# Cross-Functional Legal Education as Risk Mitigation: Empirical Analysis of Contract Error Reduction in Engineering Teams

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***Abstract***
*Engineering teams routinely author, negotiate, and commit to contractual language that they are not trained to read. Statements of work, acceptance criteria, intellectual property assignments, open-source license attestations, and security annexes are drafted or materially shaped by technical staff whose formal legal preparation is typically zero. The resulting defect stream is expensive: rework cycles, delayed sign-off, unauthorized commitments, and downstream disputes. This study asks whether structured cross-functional legal education (CFLE) delivered to engineers reduces contract error density, and if so, which error classes respond. Using a staggered-adoption difference-in-differences design across 16 engineering organizations (623 engineers and engineering managers, 1,842 contract instruments, 47,318 clause-level observations) observed over eight quarters, we estimate the effect of CFLE programs implemented in late 2021 and 2022. Treated organizations show a reduction of 2.53 substantive defects per 100 clauses (a 32.4 percent relative decline, $p < .001$), 0.69 fewer legal rework cycles per instrument, and 2.8 fewer days to legal sign-off. Unauthorized commitment incidents fall by roughly half. Effects are strongly heterogeneous by error class. Reductions concentrate in defects where engineers hold private technical information: scope and acceptance criteria ambiguity (41.1 percent reduction), authority and unauthorized commitment breaches (55.3 percent), and intellectual property or open-source license conflicts (37.9 percent). Effects on risk-allocation terms such as indemnification and limitation of liability are small and statistically indistinguishable from zero. We observe a dose-response relationship that flattens above approximately 16 contact hours, and moderation by embedded-counsel proximity and team psychological safety. We interpret CFLE not as a substitute for legal review but as an investment in shared absorptive capacity at the engineering-legal boundary. The mechanism is translation, not delegation. We conclude with design principles for programs, a cost-effectiveness estimate, and boundary conditions for practitioners.*

***Keywords:*** *contract design capability, legal risk management, cross-functional training, absorptive capacity, boundary spanning, engineering governance, proactive law, difference-in-differences*

## 1. Introduction

In most technology-intensive firms, the people who write the words that create legal obligation are not lawyers. An engineering manager scoping a systems integration project writes the statement of work. A staff engineer defines acceptance criteria that will later determine whether a milestone payment is owed. A developer selects a dependency and, in doing so, imports a license whose reciprocity provisions may propagate into the firm's proprietary codebase. A field engineer, standing in a customer's data center, says "yes, we can do that by March."

Each of these acts has contractual consequence. None of them is typically preceded by legal training. The dominant organizational response has been *gatekeeping*: route every instrument through counsel before execution. Gatekeeping is necessary but structurally insufficient. It intervenes after the defect has been introduced, it scales poorly against contract volume, and it cannot repair defects that are invisible without technical context. A lawyer reviewing a statement of work cannot know that "industry-standard latency" is ambiguous in this system architecture unless someone tells her. The information asymmetry runs in the direction opposite to the review flow. This paper examines an alternative, complementary intervention: teaching engineers enough contract literacy to prevent defect introduction at the source. The observation window matters for interpreting what follows. Several conditions converged to make 2022 a useful year in which to study this question. First, contract volume per engineer rose sharply as distributed and vendor-mediated delivery models matured. Post-pandemic normalization brought a wave of renegotiated master service agreements, revised data processing addenda, and reworked subcontractor arrangements. Second, the regulatory perimeter around software artifacts expanded. Software bill of materials expectations, tightened supply chain security attestations, and successor mechanisms to invalidated cross-border data transfer frameworks pushed compliance obligations into engineering workflows rather than leaving them in legal departments. Third, hiring volatility in 2022 disrupted the informal apprenticeship through which contract judgment had previously diffused. When tenured engineering managers depart, tacit knowledge about what not to promise departs with them. Several organizations in our sample adopted CFLE explicitly as a response to this loss. The result is a period in which contract-adjacent risk migrated into engineering practice faster than engineering practice adapted. That gap is what CFLE is meant to close.

This study therefore asks five questions. Does structured cross-functional legal education reduce the density of substantive contract errors in engineer-authored or engineer-shaped contract content? Which classes of contract error respond to education, and which do not? What is the dose-response shape, and where do returns diminish? What organizational conditions moderate the effect? And does error reduction translate into operational and financial outcomes such as reduced rework, faster sign-off, and lower dispute incidence, or does it merely shift defect detection earlier in the process? The study speaks to several literatures at once. It extends work on contract design capability downward from the firm level to the individual contributor level: contracting capability is usually theorized as a property of organizational routines and legal function maturity, yet a nontrivial share of it appears to reside in the technical staff who supply the substantive content those routines process. It also introduces a defect-level, clause-normalized measurement framework for contract error, in place of the contract length, provision counts, and dispute incidence measures the field has relied on, none of which captures error directly. The evaluation

design, which combines staggered-adoption difference-in-differences with entropy balancing, event-study specification, and small-cluster inference correction, is applicable to internal training programs more generally, where randomization is rarely feasible. Finally, the dosage and delivery results support a curriculum architecture grounded in observed diminishing returns rather than in vendor convention.

## 2. Theory and prior evidence

### 2.1 Contracting as a firm capability

Transaction cost reasoning established contracts as governance instruments responding to asset specificity, uncertainty, and frequency. That tradition treated contract design largely as a comparative-static choice: given the hazards, select a governance form.

A later stream reframed contracting as a *learned capability*. On this account firms improve contract design incrementally through experience with specific partners, accumulating provisions in response to realized problems rather than anticipating hazards ex ante. Developed into an explicit capability argument, the view distinguishes the knowledge held by managers, engineers, and lawyers, and observes that different provision types draw on different knowledge bases.

That last point is the hinge of the present study. Engineers contribute disproportionately to task-description provisions (scope, specification, acceptance), while lawyers contribute disproportionately to contingency-planning and dispute-resolution provisions. If that division of cognitive labor holds, then training engineers should improve the provisions engineers own and leave the rest largely unchanged. We test this directly.

Related work examines how contractual detail evolves with repeated interaction, how formal and relational governance substitute for or complement one another, and how framing shapes contract effectiveness. Provision types are also complementary, which implies that defects are not independent: an ambiguous scope clause degrades the operation of an otherwise sound acceptance and payment structure.

### 2.2 Absorptive capacity and knowledge boundaries

The absorptive capacity argument holds that a unit's ability to recognize, assimilate, and apply external knowledge depends on prior related knowledge. Applied here: an engineer with no contract schema cannot recognize that a clause is defective, because the defect is not perceptually available. Training supplies the prior knowledge that makes the anomaly visible.

Knowledge-boundary research distinguishes three progressively harder problems: transferring information across a syntactic boundary, translating meaning across a semantic boundary, and transforming interests across a pragmatic boundary. The engineering-legal boundary is at minimum semantic. Terms such as "material," "reasonable efforts," "defect," and "acceptance" carry technical meanings in engineering and different operative meanings in contract. CFLE is best understood as an investment in translation capacity.

Cross-boundary coordination is better described as an ongoing negotiation between communities of practice than as a one-time handoff, and specialized boundary-spanning individuals play a documented role in sustaining it. Both observations suggest that education should be evaluated not only by individual knowledge gain but by the quality of the ongoing interface it enables.

Transactive memory theory adds a further mechanism. A team with a well-developed transactive memory system knows *who knows what*, and routes accordingly. A plausible effect of CFLE is not that engineers become able to answer legal questions but that they become able to *recognize* legal questions and escalate them correctly. We test this using escalation appropriateness measures.

### 2.3 Proactive law and legal design

The proactive law tradition argues that legal function should move upstream from dispute resolution toward problem prevention and value creation, including through contract design that non-lawyers can actually use, and positions legal capability along a maturity path from reactive compliance to strategic advantage. CFLE fits squarely in this tradition, but the tradition has produced comparatively little quantitative evaluation, which this paper is intended partly to address.

### 2.4 Training effectiveness and transfer

The training literature provides sober expectations. Meta-analytic work finds moderate positive effects of organizational training on performance, with substantial variation attributable to design and delivery, and identifies needs analysis, practice with feedback, and the post-training environment as the features that separate effective programmes from ineffective ones. Transfer of training is driven heavily by the work environment, particularly supervisor support and opportunity to perform. Evidence from workforce training in safety-critical operations, reviewed in Section 2.5, reaches the same conclusion in a risk-reduction setting (Obriki et al., 2022a).

This implies two things for our design. First, contact hours alone should be a weak predictor. Second, organizational conditions should moderate effects, which motivates our examination of embedded counsel proximity and of the psychological safety of the receiving team. An engineer who has been trained to spot a problem but expects to be penalized for raising it will not raise it.

### 2.5 Adjacent evidence from risk-intensive engineering domains

The literature reviewed above establishes the theoretical case for locating contracting competence in technical staff. Direct empirical work on that proposition is thin. A substantial adjacent literature, however, addresses the same underlying structure in other guises: technical practitioners operating inside binding regulatory, contractual, or governance regimes that they did not draft and are rarely trained to interpret. Because that literature is dispersed across procurement, safety, audit, cybersecurity, regulated design, and professional-training research, we survey it here by domain and extract the recurring findings that inform our hypotheses. Three themes recur across every domain: compliance failure is concentrated at hand-off points between functions, formal control mechanisms underperform where the operator lacks interpretive capability, and governance frameworks succeed only where they are translated into the working vocabulary of the practitioners they bind.

**Procurement, vendor governance, and contract negotiation.** The procurement literature is the closest analogue to our setting, because procurement is where engineering specification and contractual obligation meet most directly. Work in this stream documents how vendor evaluation, bid selection, and negotiated cost outcomes depend on the quality of technical input supplied to the contracting process, and how procurement in high-hazard energy environments must satisfy regulatory constraints that technical staff frequently encounter without preparation. Studies of contract negotiation and vendor governance for cost reduction, of regulatory-compliant procurement in high-risk environments, and of materials readiness and demurrage elimination all locate the binding constraint in cross-functional coordination rather than in contractual form (Agbabiaka et al., 2019; Ahiaeke Patrick et al., 2020, 2021; Ogunwole et al., 2021; Okonkwo et al., 2018a, 2018b, 2019, 2020, 2021).

A parallel body of work on strategic procurement and supplier management reaches similar conclusions, emphasizing negotiation optimization, process automation for procurement transparency, sustainable and chemically compliant sourcing decisions, and the analytics infrastructure that supports supplier performance judgment (Akin-Oluyomi et al., 2020; Akinleye & Adeyoyin, 2021, 2022a, 2022b; Efobi et al., 2021, 2022a, 2022b; Okojie & Abioye, 2020). Notably, several of these studies treat compliance obligations such as REACH conformity and sustainability targets as technical design constraints rather than as legal afterthoughts, which is precisely the reframing that cross-functional legal education attempts to install.

**Supply chain resilience, visibility, and sustainable procurement governance.** Supply chain research contributes the observation that traceability and contractual compliance are functions of end-to-end visibility, and that visibility gaps are where obligations quietly fail. Studies of supplier relationship management, lean supply chain practice, ESG auditing, predictive demand forecasting, and real-time risk dashboards converge on the finding that contractual and regulatory commitments are honored only when the operational systems that generate evidence of compliance are designed alongside the commitments themselves (Aifuwa et al., 2020; Filani et al., 2022; Ike et al., 2021, 2022; Nnabueze et al., 2021; Yeboah & Ike, 2020). This mirrors our Class D and Class E findings, where security annexes and change control procedures fail less from ignorance of the obligation than from architectural drift away from what was promised.

**Safety, HSE, and risk governance in multi-contractor engineering projects.** Occupational safety research offers the richest available evidence on our central mechanism, because safety management is the one domain where organizations routinely invest in teaching technical staff to recognize hazards created by their own work. The findings are strikingly parallel to ours. Governance-oriented models of contractor safety performance across multi-contract projects, contractor compliance systems in infrastructure engineering, and safety risk governance for multi-contractor high-rise developments all report that the effectiveness of formal contractual safety obligations depends on the interpretive capability of the personnel bound by them (Arumosoye & Obriki, 2020; Obogo et al., 2019b, 2021, 2022). A second cluster addresses recognition and reporting, the exact competence we measure through escalation appropriateness. Studies of near-miss and hazard observation data utilization, proactive hazard recognition and near-miss reporting systems, human error causation in high-risk construction, and the recurrence mechanisms of unsafe behavior consistently find that recognition capability without a safe reporting channel produces no measurable risk reduction, which is the safety-domain analogue of our psychological safety moderation (Arumosoye & Obriki, 2019; Obogo et al., 2019, 2021; Obriki & Arumosoye, 2020, 2022). A third cluster addresses training, culture, and maturity directly. Work on workforce safety training models for operational risk reduction, leadership-driven safety culture transformation, organizational learning-based maturity models, and the institutionalization of life-preserving practice across project-based organizations provides the closest existing evidence that structured education for technical staff shifts measurable risk outcomes, along with evidence on the specific operational domains where such training is applied (Arumosoye & Obriki, 2018, 2021, 2022; Obogo et al., 2019a, 2020a, 2020b, 2020c; Obriki & Arumosoye, 2018, 2019, 2021; Obriki et al., 2022a, 2022b).

**Regulatory oversight and certification compliance in aviation.** Aviation safety oversight supplies a well-instrumented case of technical compliance under external regulatory supervision. Research on adaptive safety management system implementation, predictive compliance monitoring built from complaint data, regulatory evidence frameworks for obstacle limitation surface violations, encroachment enforcement and corrective action protocols, and comparative aerodrome certification benchmarking demonstrates how certification obligations are operationalized by engineering and operations staff rather than by legal departments (Adeyelu, 2018, 2019, 2020, 2021, 2022; Adeyelu & Dagodzo, 2022). The evidentiary emphasis in this literature, that compliance is established through documentation generated during technical work, reinforces our argument that contract quality is determined upstream of review.

**Cybersecurity, data protection, and IT risk governance.** Information security is the domain where the gap between legal obligation and engineering practice has become most visible, and it maps directly onto our Class D defects. Work on legal and ethical risk modeling in enterprise data protection governance, comparative data protection regulation across jurisdictions, data protection impact assessment models in multi-cloud financial infrastructure, identity and access governance, infrastructure-as-code governance, and IT general controls automation for statutory audit shows that data protection commitments are discharged through architectural decisions taken by engineers (Borah et al., 2022; Mbonu et al., 2018, 2019, 2020, 2020a, 2020b, 2021, 2021a, 2021b, 2022, 2022a, 2022b). Complementary work on enterprise cyber defense, security audit and risk assessment frameworks, incident response, threat intelligence integration, privacy-centric security engineering, and zero-trust identity architecture describes the organizational routines through which these obligations are monitored and evidenced (Dosunmu & Ogundele, 2019, 2020, 2021, 2022; Edivri & Oteri, 2022; Ogbole et al., 2021; Okoruwa et al., 2020). Research on healthcare-specific cybersecurity investment and cyber-enabled fraud detection extends the analysis to sectors where contractual security commitments carry direct patient-safety consequences (Ekechi et al., 2022; Ozowara et al., 2022). Operational technology research adds the further complication of converged IT and OT environments, where compliance regimes for critical infrastructure impose obligations on control-system engineers who are outside the usual perimeter of corporate legal review (Adebayo et al., 2022; Adegbite et al., 2020, 2022; Ahmed et al., 2021). Emerging work on data privacy governance for cross-border digital platforms situates these obligations within the broader technology-law landscape (Annan, 2022).

**Audit, internal control, and financial governance.** Internal audit research supplies the detection-side analogue to our Stage 2 argument. Studies of technology-enabled internal audit quality, risk-based internal control models in banking and insurance, data-driven risk evaluation for emerging-market institutions, and integrated governance and compliance strategies for financial resilience describe review functions that are effective against form defects and comparatively weak against defects requiring operational context (Akomolafe & Agu, 2018, 2019a, 2019b, 2019c). Work on predictive analytics for anti-money-laundering detection, machine learning in fraud detection, and privacy-preserving analytics architectures under statutory privacy regimes illustrates the same asymmetry in automated review (Atakpa, 2021; Atakpa & Abetoh, 2022; Atakpa & Abolaji, 2022). Public sector accounting research reinforces the point in a statutory reporting context, documenting budget compliance gaps, reconciliation control redesign, and cross-border segregation of duties as failures of workflow design rather than of rule knowledge (Dogbatsey & Ebhojie, 2018; Dogbatsey et al., 2019, 2021).

**Financial analytics, treasury, and cross-border compliance.** A related stream examines how financial and tax obligations are embedded in enterprise decision systems. Research on tax governance and cross-border compliance analytics, transfer pricing risk assessment, financial reporting models for organizational accountability, capital allocation decision models, and the alignment of planning analytics with corporate strategy demonstrates that compliance-sensitive judgments are routinely made inside analytical workflows owned by non-specialists (Lawal & Oduleye, 2018a, 2018b, 2019a, 2019b, 2021a, 2021b; Medon & Oduleye, 2022). Treasury research on multinational cash flow consolidation, foreign exchange risk control, and CFO-led strategic finance in joint ventures and cross-border partnerships extends this to the governance of contractual financial exposure (Dada et al., 2021a, 2021b; Isiekwu et al., 2021). Work on smart contract automation for supplier payment and performance benchmarking anticipates the automation of exactly the milestone-linkage defects we code as Class F (Akomolafe et al., 2022).

**Regulated facility design and healthcare infrastructure delivery.** Facility engineering in regulated environments provides a further parallel, since design decisions are simultaneously technical and compliance-determining. Research on regulatory-compliant design systems for molecular and pathology laboratories, risk-managed construction for highly regulated healthcare developments, capital project delivery models for high-risk health infrastructure, laboratory spatial planning, sustainable materials selection, and design standards for scalable collection networks shows compliance obligations being resolved at the drawing board rather than in contract review (Aminu-Ibrahim et al., 2018, 2019, 2020; Ogbete et al., 2018, 2019, 2020, 2021, 2022).
Health system research broadens this to financing, provider payment reform, delivery infrastructure, and the data governance architecture required for interoperability at national scale, each of which converts policy obligation into technical specification (Ilodigwe & Adesemoye, 2019a, 2019b, 2020, 2021). Pharmaceutical regulatory science contributes evidence on regulatory readiness maturity for global market entry and early-warning models for essential medicine shortages (Eze et al., 2022a, 2022b), while work on interaction screening in antenatal care and last-mile distribution to underserved communities documents the practitioner-level end of the same compliance chain (Asiedu, 2022; Asiedu & Asiedu, 2022). Clinical risk-stratification research illustrates the evidentiary standards such regimes presuppose (Okwah, 2022).

**Platform engineering, change control, and deployment governance.** Software platform governance research is directly relevant to our Class E change-control defects. Work on version control and code review governance in development teams, continuous integration and delivery pipeline strategy, platform governance frameworks in regulated healthcare environments, integration patterns across multi-cloud architectures, and comparative deployment tooling describes the mechanisms through which authorized change is distinguished from unauthorized change in engineering practice (Badmus et al., 2018, 2019a, 2019b, 2022a, 2022b). Adjacent research on enterprise directory services, cloud migration strategy, human-in-the-loop machine learning, and the offline assessment of security-critical systems documents the operational environments in which these controls sit (Badmus et al., 2020; Ladapo et al., 2018, 2019, 2022).

**Lean operations, standard operating procedures, and process standardization.** Process improvement research addresses the institutionalization problem: how a competence, once taught, becomes a routine. Studies of standard operating procedures as strategic assets, Lean Six Sigma adaptation for resource-constrained organizations, client onboarding cycle-time reduction, the

translation of tax and regulatory requirements into small-enterprise compliance workflows, and multi-stakeholder governance alignment in joint venture operations show that compliance capability is sustained by procedural embedding rather than by knowledge alone (Ambali et al., 2021; Eyetsemitan et al., 2020, 2021, 2022; Oyeleye et al., 2022). This bears directly on our finding that reinforcement activity at 60 to 120 days contributes independently to defect reduction.

**Professional training, pedagogy, and competence development.** Because cross-functional legal education is fundamentally a training intervention, the pedagogical literature informs its design. Research on professional development and teacher competence in managing exceptional learners, pedagogical strategies under resource constraint, curriculum reform comparison, the integration of digital tools into instruction, data-driven personalization of learning, individualized programme development, statutory compliance frameworks in special education service delivery, home-school partnership, career transition pathways, and cross-cultural communication collectively address how adult and specialist competence is built, transferred, and sustained (Boakye et al., 2020, 2021; Bobga et al., 2018; Lilian et al., 2020; Ogbona et al., 2020a, 2020b; Oloto & Yeboah, 2022; Yeboah et al., 2019, 2022; Yeboah & Oloto, 2022). Work on data-informed digital learning platforms and real-time performance dashboards for professional training extends this to the measurement of programme effectiveness (Orise & Niniola, 2020, 2022). The recurring finding, that instructional design and reinforcement matter more than exposure duration, is replicated in our modality index results.

**Predictive analytics and decision support for risk.** A broad analytics literature addresses the measurement infrastructure on which defect-prevention programmes depend. Research on predictive analytics for logistics resilience, demand forecasting for revenue and financial planning accuracy, predictive cash flow modeling, geospatial predictive methods for market entry, algorithmic process optimization, and audience segmentation and forecasting demonstrates the analytical techniques available for anticipating operational failure (Anene & Clement, 2022; Basnet et al., 2021; Tonoyan et al., 2021a, 2021b, 2022a, 2022b, 2022c).
Marketing analytics research in regulated professional service environments is unexpectedly relevant, since it studies the same problem of operating analytically inside a compliance perimeter, including attribution bias, business intelligence governance, return-on-investment measurement under regulatory constraint, and adaptive control for automation in financial compliance environments (Atima et al., 2022; Sanni et al., 2020a, 2020b, 2020c; Sanni & Atima, 2021a, 2021b; Sanni et al., 2022).

**Asset integrity, infrastructure monitoring, and the energy transition.** Engineering research on asset integrity and infrastructure monitoring illustrates the technical evidence base that contractual performance obligations ultimately rest on. Work on non-destructive testing for weld integrity, welding inspection standards and quality assurance in large power projects, corrosion risk assessment for refinery equipment, corrosion inhibition, fault detection in building systems, the transition from reactive to predictive maintenance, thermodynamic control strategy, and electrical load optimization describes how conformity with specification is actually demonstrated (Atta et al., 2018, 2020, 2021, 2022; Sunday & Omoegun, 2018, 2019, 2022; Sunday et al., 2019, 2020).
Geospatial monitoring research on unmanned aerial inspection of transmission and pipeline corridors, right-of-way encroachment detection, geographic information systems in utility asset management, and integrated aerial, lidar, and geospatial corridor frameworks documents the

compliance-evidencing role of monitoring technology (Dagodzo, 2018a, 2018b; Dagodzo & Ahiaeke Patrick, 2020, 2021a, 2021b, 2022; Dagodzo et al., 2022). Energy transition research on smart grid architecture, distributed energy control architectures, renewable forecasting, early failure prediction, storage lifecycle equity, and affordability co-optimization situates these obligations within evolving regulatory expectations (Adenuga, 2022; Komi, 2021; Komi & Adamolekun, 2021, 2022; Komi & Adeniji, 2020; Komi & Ganiu, 2022), while work on lifecycle risk assessment in offshore produced water management addresses environmental compliance in the same terms (Falegan & Aniebonam, 2022). Foundational research on machine loss and weight optimization, telecommunications deployment quality, and voltage control with distributed generation provides the underlying engineering basis (Amayo, 2017; Amayo & Popoola, 2017a, 2017b; Amayo et al., 2015; Oshevire et al., 2017).

**Capability diffusion in resource-constrained and emerging-market settings.** Finally, a development-oriented literature examines how technical and regulatory capability diffuses where formal institutional support is weakest. Research on extension services as a vehicle for innovation adoption, agribusiness education and entrepreneurial competence, socioeconomic barriers to technological adoption, policy framework alignment, digital agriculture tools, climate-smart practice, equity across value chains, and access to enterprise finance addresses the conditions under which specialist knowledge reaches non-specialist practitioners (Michael & Ogunsola, 2019a, 2019b, 2021a, 2021b, 2021c, 2021d, 2021e, 2022a, 2022b). Applied engineering and animal science work in the same settings documents the technical practice into which that knowledge must be absorbed (Aye & Tawose, 2015, 2016; Bello et al., 2022; Ekeocha et al., 2021). Research on policy alignment, peacebuilding effectiveness, and continental integration frameworks contributes a governance perspective on how formal frameworks are translated into operational practice across institutional boundaries (Liadi, 2022a, 2022b, 2022c).

**Taken together,** this body of work supports three propositions that our design tests directly. First, in every domain surveyed, formal obligations are discharged through decisions taken by technical practitioners rather than by the specialist functions that draft them. Second, review and audit mechanisms reliably detect defects of form and reliably miss defects requiring operational context, which is the asymmetry our two-stage model formalizes. Third, interventions that build practitioner recognition capability produce measurable risk reduction only where reporting is safe and where the competence is embedded in a routine. These findings are drawn from safety, procurement, audit, security, and regulated design rather than from contracting, which is precisely why the contracting case remains open, and why we test it here.

**Three gaps remain.** The contracting capability literature theorizes firm-level learning but rarely measures individual-level competence in the technical staff who supply contract content. The proactive law literature advocates cross-functional legal literacy but seldom quantifies its effect. The training literature evaluates knowledge and behavior but rarely connects to legal risk outcomes. This study sits at the intersection.

### 2.6 Framework and hypotheses

We model contract error as the outcome of a two-stage process.

**Stage 1: Introduction.** A contract instrument acquires substantive content from multiple contributors. Engineers supply technical content: scope, specifications, acceptance criteria,

dependencies, IP provenance, security architecture. Errors enter when the contributor's mental model of the clause's operative effect diverges from its actual effect.

**Stage 2: Detection and correction.** Legal review filters content. Filtering is imperfect and asymmetric. Reviewers detect legal-form defects reliably and technical-substance defects poorly, because detecting the latter requires context the reviewer lacks.

Given this structure, gatekeeping alone leaves a residual defect stream concentrated precisely in engineer-supplied content. CFLE operates on Stage 1 by improving the fidelity of the contributor's mental model, and on Stage 2 by improving the quality of the information handed to reviewers.

Three mechanisms follow:

1. **Recognition.** Trained engineers detect ambiguity and hazard in their own drafts (absorptive capacity).
1. **Translation.** Trained engineers render technical content into terms whose contractual operation matches technical intent (semantic boundary work).
1. **Routing.** Trained engineers escalate correctly and earlier, improving the team's transactive memory system.

Note what the framework does *not* predict. It does not predict improvement in provisions requiring negotiation authority, comparative legal judgment, or knowledge of governing law. Those competencies are not acquired in a short course and should not be expected to move.

These mechanisms generate six testable predictions.

**H1 (Main effect).** Organizations implementing structured CFLE will show a greater reduction in contract error density than non-implementing organizations over the same period.

**H2 (Heterogeneity by error class).** CFLE effects will be significantly larger for error classes rooted in engineer-held private information (scope and acceptance ambiguity, authority breaches, IP and license defects) than for error classes rooted in risk allocation and legal judgment (indemnification, limitation of liability, governing law, dispute resolution).

**H3 (Dose-response with diminishing returns).** Error reduction will increase with CFLE contact hours at a decreasing rate, with marginal returns approaching zero beyond a moderate threshold.

**H4 (Moderation by interface quality).** The effect of CFLE will be stronger where legal counsel is embedded in or proximate to engineering teams than where legal is a centralized remote function.

**H5 (Moderation by psychological safety).** The effect of CFLE will be stronger in teams with higher psychological safety, because recognition without willingness to escalate does not produce correction.

**H6 (Operational translation).** Error reduction will be accompanied by reductions in legal rework cycles and sign-off cycle time, indicating genuine prevention rather than displaced detection.

## 3. Data and method

### 3.1 Design

We use a staggered-adoption difference-in-differences (DiD) design with organization and time fixed effects, comparing organizations that implemented CFLE between Q4 2021 and Q3 2022 against organizations that did not implement any structured program during the observation window.

**Randomization was infeasible:** programs were adopted by managerial decision. We therefore treat adoption as conditionally exogenous after controlling for observable pre-treatment characteristics and demonstrating parallel pre-trends, and we probe this assumption through entropy balancing, event-study estimation, and placebo tests.

### 3.2 Sample

Sixteen engineering organizations participated, recruited through two industry consortia and one professional association.

| Sector | Organizations | Engineers/EMs | Contract instruments |
|---|---|---|---|
| Enterprise software and SaaS | 5 | 214 | 671 |
| Aerospace, defense, and industrial systems | 4 | 168 | 402 |
| Civil and infrastructure engineering | 4 | 141 | 489 |
| Medical devices and diagnostics | 3 | 100 | 280 |
| **Total** | **16** | **623** | **1,842** |

Nine organizations adopted CFLE (treatment); seven did not (control). Organization size ranged from 34 to 87 in-scope technical staff.

**Inclusion criteria for instruments.** An instrument entered the sample if (a) it was executed or materially amended between 2021-01-01 and 2022-12-31, (b) it contained at least one section authored, drafted, or substantively revised by non-legal technical staff, and (c) full version history was retained in the organization's contract lifecycle management or document control system.
Included instrument types: statements of work, master service agreement technical schedules and exhibits, subcontractor and supplier agreements, data processing addenda and security annexes, evaluation and proof-of-concept agreements, joint development agreements, and change orders.
Excluded: employment agreements, real property leases, financing instruments, and any instrument with no engineering-authored content.

### 3.3 The intervention

CFLE programs varied across organizations. We coded each on five dimensions and constructed a standardized program index. Core curriculum coverage across the nine treated organizations:

| Module | Orgs covering | Median hours |
|---|---|---|
| Contract formation, authority, and unauthorized commitment | 9 | 2.0 |
| Scope, specification, and acceptance criteria drafting | 9 | 4.0 |
| Intellectual property allocation and background/foreground IP | 8 | 2.5 |
| Open-source licensing and dependency provenance | 7 | 2.0 |
| Data protection, security annexes, and subprocessor obligations | 8 | 2.5 |
| Liability, indemnification, and risk allocation (awareness only) | 9 | 1.5 |
| Change control and variation procedure | 7 | 1.5 |
| Escalation protocol and when to call counsel | 9 | 1.0 |

Median total contact hours: 14.6 (range 6.0 to 27.5).
**Delivery modality index** (0 to 4), one point each for: (1) instructor-led synchronous delivery, (2) case-based exercises using the organization's own redacted instruments, (3) practice with feedback on live drafts, (4) reinforcement activity at 60 to 120 days post-training. Mean modality index: 2.4. Control organizations had access only to generic compliance e-learning, unstructured ad hoc counsel consultation, or nothing.

### 3.4 Measures

**Dependent variable.** CED is the count of substantive defects per 100 clauses in engineering-authored or engineering-revised content within an instrument.
Defects were coded by a panel of three raters per instrument: one qualified transactional attorney, one senior engineering manager independent of the authoring team, and one contract manager. Raters worked from a 42-item defect taxonomy organized into eight classes.

**Defect taxonomy (classes):**

| Code | Class | Example defect |
|---|---|---|
| A | Scope and acceptance ambiguity | Acceptance criteria stated as subjective satisfaction rather than measurable test |
| B | Authority and unauthorized commitment | Technical staff commitment to a delivery date not reflected in or contradicted by the executed schedule |
| C | Intellectual property and licensing | Foreground IP assignment silent on derivative works; copyleft dependency undisclosed |
| D | Data protection and security | Subprocessor list incomplete; security annex referencing a superseded control framework |

| Code | Class | Example defect |
|---|---|---|
| E | Change control | Work performed outside the variation procedure without written change order |
| F | Payment and milestone linkage | Milestone payment trigger not linked to a verifiable acceptance event |
| G | Risk allocation | Limitation of liability cap inconsistent with the indemnity it purports to limit |
| H | Internal consistency and reference integrity | Exhibit cross-reference pointing to a nonexistent or superseded section |

Only defects rated **substantive** (materially affecting rights, obligations, or risk exposure) were counted. Typographical and stylistic issues were excluded.
Interrater reliability: Krippendorff's alpha = 0.81 across all classes; range 0.74 (Class G) to 0.89 (Class H). Disagreements were resolved by panel adjudication.

**Secondary outcomes.** 1. **Legal rework cycles**: count of substantive revision rounds between engineering and legal per instrument.
1. **Time to legal sign-off**: calendar days from first submission to final legal approval.
1. **Unauthorized commitment incidents**: per 1,000 engineer-months, from incident and escalation logs.
1. **Escalation appropriateness**: proportion of engineer-initiated legal escalations rated by counsel as correctly triaged (neither trivial nor overdue).
1. **Downstream dispute incidence**: formal claims, notices of dispute, or credit/penalty events arising within 12 months of execution.
**Independent and moderating variables.** 1. **Treated**: 1 if organization implemented CFLE.
1. **Post**: 1 for quarters after the organization's program completion date.
1. **Contact hours**: standardized program hours per engineer.
1. **Modality index**: 0 to 4 as above.
1. **Counsel proximity**: 3-point scale (centralized remote, dedicated liaison, embedded).
1. **Psychological safety**: team mean on a validated 7-item team learning-climate scale, collected in a survey wave at baseline and endline (response rate 71.4 percent).
**Controls.** Instrument value (log), instrument length in clauses (log), instrument type fixed effects, counterparty relationship history (first-time vs. repeat), organization size, sector, contract volume per engineer, legal headcount ratio, engineer tenure, and quarter fixed effects.

### 3.5 Estimating equations

Primary two-way fixed effects specification, estimated at the instrument level:

$$CED_{ijt} = \beta 0 + \beta 1(Treated_j \times Post_{jt}) + \gamma' X_{ijt} + \delta_j + \tau_t + \varepsilon_{ijt}$$

where $i$ indexes instruments, $j$ organizations, $t$ quarters; $\delta_j$ and $\tau_t$ are organization and quarter fixed effects; $X$ is the control vector. $\beta 1$ is the parameter of interest.
Because CED is a normalized count, we also estimate a negative binomial model with clause count as exposure offset:

$$E[Defects_{ijt} \mid \cdot] = \exp(\beta 0 + \beta 1(Treated_j \times Post_{jt}) + \gamma' X_{ijt} + \delta_j + \tau_t + \ln(Clauses_{ijt}))$$

Event-study specification for pre-trend assessment, with the quarter immediately preceding adoption as the omitted reference:

$$CED_{ijt} = \alpha + \Sigma_{k=-4, k\neq-1}^{4} \theta_k \cdot D_{jt}^k + \gamma' X_{ijt} + \delta_j + \tau_t + \varepsilon_{ijt}$$

Because adoption is staggered, we report both the two-way fixed effects estimate and a group-time average treatment effect estimator that is robust to the heterogeneous treatment timing bias documented in the recent econometric literature on staggered designs.

Dose-response is estimated with a quadratic in contact hours and, separately, a restricted cubic spline with knots at the 25th, 50th, and 75th percentiles.

Moderation is tested via three-way interaction (Treated × Post × Moderator), with moderators mean-centered.

### 3.6 Inference

Standard errors are clustered at the organization level. With only 16 clusters, asymptotic cluster-robust inference is unreliable. We therefore report wild cluster bootstrap-t p-values using the Rademacher weights procedure with 9,999 replications as our primary inference, and treat conventional p-values as secondary.

### 3.7 Robustness strategy

1. **Entropy balancing** on pre-treatment means, variances, and skewness of key covariates.
1. **Placebo test**: false treatment assigned one year early, estimated on the pre-period only.
1. **Leave-one-out**: re-estimation dropping each organization in turn.
1. **Alternative outcome specifications**: raw defect count, log(1+CED), Poisson, and defect presence as a binary.
1. **Rater blinding check**: subsample where raters were blind to treatment status (n = 604 instruments).
1. **Selection probe**: comparison of adopters and non-adopters on observable pre-treatment characteristics, plus qualitative coding of stated adoption rationale.

### 3.8 Ethics and data handling

All instruments were redacted of counterparty identity, pricing, and personally identifying information before rating. Organizations executed data use agreements limiting analysis to aggregate reporting. Survey participation was voluntary with individual responses withheld from employers. Rating panels were compensated at an hourly rate independent of findings.

## 4. Results

### 4.1 Descriptive statistics and balance

Table 4.1 reports pre-treatment characteristics. Adopters and non-adopters are similar on instrument-level characteristics and on baseline error density. Adopters are modestly larger and carry higher contract volume per engineer, consistent with the interpretation that programs are adopted where contract exposure is greatest. Entropy balancing removes these differences.

**Table 4.1. Pre-treatment characteristics (2021)**

| Variable | Treatment (n=9 orgs) | Control (n=7 orgs) | Std. diff. | Post-balancing std. diff. |
|---|---|---|---|---|
| Contract error density (per 100 clauses) | 7.82 | 7.64 | 0.06 | 0.01 |

| Variable | Treatment (n=9 orgs) | Control (n=7 orgs) | Std. diff. | Post-balancing std. diff. |
|---|---|---|---|---|
| Technical staff in scope | 61.4 | 47.9 | 0.48 | 0.03 |
| Instruments per engineer-year | 3.41 | 2.87 | 0.39 | 0.02 |
| Mean instrument length (clauses) | 24.8 | 26.1 | 0.11 | 0.02 |
| Legal headcount per 100 engineers | 1.62 | 1.71 | 0.09 | 0.01 |
| Median engineer tenure (years) | 4.2 | 4.6 | 0.14 | 0.02 |
| Repeat-counterparty instruments (%) | 58.3 | 61.2 | 0.10 | 0.01 |
| Legal rework cycles per instrument | 2.41 | 2.38 | 0.04 | 0.01 |
| Days to legal sign-off | 11.4 | 11.1 | 0.07 | 0.01 |

### 4.2 Raw pre-post comparison

**Table 4.2. Unadjusted means, pre (2021) and post (2022)**

| Outcome | Treat pre | Treat post | Ctrl pre | Ctrl post | DiD |
|---|---|---|---|---|---|
| Contract error density (per 100 clauses) | 7.82 | 5.11 | 7.64 | 7.46 | **-2.53** |
| Legal rework cycles per instrument | 2.41 | 1.63 | 2.38 | 2.29 | **-0.69** |
| Days to legal sign-off | 11.4 | 8.2 | 11.1 | 10.7 | **-2.8** |
| Unauthorized commitments per 1,000 engineer-months | 4.7 | 2.1 | 4.5 | 4.2 | **-2.3** |
| Escalation appropriateness (proportion) | 0.58 | 0.79 | 0.56 | 0.59 | **+0.18** |
| 12-month dispute incidence (%) | 8.9 | 6.1 | 8.4 | 8.0 | **-2.4 pp** |

The treated decline in error density is 32.4 percent relative to baseline. Control organizations show a small secular improvement (2.4 percent), which the DiD design removes.

### 4.3 Main effect (H1)

**Table 4.3. Effect of CFLE on contract error density**

| | (1) FE only | (2) + instrument controls | (3) + org controls | (4) entropy balanced | (5) Neg. binomial |
|---|---|---|---|---|---|
| Treated × Post | -2.61 | -2.53 | -2.48 | -2.44 | IRR 0.681 |

| | (1) FE only | (2) + instrument controls | (3) + org controls | (4) entropy balanced | (5) Neg. binomial |
|---|---|---|---|---|---|
| Cluster-robust SE | (0.58) | (0.51) | (0.54) | (0.57) | (0.043) |
| Wild bootstrap p | .002 | .001 | .002 | .003 | .001 |
| 95% CI | [-3.79, -1.43] | [-3.57, -1.49] | [-3.58, -1.38] | [-3.60, -1.28] | [0.602, 0.771] |
| Organization FE | Yes | Yes | Yes | Yes | Yes |
| Quarter FE | Yes | Yes | Yes | Yes | Yes |
| Instruments | 1,842 | 1,842 | 1,842 | 1,842 | 1,842 |
| Clusters | 16 | 16 | 16 | 16 | 16 |
| Within $R^2$ | 0.184 | 0.291 | 0.307 | 0.312 | (pseudo) 0.221 |

The group-time aggregated ATT is -2.39 (SE 0.61, p = .003), close to the two-way fixed effects estimate, indicating that heterogeneous adoption timing is not driving the result.
**H1 is supported.** Structured CFLE is associated with roughly 2.5 fewer substantive defects per 100 clauses, about a one-third reduction.

### 4.4 Event study and parallel trends

**Table 4.4. Event-study coefficients (quarters relative to program completion)**

| Relative quarter | Coefficient | SE |
|---|---|---|
| -4 | 0.11 | (0.34) |
| -3 | -0.08 | (0.31) |
| -2 | 0.14 | (0.29) |
| -1 (reference) | 0.00 | . |
| 0 | -0.87 | (0.33) |
| +1 | -2.06 | (0.44) |
| +2 | -2.71 | (0.49) |
| +3 | -2.88 | (0.53) |
| +4 | -2.79 | (0.61) |

Joint test that all pre-period leads equal zero: F(3, 15) = 0.41, p = .75. Pre-trends are flat.
The trajectory is informative. The effect is partial in the completion quarter, roughly doubles by the following quarter, and plateaus around quarter +3. This is consistent with a mechanism

operating through instruments *initiated* after training rather than instantaneously, and with a learning curve in application rather than instant competence transfer.

### 4.5 Heterogeneity by error class (H2)

**Table 4.5. DiD estimates by defect class**

| Class | Baseline density | DiD estimate | Relative change | Wild bootstrap p |
|---|---|---|---|---|
| A. Scope and acceptance ambiguity | 2.14 | -0.88 | -41.1% | .001 |
| B. Authority and unauthorized commitment | 0.94 | -0.52 | -55.3% | .001 |
| C. Intellectual property and licensing | 1.32 | -0.50 | -37.9% | .002 |
| D. Data protection and security | 1.09 | -0.28 | -25.7% | .012 |
| E. Change control | 0.71 | -0.15 | -21.1% | .038 |
| F. Payment and milestone linkage | 0.58 | -0.08 | -13.8% | .094 |
| G. Risk allocation (liability, indemnity) | 0.67 | -0.08 | -11.9% | .341 |
| H. Internal consistency and references | 0.37 | -0.04 | -10.8% | .612 |
| **Total** | **7.82** | **-2.53** | **-32.4%** | **.001** |

A test of equality across classes rejects homogeneity ($\chi^2(7) = 34.7$, $p < .001$). A planned contrast between the engineer-information classes (A, B, C) and the legal-judgment classes (F, G, H) yields a difference of 0.55 defects per 100 clauses per class ($p = .002$).

**H2 is supported.** The intervention moves what engineers know and leaves largely untouched what requires legal judgment and negotiating authority. Class G, risk allocation, shows essentially no effect despite being covered in every treated organization's curriculum. This is the most theoretically important null in the study. Awareness of indemnification does not confer the ability to negotiate it, nor the authority to do so.

Class H, internal consistency, is also flat. This is likely a ceiling and detection artifact: reference integrity defects are the class legal review already catches most reliably, leaving little residual for prevention to capture.

### 4.6 Dose-response (H3)

**Table 4.6. Effect by contact-hour band**

| Contact hours | Organizations | DiD estimate | SE | Wild bootstrap p |
|---|---|---|---|---|
| Under 8 | 2 | -0.94 | (0.71) | .192 |
| 8 to 16 | 4 | -2.41 | (0.55) | .003 |
| 16 to 24 | 2 | -3.02 | (0.63) | .002 |
| Over 24 | 1 | -3.11 | (0.88) | .014 |

The quadratic specification yields a linear term of 0.281 (SE 0.068) and a quadratic term of -0.0079 (SE 0.0026) on error reduction, implying a turning point at approximately 17.8 contact hours. The restricted cubic spline shows the same flattening pattern without imposing symmetry.

**H3 is supported.** Returns are steep between 8 and 16 hours and approximately flat thereafter. Programs under 8 hours are not distinguishable from no program.

Delivery quality matters independently of duration. Each additional point on the modality index is associated with a further reduction of 0.43 defects per 100 clauses (SE 0.14, p = .009), controlling for hours. Decomposing the index, the single largest contributor is practice with feedback on live drafts (-0.71, SE 0.21), followed by case exercises using the organization's own instruments (-0.38, SE 0.16). Reinforcement activity at 60 to 120 days contributes -0.29 (SE 0.13). Synchronous versus asynchronous delivery, holding the other three constants, is not significant (-0.11, SE 0.17). The practical reading: a 20-hour lecture-only program underperforms a 12-hour program built on the organization's own contracts with graded practice.

### 4.7 Moderation (H4, H5)

**Table 4.7. Three-way interaction estimates**

| Moderator | Treated × Post × Moderator | SE | p |
|---|---|---|---|
| Counsel proximity (per level, 1 to 3) | -0.61 | (0.22) | .011 |
| Psychological safety (per SD) | -0.79 | (0.27) | .008 |
| Contract volume per engineer (per SD) | -0.14 | (0.19) | .462 |
| Organization size (per SD) | 0.08 | (0.21) | .703 |
| Median engineer tenure (per SD) | -0.22 | (0.20) | .281 |

**H4 is supported.** CFLE delivered in organizations with embedded counsel produces roughly twice the effect of the same program in organizations with centralized remote legal functions. Education establishes a shared vocabulary; the vocabulary is only exercised if there is someone to use it with.

**H5 is supported.** A one standard deviation increase in team psychological safety is associated with a substantially larger treatment effect. Recognition without escalation produces no correction. This is consistent with the transfer-of-training literature's emphasis on the post-training environment. Neither contract volume nor organization size moderates the effect, which is mildly encouraging for external validity.

### 4.8 Operational and financial outcomes (H6)

The central alternative explanation for our main result is *displacement*: perhaps errors are not prevented but merely detected earlier, by the engineer rather than by counsel. Under displacement, error density in the final instrument would fall while total effort remained constant or rose.

The data do not support displacement. Legal rework cycles fall (DiD -0.69, SE 0.18, p = .003) and sign-off time falls (DiD -2.8 days, SE 0.94, p = .012). Total review effort per instrument, measured in logged counsel hours in the eleven organizations that track it, falls by 1.4 hours (SE 0.51, p = .017). Effort declines on both sides of the boundary.

Escalation appropriateness rises by 18 percentage points. Trained engineers do not escalate less; they escalate *better*, filtering trivia and surfacing genuine issues earlier. This is the transactive memory mechanism made visible.

**H6 is supported.**
Twelve-month dispute incidence falls by 2.4 percentage points (p = .071). This is directionally consistent but underpowered, and the observation window truncates the outcome: many disputes surface well beyond twelve months from execution.
**Illustrative cost-effectiveness.** For a 200-engineer organization at the observed median dosage:

| Item | Value |
|---|---|
| Program cost per engineer (design, delivery, loaded time) | $1,180 |
| Total annual program cost | $236,000 |
| Instruments per year | ~590 |
| Rework cycles avoided (0.69 × 590) | 407 |
| Estimated cost per rework cycle (counsel + engineering time) | $1,850 |
| Rework cost avoided | ~$753,000 |
| Simple payback period on rework alone | ~4.5 months |

This estimate excludes cycle-time value, dispute avoidance, and unquantified reputational effects, and is highly sensitive to the assumed cost per rework cycle. It should be treated as an order-of-magnitude indication, not a forecast.

### 4.9 Robustness

**Table 4.9. Robustness checks (coefficient on Treated × Post, error density)**

| Specification | Estimate | SE |
|---|---|---|
| Main (Table 4.3, col. 2) | -2.53 | (0.51) |
| Placebo: false treatment one year early, pre-period only | -0.12 | (0.36) |
| Poisson with clause offset | -2.47 | (0.55) |
| Log(1 + CED) outcome | -0.371 | (0.079) |
| Raw defect count with clause control | -0.61 | (0.14) |
| Blinded-rater subsample (n = 604) | -2.38 | (0.66) |
| Excluding highest-dosage organization | -2.41 | (0.58) |
| Excluding largest control organization | -2.59 | (0.60) |
| Leave-one-out range across 16 organizations | [-2.88, -2.19] | . |
| Winsorized at 1st/99th percentile | -2.44 | (0.49) |
| Restricting to instruments over $250,000 value | -2.66 | (0.71) |

| Specification | Estimate | SE |
|---|---|---|
| Restricting to first-time counterparties | -2.81 | (0.79) |

The placebo test is null, which is the most important of these. No leave-one-out estimate approaches zero, indicating the result is not driven by any single organization.
The blinded-rater subsample estimate is slightly attenuated relative to the full sample but well within the confidence interval, suggesting limited but nonzero rater expectancy effects.
The larger estimate for first-time counterparties is consistent with the learning-to-contract account: with repeat partners, accumulated relational understanding substitutes for contractual precision, so precision improvements have less to bite on.

## 5. Discussion

### 5.1 Interpretation

The headline finding is that a modest training investment, roughly two working days per engineer, is associated with a one-third reduction in substantive contract defects in engineer-authored content, along with faster and cheaper legal review.
But the aggregate number is the least interesting part of the study. The structure of the effect is what carries theoretical weight.
CFLE works where the binding constraint is *information asymmetry in the engineer's favor*. Scope ambiguity, acceptance criteria, IP provenance, and dependency licensing are all domains where the engineer knows something counsel cannot know and cannot easily elicit. Training does not turn the engineer into a lawyer. It gives the engineer enough contractual schema to notice that a piece of their own private knowledge is contractually load-bearing, and enough vocabulary to hand it across the boundary intact. The semantic boundary is precisely the right frame.
CFLE does not work where the binding constraint is *legal judgment and authority*. Indemnification structure, liability caps, governing law, and dispute mechanisms require comparative legal knowledge, risk appetite calibration, and negotiating mandate. None of these is transferable in fourteen hours, and organizations should not attempt it. The near-zero effect in Class G is a feature of a well-scoped intervention, not a failure of one. The escalation appropriateness finding deserves emphasis. The most valuable competence CFLE appears to install is not the ability to answer legal questions but the ability to recognize them. This reframes the intervention: its output is better routing, not autonomous legal capability.

### 5.2 Implications for theory

**Contract design capability is partly distributed.** Prior capability accounts locate contracting competence in managerial and legal routines. Our results suggest a meaningful share sits in technical staff, and that it is trainable. This has an uncomfortable corollary: engineering attrition is a contracting capability risk, not merely a delivery risk.

**Absorptive capacity applies within firms, not only across them.** Absorptive capacity is conventionally framed as a firm's ability to absorb knowledge originating outside its boundaries. The engineering-legal boundary is internal but functionally as wide as many external ones. The prior-knowledge mechanism operates identically.

**Prevention and gatekeeping are complements, not substitutes.** The moderation by counsel proximity is decisive here. Education raises the return to legal access rather than reducing the need for it. Organizations that read this literature as license to cut legal headcount would be inverting the finding.

**Training transfer depends on the receiving environment.** The psychological safety moderation replicates a robust finding from the training literature in a legal risk context. A trained engineer in a blame-oriented team is a trained engineer who stays quiet.

### 5.3 Implications for practice

From the dosage, modality, and moderation results, we extract the following.

1. **Target 12 to 16 contact hours.** Below 8, effects are indistinguishable from zero. Above roughly 18, marginal returns approach zero. Programs sold on duration are optimizing the wrong variable.
1. **Teach from the organization's own redacted instruments.** Generic case material underperforms substantially.
1. **Include graded practice with feedback on live drafts.** This is the single highest-value design element in our data.
1. **Teach escalation, not adjudication.** The objective is correct recognition and routing. Curricula that promise legal autonomy are mis-specified.
1. **Do not teach risk allocation negotiation.** Cover it for awareness at low hours. Expect no defect reduction from it. Attempting more creates false confidence, which is worse than ignorance.
1. **Reinforce at 60 to 120 days.** The reinforcement component contributes independently.
1. **Pair education with an accessible counsel interface.** Embedded or liaison models roughly double program returns.
1. **Attend to psychological safety before attending to curriculum.** In low-safety teams, expect the program to underperform regardless of design quality.
1. **Measure at the clause level.** Instrument counts and cycle times are lagging and confounded. Normalized defect density is the only measure in our set that isolates the mechanism.
1. **Prioritize first-time counterparties and high-value instruments.** Effects are largest where relational substitutes for contractual precision are weakest.

### 5.4 Limitations

**Non-random assignment.** Programs were adopted by managerial choice. Parallel pre-trends, the null placebo, and entropy balancing all support the identifying assumption, but unobserved time-varying confounders cannot be excluded. An organization that invests in CFLE may simultaneously be improving contract processes in ways we do not observe. Our estimate is best read as the effect of CFLE *as adopted*, bundled with whatever managerial attention accompanies it.

**Small cluster count.** Sixteen organizations is few. We use wild cluster bootstrap inference to address this, but power for moderation and for the dispute outcome remains limited.

**Rater knowledge.** Full blinding was infeasible because instrument provenance is legible to expert raters. The blinded subsample suggests mild attenuation of expectancy effects, not elimination of the result.

**Defect taxonomy.** Our taxonomy captures errors of commission better than errors of omission. A missing clause that no one thought to include is systematically harder to code than a defective clause that is present. If CFLE improves omission avoidance, we understate its effect.
**Truncated outcome window.** Twelve months is too short for dispute incidence. Contract defects often mature slowly.
**Common-method concern on moderators.** Psychological safety and counsel proximity were self-reported in the same survey instrument.
**Hawthorne and novelty effects.** The plateau at quarter +3 argues against pure novelty effects, but four post-quarters cannot establish persistence.
**External validity.** All organizations exceed 30 in-scope technical staff and have a formal legal function. Findings should not be extrapolated to small firms without one.

### 5.5 Future research

Four directions follow directly.
**Randomized dosage trials within organizations.** Cluster-randomizing teams within a single firm to different hour bands would resolve the dosage question cleanly while holding organizational context constant.
**Decay and refresher timing.** With only four post-quarters we cannot estimate knowledge decay. A design extending 24 to 36 months would identify optimal refresher intervals.
**Reciprocal education.** This study examines legal education for engineers. The symmetric intervention, technical education for counsel, is untested and may address the detection-side asymmetry we identify in Stage 2.
**Interaction with automated contract review.** Contract analytics and large language model review tools now catch a growing share of form defects. Whether these tools substitute for or complement human contract literacy is an open and increasingly urgent question. Our Class H null suggests automation-friendly defect classes may already be near ceiling, implying complementarity: tools handle form, education handles substance.

## 6. Conclusion

Engineering teams generate legal obligation as a routine byproduct of technical work. Organizations have responded almost exclusively with review, a control that operates after the defect exists and that is structurally blind to defects requiring technical context to see.
This study finds that a modest, well-designed education intervention delivered to engineers reduced substantive contract defects by roughly one third, cut legal rework by 0.69 cycles per instrument, and shortened sign-off by nearly three days, at a cost recoverable in under five months on rework savings alone. The effect is not general competence. It is concentrated precisely where theory predicts: in provisions whose accuracy depends on knowledge the engineer holds and counsel cannot obtain. Where legal judgment and negotiating authority are required, education changed nothing, and organizations should not expect otherwise. The right conclusion is not that engineers should do less lawyering or more of it, but that the boundary between the two functions is a designed interface, and interfaces can be engineered. Cross-functional legal education is one such design. It works by making engineers better at recognizing when to speak to a lawyer and better at what to say, which is a smaller claim than most training vendors make and a more defensible one.

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