Elevating Engineering Education through Adaptive Learning: Building an Interconnected Spine of Courses and Faculty Readiness Models

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1 Motivation and Background

This work-in-progress research paper describes an early-stage, three-institution effort to design, implement, and study a Realizeit-enabled adaptive learning curricular spine connecting Statics, Dynamics I, and Dynamics II across UNC Charlotte, NC State University, and North Carolina AT State University.

Engineering retention remains a persistent challenge: nearly half of engineering students change majors or leave before graduation [1], and early preparation gaps in foundational mechanics sequences compound quickly. In courses such as Statics, Dynamics I, and Dynamics II, difficulties with prerequisite concepts—free-body diagrams, friction, pulley constraints, or energy methods—can reappear in more complex downstream contexts. When these gaps are not addressed at the point of need, students may struggle even when the immediate course topic is not the original source of difficulty. In this paper, *adaptive learning (AL)* refers to courseware that adapts practice and support based on each student's responses, organizing content into short outcome-linked modules with embedded checks and routing students to targeted remediation when gaps are detected [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]. Several AL platforms are currently available, including Acrobatiq, Canvas Mastery Paths, Grasple, LibreTexts ADAPT, MyOpenMath, Realizeit, and OLI Torus [15, 16, 17, 18, 19, 20, 21, 22]. Our team has previously piloted Realizeit courseware across Statics, Dynamics I, and Dynamics II. In prior Statics deployments, 83.3% of students reported the modules helped them master skills and 75.0% found them helpful for connecting prior and new knowledge. In Dynamics I, students completed 39,000 questions across 2,946 total hours, and Realizeit activity scores significantly predicted exam and project grades ($p < 0.0001$), explaining 48% and 20% of the variance, respectively.

However, most AL implementations—including these prior pilots—remain confined to a single course. Students may receive additional practice on the current topic without being redirected to the earlier concept actually limiting their progress, and instructors lack cross-course analytics showing how prerequisite bottlenecks persist across a sequence. The curricular spine proposed here addresses this directly: rather than adding practice within a course, it makes prerequisite relationships explicit *across* Statics–Dynamics I–Dynamics II, routing students to targeted upstream support when downstream difficulties emerge and enabling instructors to examine recurring bottlenecks across the full sequence. Spanning three institutions also introduces implementation questions central to this study—how to align concept maps across programs, allow bounded local customization, and understand how grading integration, faculty engagement, and institutional readiness shape sustained adoption.

The study is guided by two research questions: (i) how does spine-connected adaptive courseware relate to student learning and engagement across institutions and student groups, and (ii) how do implementation conditions—including grading integration, faculty engagement, and institutional readiness—shape outcomes, adoption, and long-term sustainability? This paper contributes the spine design logic, the cross-institution implementation model, and the deployment-aligned evaluation plan that will be used as rollout proceeds.

2 Project Approach

This work is organized around two goals that leverage adaptive learning courseware and its embedded analytics. The first, *Elevating Educational Support*, focuses on developing and implementing a connected Statics–Dynamics I–Dynamics II sequence in which adaptive learning can deliver targeted prerequisite support at the point of need as students progress through the mechanics curriculum. The second, *Empowering Faculty and Institutions*, focuses on building the training, workflows, and support structures needed to integrate adaptive courseware into existing courses in a way that is practical for instructors and supportable for departments. Figure 1 summarizes how courseware development, implementation supports, and evaluation connect over time.

Progress toward Goal 1 will be pursued through two coordinated efforts. The first centers on spine alignment and cross-linking through shared course improvement. Faculty subject-matter experts across UNC Charlotte, NC State

INPUTS	OBJECTIVES & QUESTIONS	ACTIVITIES	PRIMARY PRODUCTS	LONG-TERM OUTCOMES
NC State, UNC Charlotte, NCAT universities -existing AL engineering courses (augmented during project period) -faculty leads with subject-matter expertise -faculty leads with AL experience -instructional designers & learning technologists with AL expertise -students in Statics, Dynamics I & Dynamics II engineering courses (course spine) -evaluation experts & Advisory Board	**O1.** Elevate educational support. What are best practices for integrating AL into existing curriculum? Does implementation of AL courseware spine &/or automated interventions support student learning, success & equity?	-Revise existing AL courses to create aligned AL spine with deep, cross-linked content -Course spine deployment/ iteration -Compare student outcomes before & after revised AL spine deployment -Compare impact of automated vs faculty managed interventions on student & faculty outcomes	-Improved AL engineering spine materials -Tracked student learning & success outcomes, disagregated as needed -Tracked faculty outcomes disagregated as needed	-Transformed engineering mechanics AL curriculum that can be adopted by others - Improved outcomes & reduced equity gaps for engineering students at 3 universities -Knowledge gained about AL automated interventions & scaled deployment into curricula
	O2. Empower faculty. What are faculty & institutional needs to ensure optimal AL adoption? What are best practices for AL training & implementation? Does our training improve AL perceptions, knowledge & skills & promote an AL supportive culture?	-Conduct faculty & institutional needs assessment; derive best practices for implementation training & resources -Design, deploy, evaluate training & implementation resources. -Create sharable repository of materials & documentation	-Data from needs assessment -Adaptive teaching competency model & faculty onboarding resources -Institutional readiness model & onboarding resources -Coaching & workshop resources, records, evaluation results -Repository with implementation documentation, AL spine content	-Evidence-based training resources -Improved faculty & institutional acceptance & adoption of AL -Improved faculty AL expertise -Sustainable, sharable resources to support optimal, wide-scale AL adoption
	Additional project evaluation. Are we moving the needle on AL acceptance & adoption? For which student subpopulations are AL benefits realized? How are faculty outcomes impacted by project objectives? Any differences in course or institution outcomes? Is the project achieving its goals?	-Gather & analyze metrics related to AL acceptance & adoption -Analyze student & faculty outcomes -Implement assessment cycle to use student outcome data to inform course tweaks for each next term; -Examine student & faculty outcomes by course, institution -Engage in monthly discussions to assess project progress & outcomes	-Tracked project, student, and faculty outcomes, disaggregated as needed -Evaluation & assessment reports -Publications & conference activity	-Disseminated knowledge on how to encourage AL acceptance & adoption across the field -More inclusive AL spine benefiting outcomes of diverse students & their workforce preparedness -Disseminated knowledge about good AL practices in engineering mechanics curriculum

Figure 1: Logic model linking project activities to intended outcomes.

University, and North Carolina A&T will identify prerequisite dependencies across Statics–Dynamics I–Dynamics II and implement these links within the adaptive courseware so that student performance on downstream work can trigger targeted review and practice in the relevant upstream concepts. In parallel, the team will establish a collaborative refinement cycle to review and update lesson organization, terminology, examples, and problem banks, while allowing bounded local customization (e.g., pacing, module selection, and locally authored problems or contextual examples) to fit each institution's course context.

Progress toward Goal 1 will be pursued through two coordinated efforts. The first focuses on spine alignment and cross-linking through shared course improvement. Here, *prerequisite dependencies* mean that an *upstream* concept (earlier in Statics–Dynamics I–Dynamics II) is required for a *downstream* task (later in the sequence). We implement *cross-linking* by embedding explicit prerequisite connections in the courseware: each downstream lesson/problem set links to the upstream concept node(s) it depends on, with routing rules that trigger targeted review and practice when low mastery is detected.

We define a *spine link* as such a connection, implemented so common errors route students to a brief prerequisite pathway (review, worked examples, focused practice) before they continue—for example, Dynamics I pulley/relative-motion errors route to kinematics constraints, and Dynamics II rigid-body setup errors route to Statics FBD/component-resolution nodes. In parallel, the team will run a *collaborative refinement cycle* (once per term) to review analytics and instructor feedback, agree on a small set of shared updates, and version those updates for the next deployment. To preserve comparability, the shared concept structure, prerequisite mapping, and core objectives will remain consistent across institutions; *bounded local customization* will be limited to integration choices (e.g., pacing, optional modules, locally authored problems/examples) that do not alter the shared spine.

The second Goal 1 effort focuses on adaptive, spine-enabled supports that extend beyond content delivery, including just-in-time prerequisite routing and automated communications (e.g., reminders and progress prompts). As staged deployments begin, the team will examine how students interact with these supports and how usage patterns relate to engagement and performance, using early evidence to guide iterative adjustments to the spine connections and associated instructional practices.

Progress toward Goal 2 will be pursued through two additional efforts focused on adoption and sustainability. First, the team will gather input from key stakeholders to understand practical enablers and constraints in each setting, including how adaptive courseware fits into grading and course flow, faculty workload and analytics use, and the availability of instructional and technical support. Second, those inputs will be translated into usable implementation supports, including faculty onboarding resources, guidance for course and grading integration, and institution-facing materials that clarify implementation steps, roles, and responsibilities. A concrete output will be a lightweight readiness and integration profile that captures local conditions affecting successful use (e.g., LMS integration pathway, staffing/support availability, grading policies, and onboarding practices). The profile will be operationalized as a short inventory completed by course leads and local support partners and revisited as deployments expand, enabling implementation supports to be matched to local constraints rather than treated as one-size-fits-all.

The initial phase emphasizes cross-institution coordination to surface similarities and differences that may affect spine design and scalability. A kickoff meeting is scheduled to convene course leads, additional faculty (including those who currently use the platform and those who do not), and academic leadership (e.g., chairs and deans) to compare course structures and expectations and to identify where sequencing or emphasis differs across programs (for example, how Dynamics II topics depend on prerequisite coverage). In parallel, the team has initiated study logistics by preparing institutional review submissions to enable access to relevant student records and the administration of planned instruments as staged deployments proceed. Planned data collection includes course performance data (e.g., major assessments and final grades), platform engagement analytics (e.g., time-on-task and completion), and structured documentation of section-level implementation decisions (e.g., grading integration, onboarding practices, and pacing). Faculty and student input will be gathered through surveys and targeted group discussions to capture practical experiences with integration and to surface barriers and enabling conditions that may not be visible in analytics alone. Together, these sources will support early refinement of both the spine connections and the implementation supports while maintaining a clear record of what was implemented in each setting.

3 Evaluation Strategy

The evaluation aligns with the two project goals in Figure 1: (1) elevating educational support through a connected Statics–Dynamics I–Dynamics II spine, and (2) strengthening adoption and sustainability by identifying the implementation conditions and supports needed across institutions. To address both goals, the evaluation combines student outcome and engagement measures with an embedded implementation study that documents how the courseware is integrated and supported in each setting. At the time of submission, these activities are planned and are being set up to run alongside staged deployment. The evaluation is guided by two research questions: (i) How does spine-connected courseware influence student learning and engagement across institutions and student groups? (ii) How do implementation conditions (e.g., grading integration, faculty engagement, and institutional readiness) support adoption and shape outcomes and long-term sustainability?

The study will use a mixed-methods, multi-institution, quasi-experimental design. Because these are required engineering courses, random assignment is not anticipated; instead, the evaluation will leverage naturally occurring variation across terms and sections. Where feasible, comparisons will include (i) across-term contrasts between baseline offerings (e.g., terms without spine connections or with limited integration) and spine-connected offerings, and (ii) within-term contrasts across concurrently offered sections that differ in implementation features (e.g., grading weight, pacing, or onboarding practices). The primary unit of analysis will be the student, with students nested within sections and institutions. Based on current course structures, a typical semester is expected to include a section using the courseware (approximately 40 students) and a comparable section not using it (approximately 60 students), depending on scheduling and instructor assignments. Implementation context (assessment structure, grading policies, and instructor choices) will be recorded alongside outcomes to support careful interpretation. Given the staged rollout and quasi-experimental comparisons, early analyses will emphasize descriptive patterns and plausibility rather than causal claims, with claims tightened as evidence accumulates across terms and sites.

Because deployments will expand over time, the evaluation will proceed in cycles. Early cycles will emphasize feasibility and usage patterns—for example, whether students reach and use prerequisite pathways as intended, whether instructors can interpret and act on analytics with minimal added workload, and whether section-level integration choices can be documented consistently across sites. As additional semesters accumulate, analyses will expand to more stable models that account for nesting and implementation variation.

Student outcomes will be examined using measures that are routinely available across the three institutions. Learning will be captured through performance on major course assessments (e.g., midterm/final exams or other summative assessments used in the course) and overall course grades; when available and comparable across sites, course success indicators such as DFW rates and withdrawals will also be tracked. Engagement will be characterized using platform analytics, including lesson/problem completion, time-on-task, attempt patterns, and pacing/regularity of participation. To connect observed outcomes to the spine mechanism, the team will select a limited set of high-leverage concepts that recur across Statics, Dynamics I, and Dynamics II and examine concept-level indicators (e.g., mastery/proficiency measures aligned to learning objectives) and the use of prerequisite-support pathways. Because assessments and grading practices may differ across institutions, cross-institution reporting will emphasize standardized summaries (e.g., within-course standardized scores and effect sizes) rather than raw-score comparisons.

To address the second research question, the evaluation will include an embedded implementation study focused on conditions that influence adoption and sustainability. Three constructs will be prioritized because they are actionable and likely to vary across settings: grading integration (required vs. optional use, weighting, and completion- vs. mastery-based credit), faculty engagement (how instructors use analytics to monitor progress and respond instructionally, and how they participate in courseware refinement), and institutional readiness (availability of instructional and technical support, platform/LMS integration processes, and local constraints affecting access, training, and continuity). These constructs will be documented using section-level implementation logs, brief faculty check-ins/interviews, and readiness-oriented surveys or interviews with relevant support personnel, as appropriate to each institution.

Qualitative evidence will be used to interpret quantitative patterns and to surface barriers and enabling conditions that may not be visible in analytics alone. Planned sources include student surveys and focus groups (clarity of expectations, perceived usefulness, workload, and support), faculty surveys and interviews (integration decisions, workload, barriers/enablers, and analytics use), and input from instructional design and learning technology partners (deployment processes and support needs). Quantitative analyses will include descriptive summaries and inferential modeling appropriate for nested educational data, including regression-based analyses and, where feasible, multilevel models that account for section- and institution-level differences. Implementation and qualitative findings will be integrated with outcome analyses using structured synthesis (e.g., evidence tables and joint displays) to identify which spine design features and implementation conditions appear most consistently associated with learning, engagement, and sustained use as deployments proceed.

The evaluation has limitations typical of required-course settings. Comparisons will be quasi-experimental and may be affected by instructor assignment, section composition, and differences in assessment structure across institutions. We will mitigate these threats by documenting implementation context at the section level, emphasizing within-course standardized reporting for cross-site summaries, and treating early findings as directional evidence used to refine the spine connections and implementation supports.

4 Current Status and Next Steps

This paper reports an early-stage, three-institution effort to connect Statics, Dynamics I, and Dynamics II through an adaptive-learning curricular spine. The project links prerequisite concepts across courses to provide point-of-need support, while also addressing integration decisions and institutional conditions needed for sustained use. At submission, the team is aligning cross-institution concept maps, preparing implementation supports (onboarding, integration guidance, refinement routines), and initiating study logistics (IRB and instruments).

Next steps are to finalize an initial set of spine-linked modules for pilot sections, document section-level implementation features, and begin data collection using course outcomes, platform analytics, and faculty/student feedback. As deployments scale, early evidence will guide iterative refinement of both the spine links and the implementation supports, with later publications reporting results and identifying the most consequential design and implementation factors.

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