

## Leveraging Program Architecture to Strengthen Teaching, Teacher Learning, and K–12 Digital Learning Outcomes

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**Abstract:** We argue that K-12 digital learning outcomes depend less on delivery mode than on "program architecture"—the coordinated organizational, instructional, and structural design decisions shaping student experience. Drawing on recent evidence, the authors identify key architectural tensions and propose that uneven outcomes stem from misaligned structures rather than modality itself, calling for teacher education to prepare educators to diagnose and enact specific program architectures.

### Introduction

Digital learning is no longer a temporary response to disruption; it has become a durable feature of many K-12 systems. With that durability, the most useful questions shift. Earlier waves of research often centered on whether online learning “works,” or which delivery mode is “better.” Yet post-pandemic experience and recent evidence suggest that outcomes remain uneven across student profiles, contexts, and implementation conditions (Freidhoff et al., 2025; National Center for Education Statistics, 2024). These uneven outcomes are not well-explained by modality alone. Instead, variation appears tied to how programs structure time, interaction, pacing, and support—features that are frequently treated as background rather than primary design variables.

This paper frames those design variables as program architecture: the coordinated set of organizational, instructional, and structural decisions that shape how K–12 digital learning is experienced in practice. Architecture is more than a course shell and more than a platform. It includes enrollment and pacing models, sequencing expectations, the intended use of synchronous and asynchronous time, feedback and communication routines, staffing supports, curricular development models, and local policies that enable (or constrain) equitable implementation. These choices interact. A flexible pacing model without strong early-week routines can amplify procrastination and disengagement; a synchronous-heavy approach without interaction design can produce “closed” teacher-centered instruction; and a well-designed course can still underperform when staffing roles, grading policies, or support capacity are misaligned.

Program architecture is also deeply relevant for teaching and teacher education. Teachers do not teach “online” in the abstract; they teach inside a particular architecture. Those architectures create different instructional problems: continuous enrollment complicates community-building and whole-class pacing; self-paced designs heighten the importance of progress monitoring and individualized nudging; blended synchronous/asynchronous designs require teachers to make purposeful choices about what belongs in live time versus flexible time. Teacher education, therefore, benefits from shifting from generalized “online pedagogy” toward architecture-aware teaching—helping teachers interpret, enact, and improve the structures that shape learning trajectories.

The goals of this paper are to: (1) define program architecture and its core dimensions; (2) synthesize evidence about how architectural choices relate to student engagement and outcomes; (3) translate those dimensions into practical “architecture moves” for teacher practice and teacher education.

### Program Architecture: A Coordinated Design Problem

We use program architecture to describe the coordinated set of design decisions that collectively define how students, caregivers, and educators experience digital learning. Three interdependent dimensions are especially

salient: organizational architecture (how learners enter and progress), instructional architecture (how learning unfolds across modalities and interaction routines), and structural architecture (the capacity and conditions that make implementation feasible).

These dimensions are intertwined. For example, self-paced enrollment may increase access and scheduling flexibility, but it can also reduce opportunities for peer interaction and complicate teacher support strategies—effects that must be intentionally addressed through instructional and structural supports. Likewise, synchronous instruction may increase teacher presence on the surface, but without structural and instructional supports (professional learning, interaction design, and role clarity), it can reproduce “Zoom school” patterns that do not represent well-designed online learning (Hodges et al., 2020).

An architectural lens helps the field move beyond either-or debates. The practical work becomes which combinations of structures, routines, and supports match program architectural choices to reliably help students start strong, stay engaged, learn deeply, and complete courses and how can teacher education prepare educators to enact those combinations?

## **Organizational Architecture: Structuring Flexibility Without Losing Coherence**

One foundational decision in program architecture is whether to implement continuous enrollment—allowing students to begin courses at many points throughout the year—or cohort-based models with synchronized start dates. Continuous enrollment is often justified as enhancing accessibility and flexibility, allowing students to progress according to individual circumstances. At the same time, flexible entry can create design and support challenges: teachers must manage multiple students at different points in the course, peer interaction is harder to orchestrate, and whole-group pacing cues lose their organizing function. Cohort-based models, by contrast, can support structured learning pathways and community-building, but may be less responsive to students with atypical schedules or those who need to start outside traditional terms.

From a teacher practice perspective, these models change the instructional problem. In cohort contexts, teachers can rely more on shared deadlines, whole-group discussions, and collective norms. In continuous enrollment contexts, teachers often need stronger systems for individualized progress monitoring, proactive outreach, and communication routines that do not depend on shared timing.

Pacing expectations, self-paced versus instructor-paced, are among the most consequential organizational choices. Recent K–12 analyses show that many students in flexible pacing environments proceed out of sequence, skipping assignments or submitting work out of order, and that these movement patterns are associated with declines in performance relative to peers who follow a coherent sequence (Cuccolo & DeBruler, 2024; Cuccolo & Green, 2025). These sequencing effects appear across subject areas, including STEM and world languages.

Complementary evidence from higher education points in a similar direction: “all-at-once” course releases can depress performance compared to structured release schedules, underscoring the potential value of instructor- or course-regulated pacing (Chapman Fredrick, 2024).

Organizational architecture raises a central tension: access and flexibility versus structure and coherence. Flexible pacing can expand opportunity, but it can also overtax learners’ executive functioning, particularly self-regulation (Chapman Fredrick, 2024). Developmental scholarship emphasizes that self-regulation evolves across adolescence and remains shaped by social contexts and supportive vs. undermining teacher behaviors (Opdenakker, 2022). In digital learning contexts, syntheses show small-to-moderate relationships between self-regulated learning strategies and achievement, and moderate effects for self-regulated learning interventions (Zhao et al., 2025).

Course structures should provide clear pathways, staged releases, and developmentally appropriate pacing supports rather than assuming all learners thrive with maximum autonomy. In practice, this looks like:

- Sequencing guardrails: Build clearer pathways that discourage skipping foundational tasks and signal what comes next (Cuccolo & DeBruler, 2024; Cuccolo & Green, 2025).
- Structured release options: Use staged release or milestone checkpoints (rather than “everything at once”) when learners benefit from external structure (Chapman Fredrick, 2024).
- Workload signaling and pacing guides: Provide clear expectations about time-on-task, deadlines, and recommended weekly targets to reduce ambiguity and support planning.
- Model-specific teacher preparation: Prepare teachers differently for continuous enrollment versus cohort models—e.g., individualized monitoring and nudging systems in continuous enrollment; community facilitation and whole-group pacing in cohorts.

- Developmentally calibrated autonomy: Align flexibility to learner development, recognizing that younger learners may need more externally structured pacing and interaction supports (Walter et al., 2024; Opendakker, 2022).

## **Instructional Architecture: Designing Interaction, Presence, and Learning Across Modalities**

Instructional architecture includes decisions about the balance of synchronous and asynchronous experiences and the purposes assigned to each. Pandemic-era emergency remote teaching increased global reliance on synchronous tools, but those experiences often reflected crisis conditions rather than intentional online learning design (Hodges et al., 2020). Many educators lacked training in virtual pedagogy, professional learning supports, mentoring networks, and infrastructure, conditions that contributed to uneven quality (Walter et al., 2024). When examined outside emergency conditions, the evidence does not support an advantage for either synchronous or asynchronous learning. A meta-analysis found no overall superiority of one mode over the other, with effects influenced by context and course design quality (Zeng & Luo, 2024). Virtual schooling evaluations similarly found comparable outcomes across synchronous and asynchronous formats (Roblyer et al., 2007).

Online environments can push instruction toward more teacher-centered, closed interaction patterns unless teachers intentionally design for dialogue, help-seeking, and presence. In synchronous digital environments, teachers may struggle to monitor understanding without traditional classroom cues, and students may need to initiate help-seeking in ways that feel socially risky. Research comparing synchronous online settings with face-to-face contexts suggests online instruction can trend toward more teacher-focused strategies and more closed interaction patterns unless teachers intentionally structure dialogue and collaboration (Barbour, 2015). Distance education teachers also report that synchronous and asynchronous modalities produce distinct challenges for communication, support, and instructional presence (Murphy et al., 2011).

Interaction quality is associated with achievement, course completion, perceived learning, and satisfaction (Hawkins et al., 2013). High-quality interactions are grounded in respect, support, and connectedness.

Relationship-building is possible through asynchronous channels when responsiveness and tone are strong. In asynchronous courses, instructors frequently name strategies such as responsiveness, a welcoming tone, and personalized feedback as central to effective early communication (Cuccolo & Green, 2024). Students may also prefer asynchronous methods for help-seeking because they allow time to compose responses, reducing pressure and increasing comfort (Culbreth & Martin, 2025).

Learning is strengthened when practice is distributed over time rather than massed. A robust literature emphasizes that spaced learning episodes distributed across time is one of the most effective learning strategies available (Varkey et al., 2023). In asynchronous settings, spacing often requires deliberate scaffolding such as staged formative checks, metacognitive prompts, and embedded reflection opportunities.

Feedback serves both as a learning tool and as a relational signal. Timely, constructive, personalized feedback supports metacognition and conveys care and attention, strengthening teacher presence. Because teacher time is limited, feedback cadence must be treated as an architectural feature supported by workload expectations, course design, and structural roles.

Early-week momentum and teacher presence are strong predictors of student success, especially in high-poverty contexts where delayed starts correlate with significantly lower performance. Students who access the learning management system and submit initial work within the first week tend to finish with higher grades, while delayed starts correlate with lower performance (DeBruler et al., 2023). These patterns appear stronger in higher-poverty school contexts. A multi-site randomized trial in online credit recovery similarly found that timing and implementation details moderated effects, suggesting that early supports must be targeted and actionable to change trajectories (Zweig et al., 2021).

Effective K-12 digital learning depends on practical architecture for instructional design and teacher learning that align with how students engage and persist. In practice, this looks like:

- Purposeful allocation of live vs. flexible time: Use synchronous time for activities that benefit from immediacy and social learning (e.g., discourse, misconception checks, launching complex work), and asynchronous time for structured practice, reflection, and extended tasks (Roblyer et al., 2007; Zeng & Luo, 2024).
- Interaction structures to avoid “closed” online teaching: Support teachers in using participation structures, prompts, and routines that foster dialogue rather than lectures (Barbour, 2015).

- Multi-channel help-seeking pathways: Provide low-friction asynchronous options (messaging, LMS tools) alongside optional synchronous supports to reduce barriers to asking for help (Murphy et al., 2011).
- Early-week communication protocols: Build predictable outreach and nudging routines during the first two weeks aligned with early engagement evidence (DeBruler et al., 2023).
- Spaced learning supports: Embed distributed practice and retrieval opportunities through pacing cues, formative checks, and reflection prompts (Varkey et al., 2023).
- Feedback cadence as an expectation, not a preference: Establish norms for response time and feedback specificity so presence is reliable and equitable across instructors (Rehn et al., 2018).
- Teacher education emphasis on presence: Prepare teachers to communicate care and connectedness through consistent tone, responsiveness, and personalized feedback—especially in asynchronous environments (Cuccolo & Green, 2024).

## **Structural Architecture: Capacity, Roles, Policy Alignment, and Quality Frameworks**

Structural architecture refers to the capacity and conditions that make high-quality digital instruction feasible: staffing roles, infrastructure, leadership supports, and the systems that coordinate digital learning within districts. During emergency remote teaching, schools with stronger digital infrastructure and planning often fared better than those without (Walter et al., 2024). Research from large-scale virtual schooling contexts suggests that clearly defined systemic roles and organizational structures are essential for integrating face-to-face and virtual learning effectively (Furey & Stevens, 2008). Leaders also report that digital programs' needs are often overlooked in district-level decisions about curriculum, staffing, and resource allocation (Walter et al., 2024).

Programs vary widely in course development: in-house design, district-level development, or partnerships with external vendors. Frequently, face-to-face curricula are adapted to digital environments, but the demands of digital contexts require more than conversion; they require intentional design that accounts for pathways, pacing cues, interaction supports, and accessibility (Walter et al., 2024).

Policy and accountability frameworks shape what is feasible for both practice and research. A recent brief documents how local translation of online course scores into grading scales and transcripts can compromise comparability across contexts (Green, 2025).

Frameworks, such as recent editions of the National Standards for Quality (NSQ) Online Courses and Quality Matters (QM) K–12 rubrics update expectations around course organization, learner support, accessibility, and academic integrity. At the same time, scholars note limitations in validating some standards through traditional research practices (Adelstein & Barbour, 2018). In practice, this looks like:

Schools must prepare and support teachers in ways that match the distinct demands of digital learning.

- Role clarity for progress monitoring and outreach: Define who monitors pacing, who conducts early-week nudges, and how teachers are supported by systems and staff.
- Infrastructure and staffing aligned to instructional expectations: Ensure programs do not demand high-touch presence without providing supports, tools, and staffing models that make it feasible.
- Standards-informed course review as professional learning: Use NSQ/QM indicators as shared artifacts for course design practice and coaching, while acknowledging validation limitations and building local evidence through evaluation.
- Policy routines that preserve comparability: Establish clearer local grading translation practices to reduce unintended distortions in performance reporting.
- Leadership attention to digital program needs: Bring digital learning staffing, curriculum, and support needs into district-level decision-making rather than treating them as secondary.

## **Implications for Teaching and Teacher Education: Preparing Educators to Work Inside Architecture**

An architectural lens clarifies that teacher preparation should address not only pedagogy and tools, but also how educators interpret and enact the structural and organizational conditions that shape learning. As such, we propose the following:

1. Prepare teachers to diagnose architecture. Teachers benefit from being able to identify and interpret the architecture they are working within enrollment model, pacing model, sequencing cues, communication expectations, and available supports. This diagnostic skill helps teachers anticipate common friction points such as delayed starts or out-of-sequence engagement
2. Teach scaffolded flexibility as a core competency. Teacher education can position flexibility as a scaffolded design feature rather than a value in itself. This includes developing competence in pacing supports, progress signaling, and explicit self-regulation scaffolds aligned to evidence that self-regulated learning strategies and interventions are associated with stronger outcomes.
3. Make presence routine. Evidence suggests early-week engagement patterns are predictive of outcomes and that early supports matter. Teacher education and professional learning can therefore focus on routinized practices: welcome messages, check-in cadence, response-time norms, and low-friction help-seeking pathways.
4. Train interaction design across modalities. Because synchronous teaching can default toward closed, teacher-centered interaction patterns, teachers need explicit training in discourse facilitation and student participation structures. Teacher education should also elevate asynchronous relationship-building and engagement practices—responsiveness, tone, and personalized feedback.
5. Use quality frameworks as learning tools while building the evidence base. Rubrics offer practical anchors for course design and review. Teacher education can use these frameworks to structure design practice and reflection. Acknowledging validation limitations invites programs to treat rubrics as evolving tools that should be tested and refined through local evaluation.

## Conclusion

K-12 digital learning is a durable and evolving component of public education systems. Program architecture offers a practical framework for understanding why outcomes vary and how programs can improve. Student engagement, persistence, and achievement are shaped less by modality alone and more by the coherence of organizational choices, instructional routines, and structural conditions. For teaching and teacher education, the key implication is that effective digital instruction is not only an individual skill set; it is also a system design problem. Preparing educators to teach with architectural awareness—diagnosing program structures, scaffolding flexibility, building early momentum, and sustaining presence through routines—offers a more actionable path for strengthening student learning and equity in digital environments.

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