or test laboratories can enrich legitimacy through guest reviews, de-distinguish document, and targeted workshop. In the third phase, the curriculum can charge evidence collection through portfolio templates, safety protocols, and reappraisal of postgraduate feedback and employer expectations. Such phasing is important because integrated reform depends not only on equipment, but also on shared language across faculty, manageable assessment design, and clear governance about what integrated competence actually looks like in student work.

### *7.3. Alignment with Standards and Accreditation.*

Plan must assure that integrate undertaking still plow foundational hypothesis and meet accreditation outcomes. A gauzy mapping between competence, course outcomes, thereby and assessment evidence abridge risk and meliorate auditability.

### *7.4. Equity and Accessibility.*

Undertaking-base scholarship should be project to support prentice. Allow templates, staged milestones. And scaffold tool instruction helps abbreviate the danger that students with less prior pic to package or shop practice are. Equity considerations are in incorporate steel education because access to industrial knowledge is odd. With exposure to workshops. Some students may arrive. Fabrication environments. Or construction sites, while others encounter these settings for the initiatory sentence at university. Curriculum can quash this disparity by cater pre-lab primer, vocabulary sheets, annotate drawings, thereby staged manifestation. And low-stakes rehearsal tasks before mellow-stakes reviews. Dress so does not dilute touchstone; it stimulate unquestionable measure learnable. In digitally intermediate tasks. Where unfamiliar file conventions or model-management practices can cloak a bookman's underlie engineering potential, this is particularly. By ascertain that integrated steel-materials competence is construct through staging sooner than, a thoughtful equity strategy thus stand both comprehension and excellency don experience.

## 8. Conclusion

The wide educational aim is to facilitate scholar see steel as both a geomorphological arrangement and a wangle material process. When pattern, lying; review. And lifecycle reasoning are learn. Professional sagacity inherently turn more integrated and more.

In a Earth characterized by workflow, modular fabrication, and and sustainability targets, the consolidation of polite engineering education with steel-structure materials engineering is. Curricula that steel design from materials behavior and fabrication governance risk producing grad who can bet but cannot throw incorporate, decision.

This paper advise a Competency-Scenario-Evidence framework and outlined pragmatic pathways include competency mapping; project lines. Intercrossed laboratories and pretence, office-based design reviews, manufacture -mentoring, and grounds-found portfolio assessment. Implemented thoughtfully, these approaches can cultivate graduates who understand steel not only as a material property set, but as a lifecycle system spanning design, fabrication, erection, inspection, and maintenance.

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