Getting Down to FACTS

The Learning Experiences that Matter and AI's Role

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Executive Summary

This paper examines how artificial intelligence could be used to reshape the design of schooling and expand students' access to high-quality learning experiences for K-12 students in California. It begins from a simple premise: technology matters most when it expands access to the learning experiences that shape long-term outcomes. Rather than evaluating individual AI tools, the analysis begins by establishing the knowledge, skills, and dispositions that matter most for students' long-term success. It then synthesizes research on the learning experiences shown to cultivate these capacities, draws on qualitative evidence with students, educators, and caregivers to identify five persistent institutional barriers to access, and examines how AI can be deployed as institutional infrastructure to address those barriers and reshape the conditions under which learning occurs.

Decades of research show that students' long-term success in school, work, and civic life depends on a core set of capacities. When schools help students develop deep understanding, strong reasoning, effective communication, self-direction, and the ability to build relationships, they influence how students interpret information, collaborate with others, adapt to change, and continue learning across their lives.

Core Capacities Associated with Long-Term Outcomes

- Academic knowledge and skills
- Higher-order thinking skills
- Social skills
- Metacognition, self-regulation, and adaptability
- Autonomy skills
- Motivation
- Interest and curiosity
- Belonging and interpersonal connection
- Self-efficacy, mindset, and self-concept
- Management of context-specific anxiety, boredom, and frustration

A substantial body of research identifies educational experiences that reliably cultivate these capacities. Across grade levels and contexts, five learning experiences consistently emerge as foundational. When these experiences are present, academic growth strengthens alongside gains in motivation, agency, collaboration, and resilience.

Learning Experiences That Cultivate These Capacities

- Targeted direct instruction responsive to individual learning trajectories
- Real-world learning connected to authentic problems and communities
- Autonomy-supportive environments that structure meaningful choice and student agency
- Enriching discussions that deepen reasoning and perspective-taking
- Caring and supportive relationships characterized by sustained adult mentorship

Yet access to these experiences remains uneven. The constraint is rarely uncertainty about effective practice. Instead, longstanding institutional arrangements shape what is operationally feasible and how opportunities are distributed. Five sets of barriers commonly emerge.

Institutional Barriers Shaping Access

- Institutional structures that determine how time, staffing, and authority are organized
- Assessment and evaluation systems that shape what becomes visible and valued
- Professional capacity constraints that influence how instructional expertise develops
- Curricular and instructional material constraints that affect feasibility and preparation burden
- Communication and equity barriers that shape how opportunities are distributed across students and communities

This paper examines how AI could be designed to address the five persistent institutional barriers that have historically prevented expanded access to meaningful learning experiences. First, within institutional structures, AI can function as a coordination layer that integrates learning data with staffing, space, and scheduling constraints to enable more flexible grouping, targeted support, and time for interdisciplinary, community-connected learning. Second, within assessment systems, AI can support continuous analysis of student work—surfacing patterns in problem-solving, collaboration, and revision—so that academic mastery and competencies such as creativity and metacognition become visible in real time rather than only at the end of a unit. Third, to address professional capacity constraints, AI-enabled simulation and feedback tools can expand opportunities for rehearsal, reflection, and role-specific guidance across educator preparation programs and ongoing professional

learning. Fourth, in response to curricular and instructional material constraints, AI systems could align standards-based content to authentic challenges while differentiating for varied readiness levels without imposing unsustainable planning burdens. Finally, to mitigate communication and equity barriers, translation tools, participation analytics, and mentorship-matching platforms can broaden access to relational and experiential opportunities that might otherwise depend on uneven networks or information flows.

Across these domains, the most consequential applications of AI function as integrative systems. They coordinate data, logistics, and professional expertise across the school in service of clearly defined developmental goals. When aligned with research on student capacities and the learning experiences that cultivate them, these systems expand the range of school designs that are operationally feasible at scale. The transformative potential of AI lies in functioning as institutional infrastructure, integrating data, logistics, and expertise across systems that have long operated independently.

AI's Institutional Levers

- Coordinating time, grouping, and staffing
- Embedding continuous assessment
- Expanding professional rehearsal and feedback
- Connecting standards to authentic inquiry
- Broadening access through communication and matching systems

These applications exist at different stages of development. Near-term tools can be evaluated and deployed within existing infrastructure; the more consequential investment is in systems designed not merely to operate within the current institutional model, but to expand access to the learning experiences that matter most.

The implications extend beyond operational efficiency. When scheduling structures, assessment frameworks, professional learning pathways, curricular systems, and communication networks become more adaptive, students encounter schools organized around responsiveness rather than rigidity. Targeted instruction becomes more feasible. Inquiry has time to unfold. Student voice carries weight in discussion. Mentorship can be sustained rather than fragmented. As schools become more flexible, the experiences that cultivate deep understanding, agency, collaboration, and belonging become more consistently available.

Realizing this potential equitably requires deliberate policy design. Schools serving students with the greatest needs are often least positioned to implement AI-integrated models, and without intentional resource allocation, restructuring risks reproducing existing inequities at scale.

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Introduction

Artificial Intelligence is reshaping productivity across industries, accelerating workflows that once required extensive human effort and time. The education sector now faces a pressing question: How can this technology transform learning itself? AI systems can generate content across formats, provide real-time feedback, automate administrative tasks, and analyze large volumes of data relevant to instruction and school operations. However, rigorous evidence on the impact of AI-driven educational tools remains limited, leaving school and district leaders with uncertainty about which tools warrant adoption (Fesler et al., 2026).

The challenge of incorporating AI into the education sector is not simply technological, and the potential benefit is not simply increasing efficiency of current tasks. Explicitly defining schools' goals provides a basis for assessing whether and how AI tools support them. In this article, we center student competency development and examine how AI tools align with clearly defined educational goals. We propose a framework of essential competencies for K-12 students in California, competencies that encompass academic knowledge and skills, higher-order thinking, social interaction, self-management, and the emotional tools that sustain learning over time. These competencies prepare students to navigate their educational trajectories, pursue meaningful careers, adapt to emerging technologies, and lead healthy and purposeful lives. Grounding the analysis in student competency development means evaluating AI tools against what education is actually for, rather than adopting tools because they are available.

Student development emerges from an interaction between two broad dimensions: skills and knowledge, shaped by prior experiences and individual abilities, and affective states, including motivation, interest, and emotional well-being. The two dimensions influence how students engage with instruction, interpret feedback, and persist through challenge. Because cognitive and affective

processes operate together, learning experiences that strengthen both domains are more likely to produce sustained growth.

AI systems are reshaping how time is allocated, how feedback is generated, how student progress is monitored, and how decisions are made across classrooms and schools. In doing so, they redistribute cognitive labor among students, educators, and automated systems, influencing which aspects of learning become visible and measurable. Evaluating AI within a competency-based framework allows leaders and educators to examine how technological systems interact with relational dynamics, motivational processes, and higher-order thinking development. This perspective foregrounds the ways AI tools operate within institutional design and professional practice, making clear that their educational effects emerge from how they are integrated into broader learning environments.

Our competency-based portrait of a K-12 graduate draws from established frameworks. Over decades, researchers have identified strategies to foster these key student competencies. We explore the extent to which AI might facilitate the adoption of those strategies by addressing the barriers that prevent schools from implementing the most effective strategies.

The analysis proceeds in five stages. First, we define the key competencies highlighted in research and policy. Second, we conduct a structured review of experimental and quasi-experimental literature of educational approaches that help students build these competencies, focusing on randomized controlled trials and quasi-experimental studies. Third, we interview students, educators, and caregivers to identify learning experiences they perceive as transformative. Drawing on these sources, we identify learning experiences that advance multiple competencies simultaneously. Fourth, we analyze the structural and organizational constraints that limit the adoption of these experiences at scale, drawing on both the empirical research literature and on qualitative evidence from interviews with students, educators, caregivers, and school principals. We conducted a structured scoping review of the barrier literature and reported the review approach in line with current scoping-review guidance (Peters et al., 2020; Tricco et al., 2018). Finally, we examine categories of AI tools that may address identified implementation constraints. While AI holds potential for supporting instructional practice and school operations, its effects depend on how tools align with clearly defined educational objectives

and evidence-based strategies. Framing AI within a competency-based model provides a structured basis for evaluating its role in K–12 education.

This paper makes four contributions. First, it synthesizes established research to define a multidimensional competency framework for K–12 students. Second, it identifies empirically supported learning experiences that advance multiple competencies simultaneously, drawing on both experimental literature and qualitative evidence from students, educators, and caregivers. Third, it analyzes the institutional barriers constraining implementation, synthesizing empirical research and qualitative interview evidence to identify five recurring constraint categories and the mechanisms, including fidelity reduction and the systemic transmission of control, through which those barriers degrade implementation quality even when adoption occurs. Fourth, it organizes AI applications by barrier category, identifying the functional capacities AI systems would need to possess to meaningfully shift the institutional conditions that currently limit access to these learning experiences, and distinguishing between tools that exist today and capabilities that remain to be built.

A Competencies-Based Portrait for California K-12 Graduates

Abundant evidence supports that cognitive, social, and emotional competencies shape not only how students perform in school, but whether they thrive beyond it (Durlak et al., 2015; Jones et al., 2019). These competencies influence academic persistence, personal well-being, civic engagement, and professional success across the lifespan. They form the foundation for our examination of AI integration in education. This analysis begins by defining the competencies students need and then examining how technology may interact with efforts to develop them.

The Social and Emotional Learning (SEL) field provides essential grounding for this work. Over several decades, multidisciplinary researchers have developed frameworks that organize student competencies in multiple ways (Jones & Doolittle, 2017). Rather than adopting a single framework, we draw from five complementary models, each illuminating different dimensions of student development: The P21 Framework (Partnership for 21st Century Skills, 2009), the Farrington's framework of Non-Cognitive Factors (Farrington et al., 2012), CASEL Core Competencies (Collaborative for Academic, Social, and Emotional Learning, 2020), Self-Determination Theory (Ryan & Deci, 2000),

and the OECD Learning Compass 2030 (OECD, 2019). Overall, the frameworks encompass the range of competencies we identify as central to K–12 student development in California.

These frameworks align closely with California's policy context. California's Local Control and Accountability Plan (LCAP) process requires districts to set goals and report outcomes across academic, social-emotional, and engagement domains. This structure mirrors the skills-and-affects organization reflected in Table 1.

Table 1. Competencies for Thriving

Skills and Knowledge	Affects
Academic Knowledge and Skills	**Motivation**
Academic knowledge is factual and conceptual understanding in a targeted subject domain, and academic skills are learned procedures and strategies for applying subject-specific knowledge.	Engagement driven by enjoyment or interest in learning (intrinsic motivation) or by external rewards, expectations, or obligations (extrinsic motivation).
Higher-Order Thinking Skills	**Interest and Curiosity**
Abilities in problem-solving, creativity, innovation, and critical thinking. These skills are analytic, synthetic, and generative.	Desire to explore, ask questions, and resolve gaps in understanding.
Social Skills	**Belonging and Interpersonal Connection**
Collaboration, persuasion, and communication with peers or adults.	Learners' perception that they are valued, accepted, and legitimate members of the learning environment.
Metacognition, Self-Regulation, and Adaptability	**Self-Efficacy, Mindset, and Self-Concept**
Planning, monitoring, and adjusting one's own learning.	Beliefs about one's own ability to learn and grow through effort.
Autonomy Skills	**Management of Context-Specific Anxiety, Boredom, and Frustration**
The capacity to make independent choices.	Negative emotions towards the subject or tool that can hinder persistence and learning focus.

Note - We drew academic and thinking skills from the P21 Framework (Partnership for 21st Century Skills, 2009) and the OECD Learning Compass 2030 (OECD, 2019); social skills from CASEL Core Competencies (Collaborative for Academic, Social, and Emotional Learning, 2020) and the P21 Framework Partnership for 21st Century Skills, 2009); metacognition and self-regulation skills from Farrington's framework of Non-Cognitive Factors (Farrington et al., 2012) and CASEL Core Competencies (CASEL, 2020); adaptability and curiosity from the OECD Learning Compass 2030 (OECD, 2019); autonomy skills and motivation from Self-Determination Theory (Ryan & Deci, 2000); belonging, interpersonal connection, self-efficacy, and mindset from Farrington's framework of Non-Cognitive Factors (Farrington et al., 2012); and context-specific emotions management from CASEL Core Competencies (Collaborative for Academic, Social, and Emotional Learning, 2020)

California updated voluntary Kindergarten through Grade 12 Social Emotional Learning guidelines in 2020, which draw explicitly on the CASEL framework and affirm the state's commitment to developing the full range of competencies described here. California's accountability system also recognizes college, career, and civic life readiness as distinct outcome dimensions, consistent with the multidimensional portrait we develop below. While the frameworks we draw upon are national and international in origin, their synthesis reflects competency priorities that California policy has independently and repeatedly affirmed.

In constructing our synthesis, we draw academic knowledge and higher-order thinking skills primarily from the P21 Framework and the OECD Learning Compass 2030; social skills from CASEL and P21; metacognition and self-regulation from Farrington's framework and CASEL; adaptability and curiosity from the OECD Learning Compass; autonomy skills and motivation from Self-Determination Theory; belonging, interpersonal connection, self-efficacy, and mindset from Farrington's framework; and competencies related to emotional regulation (specifically, management of anxiety, boredom, and frustration) from CASEL. By integrating these perspectives, we aim to capture the interlocking skills, beliefs, and emotional capacities that shape students' ability to learn and persist.

Our synthesis yields ten competency groups spanning both skills and knowledge as well as affective dimensions that influence how students experience learning. We adopt ten competency groups to balance conceptual breadth with analytic clarity. The structure synthesizes established research frameworks to capture capacities consistently linked to long-term academic and life outcomes. The level of aggregation preserves distinctions that carry different instructional and policy implications (for example, between autonomy and self-regulation, or between motivation and belonging) while maintaining coherence across domains. This organization supports systematic alignment between competencies, evidence-based learning experiences, and potential technological supports. The ten-group structure therefore reflects a deliberate design choice intended to facilitate multidimensional analysis of student development and educational systems.

On the skills and knowledge side, we include academic knowledge and skills, defined as factual and conceptual understanding within a subject domain along with the procedures and strategies needed to apply that knowledge effectively. We also include higher-order thinking skills, encompassing

problem-solving, creativity, innovation, and critical thinking (abilities that are analytic, synthetic, and generative in nature). Social skills refer to collaboration, persuasion, and communication with peers and adults. Metacognition, self-regulation, and adaptability capture students' capacity to plan, monitor, and adjust their own learning processes. Finally, autonomy skills describe the ability to make independent, self-directed choices and to take ownership of one's learning trajectory.

Complementing these skill-based domains are affective competencies that shape engagement and persistence. Motivation includes engagement driven by enjoyment or interest (intrinsic motivation) as well as engagement shaped by external rewards, expectations, or obligations (extrinsic motivation). Interest and curiosity reflect the desire to explore, ask questions, and resolve gaps in understanding. Belonging and interpersonal connection refer to learners' perceptions that they are valued, accepted, and legitimate members of their learning communities. Self-efficacy, mindset, and self-concept encompass beliefs about one's own capacity to learn and to grow through effort. Finally, management of context-specific anxiety, boredom, and frustration captures students' ability to regulate negative emotions toward a subject, task, or learning tool that might otherwise hinder focus and persistence.

These ten competency groups provide a multidimensional portrait of what it means for students to thrive. They reflect not only mastery of academic content, but also the cognitive flexibility, relational skills, motivational orientations, and emotional resilience necessary to navigate complex educational pathways and an evolving technological landscape. In the following section, we examine learning experiences shown to promote these competencies and consider how AI tools may support—or constrain—their development.

Learning Experiences that Build Core Competencies

After defining our competencies of interest, we conducted a structured review of experimental and quasi-experimental literature to identify instructional strategies associated with their development. We searched ProQuest and Web of Science for peer-reviewed articles, in leading education and psychology journals, that used experimental, quasi-experimental, or meta-analytic methods. Table 2 summarizes the strategies identified through this process. The full inclusion criteria, journal selection

strategy, and screening procedures are detailed in the Appendix. These findings provide the empirical foundation for the learning experiences described below.

Table 2. Strategies for Developing Core Student Competencies

Competencies	Strategies
Academic Knowledge and Skills	- **Differentiated instruction and targeted direct instruction** including tutoring (Corcoran et al., 2018; Cortes et al., 2025; Dietrichson et al., 2017; Fuchs et al., 2022; Ritter et al., 2009) and other supplemental interventions for struggling learners (Cantrell et al., 2010; Coyne et al., 2022; Deunk et al., 2018; Puzio et al., 2017; Scanlon et al., 2018; Solheim et al., 2018). - High-quality curriculum (Cabell et al., 2025; Kim et al., 2021; Kim et al., 2023; Reinhold et al., 2020; Relyea et al., 2024; Slavin et al., 2009; Vaughn et al., 2017). - Professional development programs for teachers (Feng et al., 2025, 2025; Herman et al., 2022; O'Connor et al., 2014; Rubie-Davies & Rosenthal, 2016; Schonfeld et al., 2015; Scanlon et al., 2008). - High-quality instruction (Fuchs et al., 2022; Lee et al., 2022; Slavin et al., 2009), including a cooperative learning approach (Kutnick et al., 2008; Slavin & Lake, 2008) and teacher-led self-regulation strategies (Stoeger et al., 2014). - High-quality instructional materials aligned to standards (Feng et al., 2025, 2025; Montague et al., 2014; O'Connor et al., 2014), including educational technology solutions (Cheung & Slavin, 2012; Silverman et al., 2025). - Efficient classroom management practices (Herman et al., 2022; Slavin & Lake, 2008). - School-based social and emotional learning programs (Ha et al., 2025; O'Connor et al., 2014; Schonfeld et al., 2015). - **Positive teacher-student relationships characterized by high academic expectations for all students** (Rubie-Davies & Rosenthal, 2016). - Formative assessments and provision of feedback (Feng et al., 2025). - Game-based learning opportunities (Vita-Barull et al., 2024)
Higher-Order Thinking Skills: Creativity, innovation,problem-solving, and critical thinking	- High-quality instruction (Jitendra et al., 2015; Montague et al., 2014; Myers et al., 2022), including **teacher-led discussions**, **problem-solving activities** (Abrami et al., 2015), instruction focused on cognitive processes and metacognitive strategies (Montague et al., 2014), schema-based instruction and schema-broadening transfer instruction (Jitendra et al., 2015; Lein et al., 2020; Peltier & Vannest, 2017). - Promoting divergent thinking through creative pedagogies focused on exploration and experimentation (Paz-Baruch et al., 2025), physical activity (Jin et al., 2026) and humor (Ziv, 1976). - Instruction focused on problem types and the use of schematic diagrams to identify solutions (Myers et al., 2022; Peltier & Vannest, 2017). - **Integrated STEM education that connects abstract knowledge to real-world problems** (Chen et al., 2025a). - Acquiring domain specific knowledge (Miravete & Tricot, 2024) - High-quality curriculum (Chambers Cantrell et al., 2010). - Digital games including educational games, and games focused on exploration, puzzle-solving, solving complex tarks that require flexibility, simulation games of real-world scenarios, and role-playing games (Cheng & Weatherly., 2025). - Teacher coaching aimed at improving classroom management (Herman et al., 2022).

Competencies	Strategies
Social Skills: Collaboration	- Opportunities for in-classroom **peer collaboration** paired with individual work (Mundelsee & Jurkowski, 2021). - Group formation considering heterogeneous levels of past performance (Asterhan et al., 2014). - Providing feedback on the accuracy of responses provided by students while engaging in **collaborative tasks** (Asterhan et al., 2014).
Metacognition, Self-Regulation, and Adaptability	- **Teaching students metacognitive and self-regulation strategies focused on problem-solving** (Montague et al., 2014), **group discussion** (Paris & Oka, 1986), planning, monitoring, and self-assessment (Fyfe et al., 2022; Leopold & Leutner, 2015; Li et al., 2024; Maximino-Pinheiro et al.; 2026; Paris & Oka, 1986; Wirth et al., 2025; Zohar & Ben David, 2008). - **Integrating reflection questions to promote metacognition to in-classroom individual activities** (Fyfe et al., 2012) **and group discussions** (Zohar & Ben David, 2008), as well as in at-home learning activities with the support of caregivers (McElvany & Artelt, 2009) . - **Collaborative problem-solving activities with shared goals and resource interdependence features** (Rudmann et al., 2024). - In-classroom activities to promote positive emotions, such as writing gratitude journals, performing acts of kindness, and learning how to leverage optimistic thinking and goal-directed hope to maintain motivation (Chen et al., 2025b).
Autonomy Skills	- **Autonomy-supportive instruction.** This type of instruction involves **taking students' perspectives, offering activities that allow students to exercise autonomy and pursue their intrinsic goals, and fostering supportive, understanding teacher-student relationship**s (Cheon et al., 2019a; Jang & Reeve, 2021; Reeve & Cheon, 2021). - Offering students flexible learning materials allowing them to make the choices that better fit their needs and preferences (Rappolt-Schlichtmann et al., 2013; Schneider et al., 2018; Schneider et al., 2022). - Combining structure-supportive strategies (e.g. setting objectives, defining guiding procedures, and offering feedback) with autonomy-supportive digital environments (Cui et al., 2022)
Motivation and engagement	- **Supporting student autonomy** (Guthrie et al., 2000; Radel et al., 2014; Ruzek et al., 2016). - Opportunities to pursue **mastery-based goals and intrinsic goals in autonomy-supported contexts** (Benita et al., 2014; Vansteenkiste & Lens, 2006). - **High-quality instruction that connects skills and concepts to real-world problems, while offering opportunities for collaboration** (Guthrie et al., 2000). - **Targeted direct instruction including personalized feedback and personalized task difficulty level** (Oppmann et al., 2025). - **Emotionally supportive teacher-student relationships** (Ruzek et al., 2016). - Game-based learning environments (Syal & Netfeld, 2024) - Leveraging instructional materials with problems framed with primary knowledge contexts, which involve topics that require a low cognitive load (Lespiau & Tricot, 2019).
Interest and Curiosity	- **Problem-based learning,** allowing students to reflect on the problem and generate solutions before receiving core information to understand it (Glogger-Frey et al., 2015; Schmidt & Rotgans, 2021), and to face counter-intuitive problems (Schmidt & Rotgans, 2021). - **Tailoring learning context to students' interests** (Bernacki & Walkington, 2018; Lin et al., 2024; Walkington, 2013). - **Real-world learning experiences through immersive activities** (Makransky et al., 2021; Makransky & Mayer, 2022).

Competencies	Strategies
	- Game-based learning environments (Hong et al., 2025; Syal & Nietfeld, 2024). - **Reflection activities focused on the personal and communal utility value of the learning content** (Shin et al., 2019). Formative assessment and process-oriented feedback (Rakoczy et al., 2019). - **High-quality instruction that connects skills and concepts to real-world problems, while providing supporting student autonomy and offering opportunities for collaboration** (Guthrie et al., 2000). - Providing access to high-quality learning materials that promote inquiry experiences by intentionally presenting triggering problems before offering explanations and solutions (Schmidt & Rotgans, 2021)
Belonging and Interpersonal Connection	- **Psychological intervention to address students' thoughts and feelings** (Chrobak, 2024), including group-based interventions aimed at fostering meaningful group memberships and social identities (Cruwys et al., 2021). - **In-classroom interventions to promote prosocial skills through** instructional strategies such as setting **inclusive goals and encouraging cooperation between diverse peer groups** (Miller et al., 2025), role playing, **problem solving**, reinforcement, and modeling (DiPerna et al., 2015, 2018). - **Cooperative activities in small groups characterized by group-level recognition instead of recognition of individual performance** (Slavin, 1978). - **Supportive teachers and peers, and an inclusive school climate** (Master et al., 2026). - After-school program, hands-on activities, summer programs, and access to elective courses promote a sense of belonging in STEM education (Master et al., 2026). - Engaging in school activities with peers who share similar identities (Master et al., 2026). - Using non-stereotypical elements in terms of gender in the physical classroom environment (Master et al., 2016).
Self-Efficacy, Mindset, and Self-Concept	- Formative assessments (Rakoczy et al., 2019), and use of scoring rubrics (Camargo Salamanca et al., 2024; Panadero et al., 2012). - Peer modeling, observation of peers working on a challenging task (Schunk et al., 1987; Schunk & Hanson, 1989a; Schunk & Hanson, 1989b). - **Parental interventions to address stereotypes, brain plasticity (growth mindset), and expectations on the student's potentia**l (Lee et al., 2022, 2025). - **Provision of process-oriented feedback** (Graham et al., 2025; Rakoczy et al., 2019). - **Access to technology-assisted science-oriented experiences such as real-world learning simulations** (Cai et al., 2021; Makransky et al., 2021). - Goal setting and strategy instruction, such as strategies for planning, drafting, revising, and editing a text (Brunstein & Glaser, 2011; Graham et al., 2025). - **Opportunities to engage in cooperative learning experiences** (Hanze & Berger, 2007). - Embedding self-regulation strategies and growth mindset notions into subject-specific lessons (Bui et al., 2023). - Providing students with scientific information about brain plasticity paired with reflection opportunities to encourage a growth mindset (Xu et al., 2021).
Managing Context-Specific Anxiety and Boredom	- School-based interventions, including principles of Cognitive Behavioral Therapy (CBT), emotional regulation skills, behavioral activation, problem solving, and relaxation strategies (Chen et al., 2022; Chiu et al., 2013; Doz et al., 2025; Fernández-Martínez et al., 2020; Huang et al., 2025). - Parental interventions to address stereotypes, brain plasticity (growth mindset), and expectations on the student's potential (Lee et al., 2022, 2025).

Competencies	Strategies
	- **Integration of social and emotional learning (SEL) strategies (e.g. caring and supportive teacher language, procedures to collaborate with families, and procedures for resolving conflict in peaceful ways) into daily routines** (Griggs et al., 2013). - Integration of classroom-based interventions (e.g. reinforcement and rewards systems, collaborative rule setting, and strategic team formation considering previous child behavior) to promote prosocial behavior and reduce disruptive behavior (Vuijk et al., 2007). - Offering mental health content embedded in the school curriculum (Klim-Conforti et al., 2021). - **Professional development opportunities for teachers focused on autonomy-supportive instruction** (Cheon et al., 2019). - Game-based interventions offering adaptive feedback (Demedts et al., 2024).

Note– We highlighted the strategies related to the focal learning experiences we selected for in-depth analysis in this article. The keywords "communication" and "persuasion" (corresponding to competencies that were initially included in the Social Skills category) as well as the keyword "frustration", did not yield articles that met our selection criteria.

Effect sizes in these interventions vary substantially by student subgroup, implementation fidelity, and dosage. Meta-analyses in tutoring, social-emotional learning, and formative assessment consistently show that impacts are larger when implementation is sustained, intensive, and well-supported. As with most educational interventions, average effects mask meaningful variation across contexts and populations.

The strength of the causal evidence base varies across competency domains and instructional models. Tutoring, formative assessment, and certain social-emotional interventions are supported by multiple randomized controlled trials and meta-analyses. Evidence for whole-school project-based models, autonomy-supportive institutional reforms, and relational school designs is more context-specific and often based on smaller-scale or correlational studies.

To complement the literature review, we conducted ninety-minute focus groups with three Getting Down to Facts (GDTF) Community Advisory Groups of eight members each: students, educators, and caregivers. Participants described learning experiences they perceived as transformative, the barriers they encountered when attempting to implement such experiences, and their perspectives on the potential role of AI in schools. This qualitative input allowed us to connect research findings with lived experience and implementation realities.

Drawing on both the empirical literature and stakeholder input, we chose five focal learning experiences that contribute to the development of multiple competencies: (1) targeted direct

instruction, (2) real-world learning, (3) autonomy-supportive learning, (4) enriching discussions for developing critical thinking, and (5) caring and supportive relationships at school. These five experiences structure the analysis that follows.

Each experience is linked to specific competencies in our framework, supported by rigorous research, and illustrated through examples of schools that have embedded these practices into their instructional models. Our goal is not to present isolated programs, but to examine the structural features of learning environments that enable sustained competency development.

Targeted direct instruction

Targeted direct instruction responds to a reality of schooling: students enter classrooms with varied prior knowledge, learning trajectories, and rates of progress. Effective personalization allows students to advance at an appropriate pace, receive targeted scaffolding and feedback, address misconceptions, and, when ready, engage in more advanced material.

Grounded in Vygotskian principles, this approach enables teachers to identify each student's zone of proximal development and facilitate productive struggle—the point at which tasks are challenging but attainable (Stipek, 2002). Evidence suggests that personalization is particularly effective when delivered through relationship-based tutoring models, where sustained human connection fosters trust, motivation, and persistence (Nickow et al., 2024). Beyond improving content mastery (Fuchs et al., 2022), personalized learning has been shown to enhance student motivation (Oppmann et al., 2025). Supportive relationships embedded in tutoring also promote resilience, providing an emotional foundation for sustained effort (Werner, 1997).

Despite its promise, personalizing learning through targeted direct instruction remains difficult to implement at scale. As an educator and Community Advisory Group (CAG) member reflects: "I think a lot about how students have different timelines of learning things, and it's so easy to fall behind, and then (..) it just starts a domino effect of not meeting requirements. I wish there was a way to be more accommodating to each and every student in that way." U.S. schools are implementing targeted direct instruction in diverse ways to address this need. A technology-heavy example is Rocketship Public

Schools (RPS), a Charter Management Organization operating elementary schools in California, Tennessee, Washington DC, and Wisconsin, is a champion of personalized learning through blended approaches (Rocketship Public Schools, 2023). Their current model, one of RPS's foundational pillars, combines multiple instructional methods within the school day: students receive whole-group instruction, participate in small-group tutoring, engage in independent learning, and work with adaptive online learning programs (Rocketship Public Schools, 2025). Available evaluations suggest that RPS students perform at levels comparable to or above nearby district schools, with narrower performance gaps across student groups (Raymond et al., 2023).

A number of school models including Acton Academy schools, the Khan Lab School, and even Montessori high school models spend focused daily time (often in the morning) mastering core academic content in a mastery-based model, while the remainder of the day is devoted to collaborative projects and skill-building activities aligned with individualized plans. A unifier of these models is educators focusing on motivation, mentorship, and broader competency development. Technology plays a variable role in supporting instruction, pacing, and content adaptation depending on the model.

Targeted direct instruction primarily strengthens academic knowledge and skills and motivation, but when implemented relationally, it can also contribute to belonging and interpersonal connection.

Real-World Learning: Connecting Classroom to Community

Real-world learning (RWL) situates academic content within authentic, open-ended challenges. Rather than confronting well-structured problems with predetermined solutions, students engage in complex tasks that require judgment, creativity, and interdisciplinary thinking. Examples include project-based learning (PBL), apprenticeships, and service learning.

Connecting abstract knowledge to real-world problems fosters higher-order thinking skills (Chen et al., 2025a; Houseal et al., 2014), curiosity (Glogger-Frey et al., 2015; Schmidt & Rotgans, 2021), and motivation (Guthrie et al., 2000). Also, real-world experiences can be tailored as individual projects, allowing students to strengthen their autonomy skills (Cheon et al., 2019a; Jang & Reeve, 2021), and as

group hands-on projects that may strengthen students' social skills and sense of belonging (Master et al., 2026).

Project-based learning exemplifies this approach. Projects are open-ended, requiring students to conduct inquiry, learn content and strategies, extend their existing knowledge, and revise their thinking (Hmelo-Silver et al., 2007; Wirkala & Kuhn, 2011). These projects can cover a wide range of topics to connect with students' interests. For example, Principal Stephanie Strader, who has led K–5 schools with a multi-age, problem-based learning approach for over a decade, referenced an elementary school level PBL project that students in a school in Washington carried out, focused on studying in depth erosion and weather patterns, motivated by a town that ended up at the bottom of a lake in their home state. This project lifted up a community issue, making it relevant for the students.

The PBL approach has the potential of improving the quality of teacher-student relationships, by acknowledging students' potential and interests. Principal Stephanie Strader expressed: "the second we start saying, well, they're a first grader, this is what first graders should be doing, we've limited what our students are capable of doing. And we've restricted ourselves from being able to see them as, like, a whole being and a whole person(...). The other model (PBL) really allows you to see them as humans and people and learners, and there's an inevitable, like, amount of trust and respect and relationship fostering that comes from that."

High Tech High (HTH), a network of California charter schools, has institutionalized PBL through a comprehensive design framework developed by its Graduate School of Education (Scherer, 2022). Core elements include iterative drafting, informed critique, integration of academic standards, public exhibition of work, and structured reflection (Scherer, 2022). Although causal evidence isolating PBL at HTH is limited, attendance has been associated with increased four-year college enrollment (Beauregard, 2015), suggesting long-term academic and aspirational benefits. These findings are correlational and do not isolate the independent causal effect of project-based learning.

Apprenticeship and internship models offer another pathway. Big Picture Learning (BPL), a network spanning 27 states, integrating internships and community-based learning into students' educational experiences, has the ImBlaze platform which connects students to real-world opportunities

aligned with their interests (Big Picture Learning, 2026; ImBlaze, 2026). Such models extend learning beyond classroom walls, strengthening autonomy, expanding social networks, and fostering purpose.

Real-world learning simultaneously advances higher-order thinking, autonomy, social skills, curiosity, and motivation.

Autonomy-Supportive Learning

Traditional schooling frequently positions students as passive recipients of instruction—following prescribed curricula, completing assigned tasks, and exercising limited influence over what they learn, how they learn it, or why it matters. Autonomy-supportive learning shifts this dynamic by treating students as active agents in their own development. Grounded in Self-Determination Theory (Ryan & Deci, 2000), this approach emphasizes the importance of satisfying students' basic psychological need for autonomy while maintaining appropriate structure and expectations. Autonomy-supportive teaching does not imply the absence of guidance; rather, it involves acknowledging students' perspectives and feelings, providing meaningful rationales for learning tasks, offering bounded choices, and minimizing controlling language or practices (Deci & Ryan, 1985; Reeve & Cheon, 2021). Within such environments, teachers act not as directors of compliance but as guides who scaffold agency.

Research demonstrates that autonomy-supportive instruction strengthens students' autonomy skills directly (Cheon et al., 2019a; Jang & Reeve, 2021). Beyond this direct effect, it also promotes intrinsic motivation and mastery-oriented engagement (Benita et al., 2014; Vansteenkiste & Lens, 2006), enhances curiosity (Guthrie et al., 2000), and supports students' capacity to manage frustration and negative affect (Cheon et al., 2019a). High-quality instruction that integrates autonomy support alongside meaningful conceptual exploration and collaborative opportunities further reinforces motivation (Guthrie et al., 2000). Together, these findings suggest that autonomy-supportive environments contribute not only to autonomy skills, but also to motivation, curiosity, and emotional regulation—multiple competencies within our framework. By honoring students' agency within structured learning contexts, such instruction creates conditions for deeper, more sustainable engagement.

Focus group participants described autonomy-supportive experiences as moments when students were trusted with meaningful responsibility. One educator and CAG member recounted a middle school "24-hour production" project during students' transition from eighth to ninth grade. Students selected a film, book, or other source of inspiration and were tasked with producing a creative interpretation in a format of their choosing. They directed, assigned roles, and managed implementation, while adult mentors intentionally stepped back. As the educator described: "The young people had an opportunity to select a movie, a book, something that inspired them, and they were to produce that in whatever way they wanted to define (). They were the ones directing, creating, implementing, assigning roles, so really, they were taking ownership. There were mentors there, adult mentors. And their role was to take a step back (...). Young people have the tools, we just gotta give them the space." This example illustrates the balance central to autonomy-supportive learning: students exercise ownership and creativity within a structured environment where adults provide guidance without control.

Schools across the United States have embedded autonomy-supportive structures in systematic ways. Summit Public Schools' "Expeditions" program allows students in grades six through twelve to dedicate eight weeks to internships, independent study, community-based projects, or advanced coursework aligned with their interests and goals (Education First et al., 2022). Big Picture Learning (BPL) similarly integrates extended inquiry projects throughout the K–12 experience, including autobiographical research connecting personal history to broader social contexts and culminating in senior theses addressing community challenges (Bradley & Hernandez, 2019). These models demonstrate that autonomy-supportive learning can be institutionalized through scheduling, curricular design, and mentorship structures rather than left to individual teacher discretion.

Autonomy-supportive learning thus operates across cognitive, motivational, and emotional domains. By positioning students as capable decision-makers, it strengthens autonomy skills directly while also enhancing motivation, curiosity, and resilience in the face of challenge. Within our broader framework, it represents a core learning experience through which multiple competencies develop simultaneously.

Enriching Discussions to Develop Critical Thinking and Social Skills

Structured dialogue transforms classrooms from sites of passive information transmission into spaces of collaborative knowledge construction. Drawing on sociocultural theory, learning emerges through interaction; students refine their thinking through engagement with others (Vygotsky, 1978). When students participate in substantive discussion, they externalize their reasoning, encounter competing interpretations, and revise their understanding by grappling with differences in perspective (Michaels et al., 2008). This process simultaneously cultivates multiple competencies within our framework.

Empirical evidence suggests that well-designed peer discussions strengthen social skills, particularly collaboration and communication (Mundelsee & Jurkowski, 2021). When discussion activities incorporate structured reflection, they also promote metacognition, increasing students' awareness of their own thinking processes and biases (Fyfe et al., 2012). Inquiry-oriented dialogue can stimulate interest and curiosity (Rappolt-Schlichtmann et al., 2013), while prosocial skill development, such as practicing empathy and perspective-taking, contributes to students' sense of belonging and interpersonal connection (DiPerna et al., 2015, 2018). In this way, enriching discussions foster higher-order thinking alongside relational and motivational growth.

Discussion-based practices can take many forms. One educator and CAG member described a classroom activity in which students constructed collective timelines of historical events and then critically examined omissions, interpretations, and underlying narratives. As the educator explained, the goal was to prompt students to question what they had been taught and to recognize the multiplicity of historical perspectives. Such activities require students not only to articulate their own interpretations, but also to listen actively, challenge assumptions, and refine their reasoning in dialogue with peers. These moments of shared inquiry exemplify how structured discussion can cultivate critical analysis and intellectual humility.

Facing History & Ourselves provides a sustained model of discussion-based pedagogy designed to strengthen these competencies. The organization supports middle and secondary teachers in facilitating critical examination of moral and civic questions embedded in historical events, with the

stated aim of fostering “a more humane and informed citizenry” and strengthening democratic engagement (Facing History & Ourselves, 2026b). Its instructional approach centers on reflective analysis and structured peer dialogue, requiring students to articulate perspectives while actively listening to others (Facing History & Ourselves, 2026a). With fifty years of experience and with experience across multiple countries (Facing History & Ourselves, 2012), the program demonstrates how deliberative dialogue can be embedded systematically in school design. Experimental evidence indicates positive effects on students’ analytic skills, tolerance for differing viewpoints, and sense of personal accomplishment (Barr et al., 2015), reinforcing the potential of discussion-based learning to advance both cognitive and relational competencies.

These findings suggest that enriching classroom dialogue is not merely a pedagogical technique but a structural mechanism for cultivating higher-order thinking, communication, metacognitive awareness, and belonging, capacities central to thriving in complex and pluralistic societies.

Caring and Supportive Relationships

Caring relationships at school are not incidental to academic achievement but foundational to it. They create the conditions under which other learning experiences (personalization, autonomy support, real-world inquiry, and rich discussion) can take root. The ethics of care framework positions relational connection as central to students' multidimensional growth (Noddings, 1984, 1988, 2012). Caring and supportive relationships require open dialogue and intentional space for teachers and students to genuinely know one another and develop trust (Noddings, 1988, 2012). This relational knowledge allows teachers to set high expectations while affirming students' identities and agency, transforming the traditional instructional dynamic so that "teacher and student become partners in fostering the student’s growth" (Noddings, 1988, p. 224). In such environments, students not only receive care but are encouraged to extend care to others (through supportive peer interactions and community engagement) thereby contributing to collective well-being through lived experience (Noddings, 1988).

Within our competency framework, caring relationships operate across multiple domains. Strong teacher-student relationships contribute directly to the development of academic skills and

knowledge, particularly in tutoring contexts (Fuchs et al., 2022). They promote student motivation (Ruzek et al., 2016) and strengthen belonging and interpersonal connection (Master et al., 2026). They also serve as a foundation for autonomy-supportive instruction, enabling teachers to provide choice and voice within a context of trust (Cheon et al., 2019a; Jang & Reeve, 2021). In this sense, relational support is not a peripheral enhancement to instruction but a structural mechanism through which cognitive, motivational, and emotional competencies develop.

Some schools have embedded relational commitments directly into organizational design. Summit Public Schools institutionalizes caring relationships through a mentorship structure that ensures each student receives sustained, individualized support. Every student is paired with a teacher-mentor who conducts regular one-on-one meetings focused on goal-setting, reflection, and progress. Crucially, mentors remain consistent over four years, allowing relationships to deepen over time (Summit Public Schools, 2025). Mentors also serve as primary points of contact for caregivers, creating continuity in home-school communication and positioning the mentor as someone who understands the student across academic and personal contexts. By allocating time, defining mentorship as a formal role, and ensuring continuity, Summit demonstrates that caring relationships can be systematically embedded in school structures rather than left to individual disposition.

At the same time, participants in our focus groups emphasized the limits of relying solely on teacher relationships to meet students' broader emotional and psychological needs. One educator and CAG member reflected:

"I wish that each school in each district (had) mental health (...) professionals, like, school psychologists, for example, to each school, and not just each district, because I know with the district I grew up in, it was just one school psychologist for multiple schools, and that's… just not… not equitable and sustainable either. And because of that, a lot of the emotional, mental labor falls on the counselors at these high schools, and they're not necessarily equipped or taught to deal with… with the emotional, mental side part of a student's life. They're mainly (…) catered to (...) their academic needs. But because of just the way the system is built up, there are counselors there that have taught themselves to do that work".

This observation highlights an ongoing structural constraint in education systems: insufficient access to mental health professionals leaves students' needs unmet and shifts emotional labor onto educators who may lack specialized training. While caring teacher-student relationships are essential, they cannot fully substitute for professional mental health support. Sustainable relational infrastructures therefore require both strong mentorship structures and adequate access to trained specialists.

Caring and supportive relationships thus function as the connective tissue of student development. They strengthen academic learning, deepen motivation, reinforce belonging, and enable autonomy-supportive practice. At the same time, their effectiveness depends on institutional design and adequate professional capacity. Without deliberate structural support, relational care risks becoming an informal expectation rather than a reliable feature of schooling.

Table 3: Competencies with Linked Learning Experiences

Competency Group	Linked Learning Experiences
Academic Knowledge	(1) Targeted Direct Instruction, (5) Caring Relationships
Higher-Order Thinking	(2) Real-World Learning, (4) Enriching Discussions
Social Skills	(2) Real-World Learning, (4) Enriching Discussions
Metacognition/Regulation	(1) Targeted Direct Instruction, (4) Enriching Discussions
Autonomy Skills	(2) Real-World Learning, (3) Autonomy-Supportive Learning, (5) Caring Relationships
Motivation	(1) Targeted Direct Instruction, (2) Real-World Learning, (3) Autonomy-Supportive Learning, (5) Caring Relationships
Interest/Curiosity	(2) Real-World Learning, (3) Autonomy-Supportive Learning, (4) Enriching Discussions
Belonging/Relatedness	(2) Real-World Learning, (4) Enriching Discussions, (5) Caring Relationships
Self-Efficacy/Mindset	(1) Targeted Direct Instruction, (2) Real-World Learning, (5) Caring Relationships
Emotional Management	(3) Autonomy-Supportive Learning

In Summary

The five focal learning experiences examined here operate as structural features of effective learning environments: (1) targeted direct instruction, (2) real-world learning, (3) autonomy-supportive learning, (4) enriching discussions, and (5) caring and supportive relationships. As illustrated in Table 3, each experience is linked to multiple competency groups, and most competencies are supported by more than one experience. This pattern underscores that student development is multidimensional: competencies emerge through overlapping instructional conditions rather than isolated strategies. Across contexts, these experiences require sustained adult capacity, flexibility in scheduling and pacing, thoughtful assessment systems, and relational infrastructure. They move classrooms beyond transmission-oriented instruction toward environments that are personalized, dialogic, and developmentally responsive.

Despite strong empirical support, these learning experiences remain unevenly implemented across schools and districts. Their adoption depends not only on instructional knowledge, but on institutional conditions: time, staffing structures, assessment systems, professional capacity, and relational infrastructure. These constraints shape what educators are realistically able to enact, even when they recognize the value of student-centered approaches.If AI is understood as part of the technological infrastructure of schooling, then its relevance lies in how it interacts with these structural conditions. The central question becomes whether emerging technologies can reduce implementation barriers without undermining the relational and developmental qualities that make these learning experiences effective. Examining the barriers that limit large-scale adoption therefore provides the necessary foundation for evaluating AI's potential role.

Barriers Preventing the Implementation of Student-Centered Learning Experiences at Scale

Although experimental and quasi-experimental studies and practitioner endorsement support the five focal learning experiences examined above, institutional conditions shape whether these practices can be implemented with fidelity at scale. The barrier analysis in this section draws on two complementary sources of evidence: empirical literature on K-12 implementation, assessment,

professional learning, curriculum, and equity, and qualitative evidence gathered through interviews with our CAG, as well as with three school principals serving K-12 schools in the U.S. These sources converge on recurring constraints rooted in scheduling norms, accountability systems, staffing structures, funding patterns, and policy requirements. Because these barriers operate simultaneously at classroom, school, district, and policy levels, they shape what is feasible even when educators value student-centered approaches. Many implementation barriers are documented in systematic reviews, qualitative metasyntheses, mixed-method implementation studies, and workforce or policy reports rather than in intervention trials alone, and, as a result, we did not restrict this barrier review to experimental designs.

While barriers manifest differently across personalized instruction, real-world learning, autonomy-supportive learning, enriching discussions, and caring relationships, they consistently cluster into five interrelated categories: institutional structures, assessment and evaluation systems, professional capacity constraints, curricular and instructional material constraints, and communication and equity barriers. The sections below examine how these categories constrain the implementation of each learning experience.

Institutional Structures

Institutional structures constrain the implementation of student-centered learning experiences across multiple domains. They include, as examples, fixed schedules, age-graded classrooms, standardized pacing guides, and rigid grading policies. These design features, often established to promote administrative efficiency and consistency, create systematic barriers to flexibility, continuity, and responsiveness in teaching and learning. Research on competency-based implementation helps clarify this mechanism. In five Michigan pilot districts, flexible pacing remained difficult across sites, and districts that made more progress relied on schoolwide interventions and the ability to share students across classrooms rather than teacher initiative alone (Sutherland et al., 2023).

Time allocation and scheduling rigidity and age-graded classrooms limit educators' ability to adapt instruction to students' varying needs and learning trajectories. Fixed instructional schedules and standardized pacing guides by age and grade level prevent teachers from reorganizing time around

students' different rates of progress in personalized instruction. As Principal Stephanie Strader reflected: "Just because you're a second grader doesn't mean that that's where you are. You might be at some first grade standards, you might be at some fifth grade standards. (…) Students are gonna meet and reach different milestones on their own timelines."

Scheduling based on subject-based departmentalization works against the interdisciplinary, extended-time formats that real-world learning, autonomy-supportive projects, and sustained, exploratory dialogue require. School schedules may also deprioritize the dedicated mentorship spaces needed for caring relationships, forcing relationship-building to compete with academic content coverage within tightly constrained school days. The consequences of these structural choices show up in students' experience of the classroom itself.

Beyond scheduling constraints, the structural design of schools during adolescence is particularly mismatched with students' developmental autonomy needs. Longitudinal evidence from 34 high school classrooms found that the average classroom scored only at the midpoint of a perceived-autonomy scale, indicating that most students do not experience their classrooms as autonomy-promoting (Hafen et al., 2012). Students who did perceive meaningful autonomy in the first weeks of a course showed increasing engagement across the year rather than the typical decline—but these students were the exception, not the rule. Research has further observed that recent educational reforms have produced "curriculum and classroom structures that restrict rather than promote autonomy, only serving to further the disengagement that plagues secondary education" (Hafen et al., 2012, p. 254).

Rigid grading policies requiring common assignments and uniform deliverables also create a fundamental tension with personalized, project-based, and autonomy-supportive learning. When grading mandates synchronized timelines, it creates direct friction for individualized instruction, where students would advance based on demonstrated understanding rather than calendar dates. Research on mastery learning, a form of individualized pacing, finds that despite positive effects on achievement, teachers face substantial time demands in developing the formative tests and corrective activities required for implementation, making team-based planning support a near prerequisite for sustainability (Smale-Jacobse et al., 2019).

Assessment and Evaluation Systems

Assessment and evaluation systems, including standardized testing requirements, traditional grading structures, and externally defined benchmarks, create significant barriers to student-centered learning experiences such as personalized, project-based, and autonomy-supportive learning. Assessment systems designed to ensure accountability and comparability often inadequately capture the full range of learning outcomes valued in student-centered approaches and create institutional pressure toward uniformity even when differentiation would better serve students.

These pressures are consistent with broader accountability research. A qualitative metasynthesis of 49 studies found that high-stakes testing commonly narrows curriculum, fragments knowledge, and shifts pedagogy toward more teacher-centered instruction (Au, 2007). At the same time, performance-assessment accountability models such as New Hampshire's Performance Assessment of Competency Education (PACE) show that alternatives require substantial infrastructure for local performance assessment, moderation, and comparability rather than simply replacing standardized tests with projects (Marion & Leather, 2015).

Standardized grading structures and externally defined benchmarks create institutional pressure to align assignments and timelines across students even when their learning needs differ. The formative value of assessment depends on the speed of response. As Assistant Principal Braxton Thornley observed, a teacher who understands what students need but cannot act on that understanding for two weeks has lost the intervention window.

Standards alignment with project outputs involves resource-intensive mapping processes, making the adoption of real-world learning and autonomy-supportive projects difficult. Clarity on the prerequisites students need to master prior to engaging in a project requires formative assessments and mapping of prerequisites, standards, and outputs. Grading also becomes increasingly time-consuming for teachers when assignments allow students to pursue individual projects. In addition, accountability frameworks and assessment systems, such as the California Assessment of Student Performance and Progress (CAASPP) and the English Language Proficiency Assessments for California (ELPAC), often omit competencies developed through experiences such as real-world

learning, discouraging educators from incorporating these experiences into school activities. Relational labor is also rarely formally recognized, which can reduce institutional incentives to protect time for mentoring and advisory practices. If evaluation and assessment systems are focused primarily on academic outputs, relational work may be treated as supplementary rather than central.

Assessment pressure compounds the problem in a specific way: teachers implementing PBL under standardized accountability systems report compressing project timelines and reducing open-ended inquiry in order to cover testable content (Saavedra & Rapaport, 2024). The result is what researchers describe as "attenuated PBL," a version that preserves surface features such as student-produced products while eliminating the depth of inquiry and interdisciplinary integration that generate the documented learning gains. Accountability pressure therefore goes beyond preventing PBL adoption; it actively degrades PBL quality among teachers who are attempting to implement it. A further asymmetry compounds the problem: PBL's evidence base is notably stronger in science and social studies than in math and literacy (Condliffe et al., 2017), yet math and literacy face the most intense standardized-test pressure, meaning the subjects where PBL evidence is weakest are precisely those most constrained by accountability.

Assessment systems face challenges in tracking individual contributions in collaborative work and in leveraging multimodal data for evaluating learning progress, presenting a barrier for the implementation of experiences such as enriching discussions and real-world learning projects. The learning that occurs through sustained dialogue, including refined reasoning, perspective-taking, intellectual humility, and collaborative meaning-making, is difficult to assess within grading systems designed for individual written products. In addition, the absence of capacity for assessing individual contributions can also lead to unequal student participation.

Limited access to accurate formative assessments further constrains teachers' ability to respond to student needs in targeted instruction. The barrier operates as a structural feedback loop: individualized instruction requires granular, real-time knowledge of each student's learning trajectory, yet the very institutional conditions that prevent differentiation, including large class sizes, fixed schedules, and standardized pacing requirements, simultaneously prevent teachers from generating that diagnostic information (Smale-Jacobse et al., 2019; Deunk et al., 2018). Without reliable data on

where students are, teachers face a choice between undifferentiated instruction and time-consuming informal assessment that competes with content delivery. The feedback-loop structure is one reason that even motivated, well-trained teachers find individualization operationally difficult to sustain.

Accountability systems—which create incentives and compliance requirements informed by assessment data that shape relationships among school actors— affect autonomy-supportive learning through an additional mechanism not captured in the categories above: the systemic transmission of control. Research on teacher motivation finds that when teachers operate in institutionally controlling environments, characterized by top-down curriculum mandates, accountability pressure, and scripted lesson requirements, they are more likely to adopt a controlling motivating style with their own students, regardless of their beliefs about the value of student agency (Reeve, 2009). Reeve identifies seven institutional pressures that push teachers toward controlling instruction, including time pressure, student resistance, and accountability requirements. The transmission mechanism means that the problem of insufficient autonomy support cannot be solved solely through teacher professional development; the institutional conditions in which teachers work actively undermine their capacity to provide students with the structured choice, meaningful rationales, and noncontrolling language that autonomy-supportive learning requires.

Professional Capacity Constraints

Professional capacity constraints create significant barriers to student-centered learning implementation, which requires skills rarely emphasized in traditional teacher training. Examples of these constraints include gaps in teacher preparation, insufficient staffing levels, limited access to specialized personnel, and time limitations. Professional capacity constraints are among the strongest empirically supported barriers in this section. A meta-analysis of 60 causal studies found that teacher coaching improved instruction by 0.49 standard deviations and student achievement by 0.18 standard deviations, suggesting that complex student-centered pedagogies are more likely to scale when teachers receive sustained, job-embedded coaching rather than one-off workshops (Kraft et al., 2018). Capacity constraints are also staffing constraints. The national student-to-school-counselor ratio remains 372:1, well above the ASCA-recommended 250:1 ratio (American School Counselor

Association, 2025), and the national student-to-school-psychologist ratio was 1,065:1 in 2023–2024, well above NASP's recommended 500:1 ratio (Affrunti, 2025).

Teacher training and professional development programs inadequately develop the skills required for student-centered instruction, leaving teachers to default to more familiar, transmission-based approaches. Facilitating a genuinely enriching discussion requires teachers to tolerate ambiguity, follow student thinking rather than directing it toward predetermined conclusions, manage unequal participation without suppressing authentic contributions, and maintain intellectual rigor while keeping the conversation genuinely open. Similarly, autonomy-supportive learning requires specific skills: taking students' perspectives, providing meaningful rationales for tasks, offering bounded choices, and using non-controlling instructional language. Real-world learning requires further competencies: identifying meaningful problems, structuring productive ambiguity, engaging in time-consuming planning, coordinating with community partners, and assessing heterogeneous outputs. These skills are rarely developed systematically in teacher preparation programs.

The pedagogical complexity of structured autonomy compounds the training gap. Autonomy-supportive teaching requires meaningful choice within a scaffolded framework that simultaneously builds students' competence to exercise that choice productively (Niemiec & Ryan, 2009; Jang et al., 2010). Teachers often err in one of two directions: they over-structure, reducing choice to compliance, or they under-structure, leaving students without the competence scaffolding necessary to benefit from independence. When both choice and scaffolding are not simultaneously present, autonomy-supportive environments collapse into either permissiveness that undermines learning or control that undermines agency. Professional development programs rarely address this dual demand explicitly.

Teacher resistance to differentiated instruction takes specific, documented forms beyond general skill gaps. Case-study evidence from one middle school's implementation of district-mandated differentiation found that teachers perceived the approach as a passing fad, expressed anxiety about classroom management in heterogeneous groups, and feared that differentiation would conflict with test preparation requirements (Tomlinson, 1995). These reactions were compounded by administrative pressure to comply with mandates without adequate support structures, a dynamic that eroded

teacher self-efficacy and fueled resistance. A systematic review of differentiated instruction in secondary education confirmed that guiding heterogeneous groups is challenging for teachers, and that addressing the learning needs of all students in mixed-ability settings requires competencies that most teacher preparation programs do not systematically develop (Smale-Jacobse et al., 2019).

The traditional conception of teaching as direction rather than facilitation reinforces these gaps. Teachers have often internalized transmission-based models and struggle to reconceptualize classroom practice to include student-centered learning experiences. Principal Lori Petersen reflected: "I honestly think it's a control thing. Like, I went to school. I have the information I want you to know (...) because I have a lesson plan, and I have a curriculum guide, and I have to get through this." Shifting this directional orientation requires sustained reflective practice and coaching in addition to formal professional development, conditions that time-constrained systems struggle to provide consistently. In the context of PBL specifically, case-study evidence shows that new instructional approaches conflict with deep-seated teacher beliefs in ways that can take years to resolve, and that teachers can be observed doing PBL in name while retaining directive, transmission-based practices in substance (Thomas, 2000). This gap between nominal and fidelity implementation is a key mechanism through which PBL fails to produce learning gains even when formally adopted: students engage in projects without the extended inquiry, iterative revision, and authentic audience presentation that the evidence base supports (Condliffe et al., 2017).

Insufficient time for individualized support and relationship-building limits educators' capacity to provide personalized instruction and sustain caring relationships. When students work simultaneously on different projects, classroom management complexity increases substantially, adding to the cognitive and logistical demands already straining teacher capacity.

Limited access to specialized personnel further restricts schools' capacity to support the full range of student needs. Caring relationships often surface mental health concerns, learning differences, or family challenges that require specialized expertise, such as learning specialists, counselors, and school psychologists. As a result, teachers often absorb emotional and behavioral support responsibilities without formal training or protected time, straining instructional capacity while leaving student needs partially unmet.

Curricular and Instructional Material Constraints

Curricular and instructional material constraints, including the absence of adaptive materials, discipline-bound content organization, and uneven access to community partnerships, affect educators' ability to implement personalized and project-based approaches effectively. This barrier is not only about whether materials exist, but also about whether teachers receive curriculum-specific support to use them effectively. Recent RAND survey evidence links teachers' instructional-material use to school and district supports and professional learning (Doan et al., 2025). A recent systematic review of adaptive learning in schools likewise found that most studies focus on elementary mathematics and adapt primarily on the basis of performance data, highlighting how limited the current evidence base remains (Bach et al., 2025).

Limited availability of adaptive instructional materials poses particular challenges for personalized instruction. Most available materials are designed for a single grade-level entry point and a standardized learning sequence. The absence of materials built for flexible entry points and varied learning trajectories forces teachers to choose between using available resources in standardized ways or investing substantial time and energy in creating or adapting differentiated materials themselves. This preparation burden falls disproportionately on individual teachers rather than being absorbed at the system level.

Materials organized around discrete disciplines and fixed pacing sequences make problem-centered inquiry more difficult to implement. Even when project-based resources exist, aligning them with accountability requirements and local educational standards requires additional preparation that individual teachers must absorb on top of regular instructional planning. Interdisciplinary project design, a hallmark of high-quality PBL, requires logistical coordination and institutional support that most schools lack. Without that support, schools default to discipline-specific, single-subject iterations of PBL that sacrifice the cross-subject connections most associated with deep learning (Morén et al., 2025). The version of PBL that gets implemented in these conditions is often a reduced form that preserves the surface structure of student projects while losing the integrative inquiry that generates learning gains.

Uneven access to partnerships, materials, and field-based opportunities creates a third layer of constraint. Real-world learning and student-led projects often require specialized materials, technology platforms, community partnerships, or field experience opportunities that are distributed unevenly across schools. Schools with limited access to these resources face barriers in providing meaningful learning experiences regardless of educator commitment or pedagogical expertise, meaning that the learning experiences most associated with motivation, autonomy, and higher-order thinking are also among the most dependent on resources that communities do not hold equally.

Communication and Equity Barriers

Communication and equity barriers shape how student-centered learning experiences are distributed across student populations and whether the benefits of those experiences reach students equitably. The barriers operate through uneven access to technology, language and communication gaps between schools and families, and participation inequities that reproduce existing social hierarchies within classrooms. Communication and relationship infrastructures are central rather than peripheral supports. A second-order meta-analysis of 23 meta-analyses and 1,177 primary studies found a positive overall association between parental involvement and academic achievement (Kim, 2022), and a systematic second-order meta-analytic review found that teacher-student relationships had large, significant associations with academic, motivational, behavioral, and well-being outcomes (Emslander et al., 2025).

Uneven access to digital tools and enriching learning environments outside school constrains targeted direct instruction. Students' ability to engage in self-paced or adaptive learning depends partly on access to devices, reliable internet connectivity, and technology-supported learning tools at home. When these resources are distributed unevenly, schools that adopt personalized learning approaches risk widening rather than narrowing gaps between students, as those with stronger home learning environments are better positioned to benefit from self-directed work (Warschauer & Matuchniak, 2010).

Language barriers and weak communication infrastructure limit family engagement across all five learning experiences. Families from historically marginalized communities, including families whose

primary language is not English, face compounding barriers when schools communicate primarily in English and through systems families find difficult to navigate. In real-world and project-based learning contexts, these challenges intensify: caregivers may struggle to understand non-traditional assessment formats, interpret student progress, or provide the home support that extends learning beyond the school day (Condliffe et al., 2017). Sustaining the outreach required to bridge these gaps demands time and multilingual capacity that many schools lack.

Inequitable participation patterns within collaborative learning settings create a further barrier. Discussion-based learning and collaborative projects do not distribute voice and recognition evenly across students. Without deliberate facilitation, participation patterns reproduce social inequities shaped by gender, race, language proficiency, and prior academic status (Cohen & Lotan, 2014; Michaels et al., 2008). Students from historically marginalized communities are less likely to have their contributions taken up, elaborated upon, or credited by peers and teachers. Student-centered approaches that present themselves as opening access can, under these conditions, function as mechanisms that reinforce existing advantage (Delpit, 1988). Broader community-level stressors, including economic instability, housing insecurity, and exposure to systemic racism, further affect student well-being and relational dynamics within schools (Darling-Hammond, 2010; Reardon, 2011). These forces extend beyond what schools can control directly, but they shape how students experience caring relationships and autonomy-supportive structures in practice, and any account of equity barriers that omits them understates the challenge schools face.

In Summary

Across the five learning experiences, the barriers summarized in Table 4 cluster into five recurring categories: institutional structures, assessment and evaluation systems, professional capacity constraints, curricular and instructional material constraints, and communication and equity barriers. These categories identify the institutional conditions that shape what educators are realistically able to implement, even when evidence and motivation are present.

Table 4: Learning Experiences with Linked Barriers to Access and Scale

Barrier Types	Barriers to Access and Scale	Learning Experiences
(1) Institutional Structures	• Fixed schedules and age-graded structures limiting flexible pacing and grouping • Grading policies requiring uniform assignments or synchronized timelines	1, 2, 3, 4, 5
(2) Assessment and Evaluation Systems	• Lack of flexibility to accommodate differentiated student work • Standards alignment with project outputs involves resource-intensive mapping processes • Assessment systems face challenges in tracking individual contributions in collaborative work and in leveraging multimodal data for evaluating learning progress • Limited access to accurate formative assessments constrains teachers' ability to respond to student needs in targeted instruction • Relational labor is rarely formally recognized, which can reduce institutional incentives to protect time for mentoring and advisory practices	1, 2, 3, 4, 5
(3) Professional Capacity Constraints	• Teacher training and professional development programs generally do not prioritize the development of teacher skills for student-centered instruction •The traditional conception of teaching is focused on direction rather than facilitation. •Insufficient time for relationship-building and individualized support creates constraints for developing caring relationships and providing targeted direct instruction. •Limited access to specialized personnel, such as learning specialists, counselors, and school psychologists.	1, 2, 3, 4, 5
(4) Curricular and Instructional Material Constraints	•Limited availability of adaptive instructional materials. •Materials are mostly organized around discrete disciplines and standardized pacing sequences •Uneven access to partnerships and materials for student-centered experiences, such as specialized building materials, technology platforms, community partnerships, or field experience opportunities	1, 2, 3, 4

(5) Communication and Equity Barriers	• Uneven access to digital tools and enriching learning environments at home • Language barriers and structural obstacles limiting family engagement •Challenges to clearly convey to caregivers information on students' learning progression through student-centered experiences • Reproduction of social inequities in participation patterns	1, 2, 3, 4, 5

Note. Learning experiences numbers indicate the five cross-cutting categories identified in the analysis: (1) Targeted Direct instruction; (2) Real-World Learning; (3) Autonomy-Supportive Learning ;(4) Enriching Discussions ; and, (5) Caring Relationships

The five barrier domains described above function together as the operating system of schooling. They determine how time is allocated, how learning is recognized, how expertise develops, how materials are aligned, and how opportunity is distributed. Because these domains operate simultaneously, changes in one area often reverberate across the others. Implementation research strengthens this interpretation. Reviews of K-12 intervention research note that fidelity is often weakly defined or measured (O'Donnell, 2008), and a recent scoping review found that studies of scaling school-based interventions often underreport context, determinants, and implementation outcomes (Ryan et al., 2024).

Across all five learning experiences, a common pattern compounds these barriers: schools often adopt the surface forms of student-centered practices, including project structures, choice menus, and advisory periods, while structural constraints strip out the elements most responsible for learning gains (Condliffe et al., 2017; Thomas, 2000). This fidelity-reduction dynamic means that implementation failures are frequently invisible: schools appear to be implementing evidence-based approaches while students receive diluted versions that do not reliably produce the documented outcomes. At the same time, the current causal evidence base on AI in K-12 remains limited, especially for schoolwide implementation and longer-term equity effects (Fesler et al., 2026). Systematic review evidence also shows that much more research focuses on AI in teaching than on AI for teacher professional development (Tan et al., 2025).

Artificial intelligence, when understood as part of the technological infrastructure of schooling, becomes relevant to the extent that it interacts with these structural conditions. AI can operate across

these domains simultaneously, reshaping how institutional systems coordinate with one another and influencing the broader conditions under which teaching and learning take place.

The following section therefore organizes AI applications according to the institutional constraints they may address. This framework makes it possible to examine not only what AI tools can do technically, but how they intersect with the recurring bottlenecks that limit the scale of student-centered learning experiences.

Accessing and Scaling K–12 Learning Experiences with AI

The five learning experiences described above (targeted direct instruction, real-world learning, autonomy-supportive learning, enriching discussions, and caring and supportive relationships) are supported by strong empirical evidence but constrained by five recurring institutional barriers. This section examines what schools need from AI in order to address those barriers. Rather than cataloging currently available products, the analysis identifies the functional capacities and applications that AI systems would need to possess in order to shift institutional conditions in ways that expand access to these evidence based learning experiences.

Technology is increasingly pervasive in the lives of young people and adults. As digital systems shape communication, information access, and social interaction outside of school, the role of school as a space for sustained human connection, shared inquiry, intellectual challenge, and mentorship takes on heightened importance. The value of educators as skilled and caring adults guiding students through complex ideas and social experiences remains central within this context. Beginning with the knowledge, skills, and capacities we seek to develop in students places human judgment at the center of decisions about how, when, and where AI is deployed. The relevant question is not whether AI can automate isolated instructional tasks, but whether it can function as infrastructure that coordinates time, information, and professional expertise across the school as a whole in service of these developmental goals.

This section organizes AI applications according to the five barrier categories identified above: institutional structures, assessment and evaluation systems, professional capacity constraints,

curricular and instructional material constraints, and communication and equity barriers. For each category, it identifies the functional capacities AI would need to possess to meaningfully shift institutional conditions, distinguishing between tools that exist today in partial or early-stage form and capabilities that remain to be built.

Institutional Structures

One of the most persistent barriers to richer learning experiences lies in how schools are structurally organized. Fixed schedules, age based cohorts, rigid subject blocks, and staffing models designed for whole class instruction constrain flexibility even when educators are committed to personalization and real-world learning. Institutional structures determine how time, staffing, and authority are distributed, shaping what is operationally feasible.

AI systems responsive to individual student learning levels can support more differentiated grouping and scheduling decisions. Tools that analyze performance patterns and engagement indicators can identify students in need of targeted support, adjust pacing as mastery develops, and recommend flexible groupings. When AI assumes portions of routine instructional delivery and practice feedback, educator time can be reallocated toward small group facilitation, mentorship, advisory, and interdisciplinary project guidance.

At a broader level, what is required is a coordination layer capable of integrating formative assessment data, staffing availability, space constraints, and instructional priorities into dynamic scheduling recommendations. Rather than static master schedules set months in advance, grouping and time allocation could adjust as students demonstrate mastery or require additional support. School leaders could use modeling systems to simulate alternative blocking structures that create extended time for interdisciplinary, community connected learning while ensuring foundational academic skills are addressed efficiently.

Consider a middle school redesigning its day so that mornings are dedicated to focused literacy and mathematics instruction while afternoons are reserved for interdisciplinary, project based work connected to local challenges. Under current conditions, implementing such a model would require

extensive manual coordination across grade levels, teacher assignments, room usage, transportation, and shifting student mastery levels. Systems that synthesize learning data with logistical constraints could make such designs feasible without weeks of manual recalibration. Cross grade groupings for skill instruction could be recommended based on demonstrated mastery, group sizes could adjust as students progress, and targeted interventions could be flagged before gaps widen. In this model, logistical complexity becomes manageable, allowing educators to focus on instruction, mentorship, and the design of meaningful learning experiences rather than schedule management. The most consequential data requirements for such a system are real-time formative assessment results and the master schedule, because the coordination logic depends on being able to move students across groups as mastery shifts rather than on a fixed calendar. Without live assessment data feeding into scheduling decisions, the system reduces to a more sophisticated version of the static planning tools schools already have.

These structural shifts matter because each of the five learning experiences depends on flexibility in how time and adult attention are organized. Targeted direct instruction requires responsive grouping. Real-world learning depends on extended blocks of inquiry. Autonomy-supportive environments require time for dialogue and mentoring. Enriching discussions require space that is not compressed by coverage demands. Caring relationships depend on continuity and repeated contact. When AI interacts with scheduling and staffing, it alters the institutional conditions that make these experiences feasible within the school day.

Assessment and Evaluation Systems

Assessment systems shape what becomes visible and valued within accountability frameworks. Episodic testing and grading structures organized around uniform written products limit the recognition of collaborative reasoning, oral communication, metacognitive adjustment, and sustained intellectual effort. Without reliable ways to measure these capacities, schools remain structurally incentivized to prioritize what is easiest to test over what policy frameworks increasingly identify as important.

AI systems enable ongoing analysis of student work in progress. Continuous monitoring of problem-solving processes, revision patterns, discussion transcripts, and collaborative artifacts can

generate timely indicators of understanding and areas requiring support. AI tools can also be used to draft and apply rubrics to assess real-world learning and individually developed projects, taking into account educational standards, student goals, and educator judgment. Over time, such systems can support longitudinal competency profiles that document growth across academic, collaborative, and metacognitive domains, reducing reliance on isolated testing events.

Consider a high school implementing interdisciplinary, project-based learning aligned to state standards. In current practice, students may receive a final project grade and later a summative assessment score, but teachers have limited visibility into how effectively students collaborated, revised their thinking, or adjusted strategies throughout the process. AI systems capable of analyzing work products, revision histories, and peer interactions could surface patterns of uneven participation, highlight evidence of strategic adaptation, and alert teachers to persistent misconceptions before they become entrenched. When aligned with academic standards and social-emotional learning frameworks, these tools expand the evidence base available to educators without displacing professional judgment. The requirement that distinguishes this from existing gradebook tools is access to student work in process rather than final products: revision histories, discussion transcripts, and collaborative artifacts. Without visibility into how students are thinking rather than only what they submit, the system can document outcomes but cannot surface the patterns of reasoning, participation, and metacognitive adjustment that determine whether formative intervention is timely or too late.

Professional Capacity Constraints

Expanding the five learning experiences requires instructional skills that are demanding and unevenly distributed. Discussion facilitation, autonomy-supportive teaching, interdisciplinary project design, and relational mentorship require practice, feedback, and sustained development that many preparation pathways struggle to provide. The skills most central to these experiences are also those least amenable to traditional one-time professional development, because they require repeated practice with feedback rather than declarative knowledge.

AI-supported simulation environments can create structured rehearsal opportunities within preservice programs and early career induction. Teachers can practice facilitating discussions, offering bounded choices, responding to disengagement, and navigating complex classroom interactions in environments that provide immediate feedback. Transcript analysis systems can extend this feedback into live classrooms by highlighting participation patterns, questioning strategies, and discourse quality.

Consider a California teacher preparation program partnered with a high-need district experiencing early-career attrition and uneven access to instructional coaching. Candidates preparing to teach in linguistically and culturally diverse classrooms may have limited structured opportunities to rehearse facilitating rigorous, standards-aligned discussions before assuming full classroom responsibility. In this scenario, what a program would need from AI is a rehearsal and feedback infrastructure that would allow candidates to practice responding to varied student thinking, navigate moments of confusion or disengagement, and experiment with autonomy-supportive instructional moves in a low-stakes simulation. Once in their own classrooms, recorded lessons could be analyzed to provide formative feedback on patterns such as disproportionate teacher talk, limited student-to-student interaction, or missed opportunities to press for reasoning. Rather than relying solely on infrequent mentor observations during induction, feedback could become more continuous and specific, accelerating skill development while preserving the role of human coaching. The critical data requirement is classroom recordings with appropriate permissions, because the feedback value depends entirely on analyzing actual instructional behavior rather than self-report. Student engagement and performance indicators are equally important as context: feedback that tells a teacher she is talking too much means something different in a classroom where students are productively confused than in one where they have disengaged entirely.

Integrated across preparation programs, residency models, and induction years, AI-supported systems could reshape how instructional expertise is developed. Structured rehearsal and performance-based feedback could become routine components of teacher formation rather than supplemental experiences. In relational domains, simulation tools can assist educators and counselors in practicing responses to students experiencing emotional distress. Data synthesis platforms that

integrate attendance, performance, and engagement indicators can help identify students in need of support earlier, enabling more deliberate allocation of relational time.

AI systems that extend rehearsal and feedback can influence whether these practices become durable features of schooling or remain dependent on individual expertise.

Curricular and Instructional Material Constraints

High quality instructional materials aligned to standards are often organized around fixed sequences and discrete subject domains. Connecting these materials to real-world challenges or differentiating them for varied readiness levels requires substantial time and expertise. Material constraints therefore shape the feasibility of personalization and interdisciplinary learning.

As Principal Lori Peterson observed, no teacher can realistically hold 27 differentiated learning profiles in mind simultaneously when planning; the cognitive and logistical burden is simply too high. AI systems address this constraint directly, supporting instructional planning by producing differentiated texts, inquiry prompts, and project frameworks aligned to standards. Rather than functioning only as content generators, these systems can operate as coordination layers that connect standards-aligned materials, student performance data, and instructional decision making. Adaptive tools can flag where additional scaffolding or enrichment is required, allowing teachers to maintain coherence with accountability frameworks while tailoring instruction.

Consider a California district that has recently adopted state-approved, standards-aligned mathematics and ELA materials to ensure coherence with CAASPP expectations. Teachers are expected to follow a prescribed pacing guide, leaving limited room to connect lessons to local community issues or to adjust materials for students reading below or above grade level. A teacher seeking to design a project around a regional water conservation challenge, for example, must manually align the project to grade-level standards, adapt complex informational texts for multilingual learners, and ensure coverage of required curricular units, all while staying on pace for benchmark assessments. In this scenario, what schools and teachers need from AI is a coordination layer that can map state standards to interdisciplinary project frameworks, generate leveled texts and scaffolds aligned to adopted

materials, and suggest pacing adjustments without compromising required coverage. AI could make alignment and differentiation more operationally feasible within California's standards-based instructional systems, allowing teachers to pursue both curricular fidelity and meaningful, real-world learning rather than treating them as competing demands. The requirement that moves this beyond a generic AI lesson-planning tool is access to the district's adopted instructional materials and pacing guides specifically. A system working from generic standards can generate plausible-sounding differentiated content that nonetheless conflicts with the sequence, vocabulary, and conceptual framing of the curriculum teachers are required to follow. Multilingual learner profiles are the second distinctive requirement: without them, leveled texts are calibrated to grade-level reading without accounting for the linguistic demands that make the same text more or less accessible depending on a student's language background.

Communication and Equity Barriers

Communication and equity barriers influence how learning experiences are distributed across students and communities. Language differences between families and schools, unequal access to supplemental support, and variation in access to community networks shape students' opportunities to participate fully in personalized instruction, real-world learning, autonomy-supportive environments, enriching discussions, and sustained relational support.

AI enabled translation systems can facilitate sustained two way communication between educators and families. Tools that analyze classroom discourse can surface patterns in participation, drawing attention to whose ideas are extended or overlooked. Matching platforms can connect students to mentors and apprenticeship opportunities beyond their existing networks, expanding access to community connected learning. Systems that synthesize learning and engagement data can support earlier relational intervention.

Consider a California district in which a substantial proportion of students are designated English learners and in which reclassification to fluent English proficient status is a consequential milestone affecting course placement, instructional support, and long-term academic trajectory. Under current conditions, reclassification involves synthesizing results from the annual ELPAC administration,

classroom-based evidence of academic language use, teacher evaluations of student performance across content areas, and parent or guardian input gathered through meetings that often require interpretation services the district may struggle to schedule consistently. Each of these data streams is typically managed in separate systems by different staff, and the synthesis required to make a reclassification determination falls largely on individual teachers and administrators working without integrated tools.

What schools and districts in this situation need from AI is a coordination layer that integrates these data streams and reduces the procedural burden on educators and families alike. At the intake stage, such a system would synthesize ELPAC scores, benchmark assessment results, and classroom performance data into a unified longitudinal profile for each English learner, flagging students who are approaching reclassification thresholds and identifying any data gaps that would delay the process. Rather than waiting for annual reviews, the system would surface readiness indicators continuously, allowing educators to initiate reclassification earlier when evidence warrants it. For families, the system would generate bilingual progress summaries in home languages, explaining in plain terms where a student stands relative to reclassification criteria, what evidence is still needed, and what the reclassification decision will mean for their child's coursework and support services. Rather than families receiving a single notification after a determination has already been made, communication could become an ongoing, two-way process in which caregivers understand the criteria, track their child's progress, and are meaningfully included in the decision. At the meeting stage, real-time interpretation support would allow substantive dialogue rather than simplified one-directional communication, and the system would document caregiver input as part of the formal record.

The requirements that distinguish this from a translation or notification tool are ELPAC score histories linked to ongoing classroom performance data, and family language preferences tied to communication logs. The first pairing is what enables the system to surface reclassification readiness continuously rather than only at annual testing; without the longitudinal connection between standardized scores and daily classroom evidence, the system cannot identify the students whose readiness the annual assessment will miss. The second pairing is what makes communication genuinely bidirectional: knowing a family's language preference is necessary but not sufficient if the system has

no record of what has already been communicated and how families have responded. Adequate two-way communication can then enable caregivers to partner with schools in supporting their children's language development during the reclassification process.

When deployed within environments that prioritize shared inquiry, social interaction, and mentorship, these systems influence not only instructional design but the distribution of experiential and relational opportunities. In doing so, they contribute to the relational infrastructure through which the five learning experiences are made accessible to a broader range of students.

In Summary

Organizing AI applications by barrier category clarifies how technological systems intersect with institutional conditions. Institutional structures determine how time and staffing are allocated. Assessment systems determine which competencies are recognized and documented. Professional capacity constraints shape whether complex pedagogical practices can be enacted consistently. Curricular constraints influence the preparation burden associated with personalization and interdisciplinary learning. Communication and equity barriers affect how opportunities are distributed.

Across categories, the most consequential applications of AI are those that function as integrative systems, coordinating data, logistics, and professional expertise in service of clearly defined developmental goals. When grounded in evidence based learning experiences and human centered priorities, AI can help make organizational designs that once seemed logistically impractical more feasible. The role of AI within K-12 education is best understood in relation to the institutional conditions it reshapes and the community oriented learning environments it supports.

Table 5 organizes these applications by barrier category, distinguishing between existing tools and the functional capacities required for more substantial institutional shifts. It provides a structured representation of how AI systems intersect with institutional design to expand access to the learning experiences identified in this paper.

Table 5. Barrier Categories and Potentially Supportive AI Tools

Barrier Category	Current Tools (Partial or Early-Stage)	Tools to Build (Functional Requirements)
Institutional Structures	• Adaptive tutoring platforms (e.g., i-Ready, DreamBox) • Learning management systems logging student activity • Budget and scheduling software	• Restructured staffing infrastructure: AI systems capable of absorbing routine instructional tasks at sufficient quality to allow redesign of teacher roles and schedules • Organizational modeling tools: Simulation systems enabling leaders to test alternative schedules, interdisciplinary blocks, advisory expansion, and staffing reallocations
Assessment and Evaluation Systems	• Progress-monitoring dashboards • Multimodal grading tools • AI writing feedback platforms (e.g., Writable)	• Ambient continuous assessment: Longitudinal inference of student understanding from ongoing work • Multimodal and collaborative assessment infrastructure: Systems capable of evaluating projects, oral reasoning, individual participation in group work, and iterative drafts • Assessment of competencies: Tools capturing competencies such as creativity, persistence, and intellectual risk-taking
Professional Capacity Constraints	• Mixed-reality teacher simulation platforms (e.g., Mursion) • AI instructional coaching tools • Counselor role-play tools • Post-session transcript analytics (e.g., TeachFX)	• High-fidelity rehearsal environments: Simulation tools grounded in research on discussion facilitation and autonomy support • Equity-sensitive facilitation feedback: Systems surfacing participation patterns and dialogic moves • Expanded mental health rehearsal capacity: Tools supporting practice responses to student distress
Curricular and Instructional Material Constraints	• AI lesson-planning tools (e.g., MagicSchool AI, Diffit) • Project-planning assistants • Generative inquiry prompts • Adaptive content platforms	• Flexible pathway generation: Systems producing multiple valid routes through standards • Interdisciplinary curriculum generation: Coherent, standards-aligned project frameworks across subjects • Robust AI instructional systems: Capable of sustained, conceptually complex tutoring beyond drill-and-practice
Communication and Equity Barriers	• Translation tools (e.g., Talking Points, ParentSquare) • Early-warning systems • MTSS dashboards (e.g., Panorama) • Community partnership platforms (e.g., Pathful)	• Equitable opportunity matching: Platforms deliberately redistributing access to mentors and apprenticeships • Equity-centered tutoring scaffolds: Systems designed for students furthest behind • Bidirectional family communication tools: Supporting substantive dialogue across language differences • Informed attentiveness systems: Actionable synthesis of relational risk signals without surveillance overreach

Discussion

This paper began with a reorientation. It asked first what students need, and then whether AI might help deliver it, rather than asking what AI can do in education. AI tools adopted without reference to clearly defined developmental goals risk optimizing for what is measurable rather than what is important: narrow performance indicators over the cognitive flexibility, relational capacity, and motivational orientations that determine whether students thrive beyond school. By anchoring the analysis in a competency-based portrait of a California K--12 graduate, this paper provides a structured basis for evaluating emerging technologies against the outcomes that education is actually for.

Distinguishing Near-Term Tools from Structural Investments

The AI applications described above are at different stages of development, and California's approach to adoption is strengthened by distinguishing between them. Tools available now (translation platforms, lesson planning assistants, caregiver communication systems, and progress-monitoring dashboards) can be evaluated and adopted within existing budgets and infrastructure. They are worth deploying carefully, with attention to equity of access and evidence of impact. The more consequential investment is in tools designed not merely to operate within the current institutional model, but to expand access to the kinds of learning experiences this paper identifies as most developmentally consequential. These represent the frontier of the R&D agenda this paper is calling for.

The barriers that currently most lack adequate technological responses (equitable participation in discussions, geographic inequity in real-world learning access, and the cultural dimensions of autonomy-supportive teaching) are also among the most consequential for students from historically marginalized communities, and represent areas where targeted development investment is most needed. However, such investments require careful considerations. Evidence on the cost-effectiveness of whole-school student-centered restructuring models remains limited and uneven. Any AI-enabled restructuring must therefore be evaluated not only for instructional impact but also for long-term fiscal sustainability, staffing implications, infrastructure requirements, and equitable resource distribution across districts.

Designing AI primarily to fit existing scheduling structures, grading systems, and staffing ratios risks embedding those constraints into the next generation of educational infrastructure. Tools optimized for the current system will tend to reproduce its limitations, extending efficiency without expanding access to high-quality, competency-building experiences. If AI is to broaden access rather than simply streamline existing practices, tool development must be guided by the structural conditions required for those experiences to scale.

AI as a Lever for School Restructuring

The more significant long-term opportunity may lie not in any individual tool, but in what AI-enabled automation of certain educational functions makes possible at the level of school organization. If AI systems can support specific tasks at scale and if schools deliberately choose to reallocate any resulting efficiencies, educator time could potentially be redirected away from routine adaptive academic practice, progress monitoring, administrative coordination, and basic family communication, and toward the work that research consistently identifies as most consequential: sustained relationships, substantive dialogue, real-world learning facilitation, and autonomy-supportive mentorship that develops students as self-directed learners.

Historical experience with educational technology suggests that such time reallocation is not automatic and depends on policy, leadership decisions, staffing models, and accountability structures. Automation alone does not guarantee that educator time will be freed or restructured. Realizing this potential requires deliberate choices about school design and educator roles. Without deliberate redesign, automation may simply compress existing practices rather than creating space for more relational, dialogic, and autonomy-supportive learning.

The design challenge for California policymakers and district leaders is to align AI development and school restructuring so that emerging technologies expand access to the most evidence-supported learning experiences rather than reinforcing existing instructional patterns.

School models such as Montessori programs and High Tech High have demonstrated for decades that the learning experiences this paper identifies as most consequential can be

institutionalized at the school level (High Tech High, 2025; Randolph, 2023). The barrier has never been proof of concept; it has been scale. The most promising applications of AI in this context are those that reduce the logistical and planning burdens that have historically kept relational, dialogic, and inquiry-rich learning confined to well-resourced or purpose-built schools.

For AI to effectively unblock historical barriers, depends not only on AI tools but on a set of broader underlying technical capacities and enabling conditions that currently are not consistently reliable or developed. These include strong data governance and privacy protections, developmentally appropriate guardrails for student-facing systems, reliable and interpretable assessment of multimodal student contribution, mechanisms for authorship attribution, longitudinal student modeling systems with academic year long validity, interoperability across schoolwide systems, and governance structures that ensure human oversight and accountability. Without meeting these fundamental criteria, AI systems risk reinforcing existing constraints, introducing new forms of bias, or undermining the human relationships and developmental conditions essential to the core of learning.

Equity and Restructuring

Historically, structural innovations in education have benefited advantaged students and communities first, with benefits reaching under-resourced schools later and less completely. AI-enabled restructuring carries the same risk. Schools with stronger technology infrastructure, more experienced teachers, and greater administrative capacity are better positioned to implement complex AI-integrated models, and districts serving wealthier communities are more likely to have the resources and stability to experiment with restructured school designs. California has policy tools through LCAP goal-setting, LCFF funding allocation, and categorical programs to shape how AI-enabled restructuring is distributed across the system. Ensuring that the schools serving students with the greatest needs have access to both the tools and the implementation support required to restructure meaningfully is a policy design question as much as a technology question. The competency-based framework developed in this paper provides one basis for that conversation: identifying the learning experiences shown to matter most for long-term student outcomes, the barriers that most constrain access to those experiences in

under-resourced settings, and the AI tools and structural changes most likely to address those barriers equitably.

AI's potential to expand access to high-quality learning experiences depends on both technological capacity and institutional design. Building systems capable of supporting complex instructional, assessment, and coordination tasks is one dimension. Equally consequential is whether school structures evolve in ways that take advantage of those capabilities. When AI applications operate within existing institutional arrangements, their effects are bounded by those structures. When technological development and institutional design evolve together, the scope of change broadens.

A central question for the education sector is the extent to which AI interacts with the institutional constraints that limit access to evidence-based learning experiences. Framing AI within a competency-based model and an institutional analysis of barriers provides a disciplined basis for evaluation. Some technology applications reduce friction within existing systems. Others reshape how time, expertise, assessment, and opportunity are organized. The distinction between these approaches carries significant implications for how educational opportunities are distributed at scale. In practice, this will determine whether the five learning experiences identified in this paper remain episodic innovations or become durable features of school design.

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Appendix - Literature Review Methodology

This review identifies well-supported instructional strategies associated with the competency domains outlined in this paper. The process prioritizes experimental rigor while focusing on identifying evidence-based practices relevant to K–12 education.

Inclusion Criteria

The review includes peer-reviewed studies focused on K-12 education that use experimental or quasi-experimental methods, including randomized controlled trials (RCTs), controlled trials, experiments, quasi-experiments, and meta-analyses. To capture these designs, the search incorporates methodological keywords such as “randomized,” “controlled trial,” “experiment,” “RCT,” and related variations (e.g., experimental, quasi-experimental).

Keyword Development

The search uses keywords aligned with each competency domain (e.g., “autonomy”). In some cases, preliminary searches produce results misaligned with the review’s objectives. When this occurs, the search substitutes alternative terms (e.g., “interpersonal” instead of “interpersonal connection”) to improve alignment. All searches also include general education-related terms such as “education,” “school,” “student,” and their variations.

The competency-related keywords we use are the following: Motivation, problem-solving, anxiety, engagement, interest, metacognition, communication, self-efficacy, self-regulation, collaboration, interpersonal, autonomy, innovation, creativity, critical thinking, belonging, growth mindset, academic self-concept, curiosity, academic skills, math, reading, persuasion, adaptability, boredom, and frustration.

Database Search

The review conducts searches in ProQuest and Web of Science. Initial queries that combine competency-related keywords with education and methodological terms produce large result sets. For example, combining “motivation” with education and experimental-method filters yields 14,390 articles in ProQuest. To increase specificity and manageability, the review applies additional refinement steps.

Journal Selection

To narrow the scope to high-quality empirical research, we limited results to 13 journals in educational research and psychology with impact factors ranging from 4.9 to 11.4. This restriction reduces the likelihood of including lower-quality studies while maintaining coverage of leading scholarship in the field.

The selected journals are the following: American Psychologist; British Journal of Educational Technology; Developmental Review; Educational Psychologist; Educational Psychology Review; Educational Research Review; Human Development; Journal of Affective Disorders; Journal of Educational Psychology; Learning and Individual Differences; Learning and Instruction; Metacognition And Learning; and Review of Educational Research.

Citation Compilation

We conducted separate searches for each competency domain, combining domain-specific keywords with education and methodological terms and restricting results to the selected journals. An example query is shown below:

TS=((collaboration AND school*) OR (collaboration AND education) OR (collaboration AND student*)) AND TS=(randomized OR randomised OR"controlled trial" OR experiment* OR RCT) AND SO=("EDUCATIONAL PSYCHOLOGIST" OR "Educational Research Review" OR "Learning and Individual Differences" OR "Educational Psychology Review" OR "British Journal of Educational Technology" OR "Review of Educational Research" OR "American Psychologist" OR "Journal of Educational Psychology" OR "DEVELOPMENTAL REVIEW" OR "HUMAN DEVELOPMENT" OR "Journal of Affective Disorders" OR "Learning and Instruction" OR "Metacognition and Learning")

We downloaded citation records from ProQuest and Web of Science and combined them into a single dataset. The full search produced 5,816 citation records.

Screening Using ASReview

We uploaded citation records into ASReview, an AI-assisted screening tool that prioritizes articles based on iterative relevance classification. As the reviewer labels studies as relevant or non-relevant by manually reviewing the articles' abstracts, ASReview updates its ranking of remaining records. The tool identified approximately 3,811 distinct articles within the dataset.

Stopping Rule

For searches yielding 200 or more citation records, we applied an 8 percent stopping threshold, consistent with procedures used in related work. Under this rule, abstract screening stops after 8 percent of citation records are consecutively classified as non-relevant. For searches yielding fewer than 200 records, we screened all abstracts manually.

Final Selection

We reviewed the articles identified through the ASReview classification process. Our final selection includes articles reporting positive effects on our competencies of interest in K-12 settings. When multiple articles examined the same competencies and interventions, we prioritized studies with larger sample sizes. We also included meta-analyses and systematic literature reviews.

Scope and Limitations

This review does not conduct a formal meta-analytic effect-size synthesis, report inter-rater reliability statistics, or test for publication bias. Instead, it aims to identify instructional strategies supported by rigorous empirical designs rather than to produce pooled quantitative estimates. The review therefore represents a structured and methodologically bounded scan of the experimental literature rather than a comprehensive systematic review or meta-analysis.