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LED EDUCATION

D3.1 Research Report on Educational Methodologies: Recommendations for designing biophilic learning environment

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Lead Author (Partner)	Kadri Mettis, Janika Leoste, Sirly Väät (Tallinn University)
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HAW HAMBURG TALLINN UNIVERSITY ELIZABUILD AIXEDU

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ABSTRACT

Deliverable 3.1 – Research Report on Educational Methodologies: Recommendations for designing biophilic learning environment.

This report presents a comprehensive review of innovative educational methodologies aimed at enhancing primary and secondary education through the integration of digital technologies, personalised learning, socio-emotional learning (SEL), and biophilic design principles. By synthesising recent global research and case studies, the report identifies best practices for creating learning environments that support both cognitive and emotional development. The study explores the theoretical foundations, implementation strategies, and documented impacts of key educational innovations, including the use of immersive technologies, adaptive learning systems, SEL frameworks, and nature-integrated spaces. A focal point of the report is the intersection between digital tools and biophilic learning environments, highlighting how these approaches can be synergised to foster holistic student well-being and achievement. The findings offer actionable recommendations for educators, policymakers, and school designers seeking to transform educational spaces into engaging, health-promoting, and future-ready environments.

KEYWORDS

Socio-emotional learning, Biophilic learning environment, Technology-rich learning environment, Digital tools integration, Personalised learning, Education innovation

DISCLAIMER

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List of Abbreviations and Acronyms

CA	Consortium Agreement
D	Deliverable
DoA	Description of the Action
GA	EU Grant Agreement
PC	Project Coordinator
PCO	Project Coordination Office
TL	Task Leader
SO	Specific objective
WP	Work Package

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Executive Summary

This report, developed under the LED Education project (Deliverable D3.1, WP3), provides research-based guidance for designing future-focused learning environments that align with 21st-century educational goals. It addresses five interconnected domains:

- Digital Tools Integration: Reviews current practices and impact of technologies such as learning management systems, mobile devices, AR/VR, and AI-driven tutoring systems. The report confirms modest academic gains and enhanced engagement when tools are thoughtfully integrated with pedagogy.
- Personalised Learning: Analyses adaptive learning technologies and data-informed instruction strategies. Evidence supports improvements in student outcomes, especially for underperforming learners, while also enhancing autonomy and engagement.
- Socio-Emotional Learning (SEL): Explores SEL frameworks, particularly CASEL's model, and their integration into curriculum and school culture. SEL contributes significantly to student mental health, behaviour, and academic performance, with long-term life benefits.
- Biophilic Learning Environments: Highlights the educational benefits of integrating natural elements into school design. Research links biophilic features with reduced stress, improved attention, and stronger academic results.
- Interplay Between Technology and Nature: Investigates how digital and biophilic strategies can coexist. Synergistic models – like tech-supported outdoor learning and virtual nature simulations – emerge as promising avenues for balanced development.

The report culminates with a set of actionable recommendations tailored for educators and policymakers, advocating for a blended approach that aligns digital innovation with human-centred, nature-based design. This integrated vision supports student well-being, equity, and future readiness in learning environments across diverse educational settings.

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1. Introduction

Education is evolving beyond traditional paradigms to embrace methodologies that not only improve academic performance but also enhance student well-being and digital competence. In the 21st century, schools are exploring innovative approaches – from high-tech classrooms to nature-integrated campuses – to support the "whole child" (Greenberg, 2023). This review provides a comprehensive examination of key innovations in primary and secondary education worldwide, drawing on peer-reviewed research from both recent years (last 5–10 years) and foundational studies. We focus on five interrelated domains: (1) Digital Tools Integration (e.g. learning management systems, interactive platforms, virtual reality); (2) Personalised Learning Approaches (adaptive and data-driven learning); (3) Socio-Emotional Learning (SEL) Strategies; (4) Biophilic Learning Environment Design (incorporating natural elements into learning spaces); and (5) the Interplay Between Digital Innovations and Biophilic Environments. Each section analyses theoretical frameworks, methodological practices, and real-world applications, including case studies of successful implementations. We then offer evidence-based recommendations for educators and policymakers to create learning experiences that are engaging, supportive of mental health, and effective in building both academic and digital skills.

By synthesising global research, this review underscores how combining technological innovation with attention to social-emotional and environmental factors can foster more holistic educational outcomes. The findings highlight that academic success need not come at the expense of well-being. Strategies that support students' emotional and physical needs often boost cognitive performance as well (Greenberg, 2023). In the following sections, we examine each approach in depth, noting theoretical underpinnings, practical techniques, and documented impacts on student learning and development.

2. Digital Tools Integration in Education

Modern classrooms increasingly employ digital tools and platforms to enhance teaching and learning. These range from basic productivity tools and Learning Management Systems (LMS) to immersive technologies like virtual reality (VR) and augmented reality (AR). The integration of Information and Communication Technologies (ICT) in schools is driven by the potential to enrich educational content, personalise learning, and prepare students with critical digital competencies for the future (Timotheou, Miliou, Dimitriadis, Sobrino, Giannoutsou, Cachia, Monés & Ioannou, 2023). In this section, we explore frameworks for technology integration, the types of digital tools used, their impact on learning outcomes and digital skills, and factors influencing their effectiveness.

Theoretical Frameworks and Rationale

Educators often refer to models like TPACK (Technological Pedagogical Content Knowledge) and SAMR (Substitution, Augmentation, Modification, Redefinition) to guide meaningful tech integration. These frameworks emphasise that technology should not be used for its own sake, but rather to enable new forms of learning (e.g. collaborative projects, simulations) that were previously not possible. Underlying the push for digital tools is the recognition that today's students are "digital natives" who can benefit from interactive and multimedia content. Moreover,

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technology can facilitate student-centred learning, allowing learners to access information, create content, and collaborate beyond the confines of the physical classroom (Timotheou et al., 2023). For instance, the use of online learning platforms enables access to a wider variety of resources, self-paced study, and opportunities for self- and peer-assessment (Timotheou et al., 2023). This aligns with constructivist theories, where students build knowledge actively. Digital tools (like simulations or educational games) provide rich environments for such active learning.

Another theoretical rationale is the need to develop students' digital literacy and competence. As literature review by Timotheu and colleagues (2023) notes, effective technology integration requires not just infrastructure but also cultivating a "culture" and skillset among students and staff to use digital tools productively (Timotheou et al., 2023). In fact, using ICT in learning can itself enhance students' and teachers' digital skills. Studies have found that integrating technology in lessons improved teachers' basic ICT competencies and confidence (Timotheou et al., 2023), which in turn benefits students' experience. Thus, digital integration serves a dual purpose: it is a medium for instruction and a subject of instruction (learning with and about technology).

Types of Digital Tools and Platforms

Schools globally are experimenting with a spectrum of digital tools:

- Learning Management Systems (LMS) & Virtual Learning Environments: Platforms like Google Classroom, Moodle, or Canvas organise content, assignments, and communication. They extend learning beyond class time and support blended learning approaches. Research finds that such learning platforms allow students to access quality resources anytime and engage in independent learning, while also enabling teachers to track progress and give feedback (Timotheou et al., 2023).

- Interactive Multimedia and Educational Software: This includes everything from digital textbooks and slideshow presentations to subject-specific software (e.g. math drill programs, language learning apps) and open educational resources. Interactive simulations in science or virtual labs can visualise concepts in engaging ways. Game-based learning and educational apps leverage principles of gamification to motivate learners. A recent review of K-12 math education concluded that integrating digital games can improve student performance in mathematics, making learning more engaging (Timotheou et al., 2023). Similarly, gamified STEM programs have shown increased learning gains compared to traditional instruction (Timotheou et al., 2023).

- Mobile Devices and 1:1 Initiatives: Many schools have adopted one-device-per-student programs (e.g. one-to-one laptop or tablet initiatives). Mobile devices allow learning to be more portable and personalised. A meta-analysis by Sung et al. (2016) reported that using mobile devices in the classroom had a moderate positive effect on students' academic performance compared to using only desktop computers or no devices. Tablets and laptops enable interactive activities, quick research, and multimedia projects. Notably, studies of 1:1 laptop programs found not only small gains in academic achievement but also increased student engagement and development of various skills such as information literacy, media use, and organisation (Zheng et

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al., 2016). In such classrooms, technology becomes a routine part of learning, and students often show greater enthusiasm for project-based and individualised learning tasks.

- Multimedia and E-Learning Platforms: Including Narrated Lectures and Podcasts and Video-Conferencing tools. These tools provide diverse and flexible learning opportunities, making education more accessible and engaging (Bansal et al., 2023). Platforms like Zoom and Teams facilitate real-time interaction and support both synchronous and asynchronous learning and real-time communication, supporting virtual classrooms (Rajeshkumar & Rajakumari, 2024).

- Augmented and Virtual Reality: AR and VR bring immersive experiences into education. AR overlays digital information onto the real world (for example, an app that displays 3D models when pointing a tablet at a textbook diagram), while VR can simulate entire environments (such as a virtual science lab or a historical setting). Meta-analyses indicate that AR applications have a medium effect size in improving student learning outcomes over traditional methods (Garzón & Acevedo, 2019, Garzon et al., 2020). VR has also shown moderate positive effects on learning, particularly in STEM subjects (Villena-Taranilla et al., 2022). Importantly, fully immersive VR tends to yield higher learning gains than non-immersive or semi-immersive experiences (Villena-Taranilla et al., 2022), presumably because of greater engagement and presence. For example, one study noted that immersive VR use in K–6 education led to significantly better understanding of content than using textbooks or videos (Chen et al., 2022). These tools can spark interest and cater to diverse learning styles (visual, kinesthetic, etc.), though they require careful integration to align with curriculum goals.

- Artificial Intelligence and Intelligent Tutoring Systems: AI is increasingly present in education via adaptive learning systems (discussed more in the Personalised Learning section). Additionally, AI-focused content is entering curricula – one study showed that using AI tools in class significantly improved students' understanding of AI and machine learning concepts (Su & Yang, 2022; Su et al., 2022). AI-driven chatbots or tutoring programs can offer instant feedback and hints to students, providing a form of one-on-one support.

For fully online learning courses previously mentioned tools are essential but the following additional tools could give additional support for students enrolled in online learning courses:

- Collaborative tools: Communication platforms like Zoom, Teams, Google Meet are widely used for enhancing virtual classroom communication and group works (Rajeshkumar & Rajakumari, 2024). For supporting online groupwork discussion forums, chats and collaborative documents could be used.

- Self-Regulated Learning Support: Digital tools that support self-regulated learning help students plan, monitor, and evaluate their learning progress, leading to better performance (Baughman, Gatti & Boden, 2023). Also regular surveys and feedback mechanisms are used to support and enhance self-regulated learning (Baughman, Gatti & Boden, 2023).

All these tools, when used in combination, contribute to what some call a "digital ecosystem" in schools. The COVID-19 pandemic accelerated the adoption of many of these technologies, revealing both their promise and the challenges in implementation (Timotheou et al., 2023). It became evident that schools need robust digital capacity and training to effectively harness these

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tools. In sum, the array of digital options is broad, and their integration requires strategic planning aligned with pedagogical objectives.

Impact on Learning Outcomes and Digital Competence

Academic Outcomes: By and large, research indicates that integrating digital tools can modestly improve student learning outcomes – though results vary by context and implementation quality. A comprehensive review by Higgins et al. (2012, 2019) found consistent but small positive associations between classroom technology use and the attainment of school-age learners. For example, Chauhan (2017) reported a medium positive effect of technology-enhanced learning in primary education compared to traditional instruction. In a meta-analysis of 1:1 laptop programs spanning various countries, researchers found a small positive effect on students' test scores, alongside qualitative benefits like greater engagement (Zheng et al., 2016). Mobile learning initiatives also yield moderate gains as noted earlier (Kalati & Kim, 2022).

Importantly, when digital tools are used to augment instruction (rather than replace it), they can support deeper understanding. Interactive simulations, educational games, and multimedia content often increase student engagement, which is a key mediator for learning gains. A review of digital game-based learning in K-12 found that incorporating games led to improved performance in both mathematics and science, as games allowed practice of skills in motivating contexts (Pan et al., 2022). Likewise, studies have documented technology-driven improvements in specific skills: for instance, literacy outcomes have benefited from ICT use with positive effects on language learning, writing, reading comprehension (Chen, Wang & Wang, 2022; Savva, Higgins & Beckmann, 2022). Also there are reports on higher mathematics achievement through computer-assisted instruction (Ran, Kim & Secada, 2022; Pan et al., 2022).

However, not all findings are universally positive. A subset of studies report no significant differences or even negative effects on learning from technology use (Kalati & Kim, 2022; Timotheou et al., 2023). In one review of tablet interventions, 5 out of 23 studies showed no benefit and 2 showed negative impacts on learning outcomes (Timotheou et al., 2023). Another analysis of touchscreen device use with young children found mixed results – while roughly two-thirds of studies showed positive effects, some showed null or negative effects (Zheng et al., 2016). These mixed results underscore that technology's impact depends on how it is implemented. Factors like the quality of software content, the teacher's ability to integrate the tool into pedagogy, and the alignment with curriculum all influence outcomes. When devices are used primarily for passive consumption or when teachers are not adequately trained, the gains can be minimal. On the other hand, structured programs with clear instructional design (e.g. combining pre-lesson activities, guided use during class, and post-lesson reviews) tend to yield better results (Bado, 2022).

Digital Competence: One often overlooked outcome of digital integration is the development of students' (and teachers') digital competencies. By working regularly with technology for learning, students naturally acquire skills in navigating information, using productivity tools, and creating digital content. Research confirms that ICT use in education boosts digital skills – for example, a study noted that exposure to digital tools in class improved teachers' ICT skills, especially among those who had experience integrating tech into lessons (Didmanidze et al., 2023) Students in one-

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to-one laptop classrooms also demonstrated gains in information literacy, media literacy, and technical skills as a direct result of frequent device use (Zheng et al., 2016). The relationship is bidirectional: greater digital competence allows more effective use of technology, which in turn can further enhance competence (Timotheou et al., 2023). Consequently, many education systems now include digital literacy in their core learning objectives, treating it as a critical outcome alongside traditional academics.

Broader Skills and Engagement: Effective tech integration can foster 21st-century skills such as critical thinking, problem-solving, collaboration, and creativity (Fielding & Murcia, 2022; Haleem et al., 2022; Liu et al., 2022; Quah & Ng, 2022). ICT is often linked to more student-centred pedagogies – e.g. project-based learning, collaborative research, and creative multimedia projects. Studies have found that technology-rich environments encourage students to take more ownership of their learning (self-directed learning) and engage in collaborative inquiry (Lei et al., 2022). For instance, using online collaboration tools and communication platforms in class has been associated with improved teamwork skills (Donia et al., 2021) and more frequent peer learning interactions (Banson & Hardin, 2022). Additionally, certain digital tools build specific cognitive skills: one review highlighted gains in metacognitive skills, computational thinking, and even emotional regulation skills through targeted educational software (Verschaffel et al., 2019). These ancillary benefits suggest that digital integration, when aligned with pedagogy, can contribute to well-rounded skill development, not just content knowledge.

Factors Influencing Effective Integration of Technology

Research consistently shows that the effectiveness of technology in education depends on implementation factors. Key factors include:

- Teacher Training and Pedagogy: The presence of skilled, confident teachers is perhaps the most crucial factor. Teachers need professional development to learn not only the technical aspects of new tools but also the pedagogical strategies to incorporate them into lessons. Teachers who receive training and support for technology use report significantly higher effects on student outcomes compared to those without such support. This is supported by multiple studies highlighting the importance of professional development, teacher self-efficacy, and continuous support in enhancing the effectiveness of technology integration in education (Jiang et al., 2025; Malik, 2023; Wang, 2024). Conversely, a lack of teacher knowledge about how to integrate ICT (both technically and instructionally) can limit the benefits. Teachers' attitudes also matter – those with positive attitudes toward ICT and a belief in its value are more likely to use it effectively. Building teachers' digital competence and comfort (through ongoing coaching and communities of practice) can therefore amplify the impact on students.

- School Leadership and Infrastructure: A supportive school leadership that prioritises innovation and provides necessary resources creates an environment where digital integration can flourish. Adequate infrastructure (reliable internet, sufficient devices, technical support) is foundational. Studies during the pandemic noted that schools with higher "digital capacity" – including infrastructure and staff competence – were able to transition more smoothly to online learning and mitigate learning losses. Leadership can also set policies (e.g. on device use, digital

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citizenship) that maximise positive uses of tech and minimise distractions or misuse. (Timotheou et al., 2023)

• Integration Strategy (Blend and Balance): How technology is blended with traditional teaching affects outcomes. It's most effective when used to supplement and enhance teacher-led instruction, not simply automate learning. For example, blended learning models (combining face-to-face teaching with online components) have shown success because they leverage the strengths of both. A review by Tamim et al. (2015) found that using tablets in a blended approach led to improved note-taking, organization, communication, and creativity among students. Similarly, structured use of games or simulations (with pre-briefing and post-activity debriefing by teachers) maximises learning gains (Bado, 2022). It's also important to balance screen time with other activities – pure digital immersion without variation can diminish returns (we discuss this balance more in the section on Digital-Biophilic interplay).

• Student Age and Subject: The impact of technology can differ by grade level and subject area. Some research suggests younger students need more guided and tactile learning experiences, so tech tools for early childhood should be used judiciously (e.g. interactive stories or educational games with adult support). In contrast, older students can benefit from more self-directed online learning opportunities. Subject-wise, technology integration in math and science (such as simulations, virtual labs) often yields clearer gains in test scores (Çelik, 2022), whereas in reading and writing the results have been more varied. Nonetheless, numerous studies have shown positive effects of word processors, blogs, or online feedback systems on students' writing quality (Wen & Walters, 2022). The key is selecting tools appropriate to the learning objectives of each subject and the developmental stage of students.

In summary, digital tool integration offers significant opportunities to enrich education, fostering interactive learning and preparing students with essential digital skills. The evidence base shows modest but positive effects on academic achievement when technology is well-implemented, with notable improvements in engagement, personalised learning, and skill development (Timotheou et al., 2023). The most successful integrations treat technology as one component of a broader pedagogical strategy, supported by training, infrastructure, and ongoing evaluation. As we turn to the next section, we delve deeper into personalisation, a pedagogical approach greatly enabled by digital innovation.

3. Personalised Learning Approaches

Every student has unique learning needs, paces, and interests. Personalised learning approaches aim to tailor education to the individual learner, often leveraging technology and data to do so. This section examines adaptive learning technologies, data-driven personalisation methods, and their effectiveness in improving academic outcomes. We also discuss theoretical foundations of personalized learning and practical examples of its implementation.

Concept and Theoretical Foundations

At its core, personalised learning seeks to move away from the one-size-fits-all model of instruction toward a more customised experience for each student. The concept is supported by educational theories dating back decades. Bloom's mastery learning (Bloom, 1968) and his

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famous “2 Sigma Problem” (1984) demonstrated that one-on-one tutoring and allowing students to master content at their own pace could yield performance two standard deviations higher than traditional class instruction. This provided a benchmark for what highly personalised, mastery-based learning could achieve. However, individual tutoring for every student is impractical at scale – a challenge Bloom posed to educators to “find group methods as effective as one-to-one tutoring.” Modern personalised learning, especially with computer-based tutors, is in many ways a response to that challenge, using technology to approximate individualised support for each student.

Adaptive learning technology is a key enabler. These are software systems (often driven by algorithms and AI) that continuously assess a learner’s performance and adjust the difficulty or type of content accordingly. For example, an adaptive math program will give slightly harder questions once a student demonstrates mastery of a concept, or provide remediation on topics where the student struggles. The underlying principle is Vygotsky’s Zone of Proximal Development (ZPD) – teach in the zone where the material is just beyond the student’s current ability but can be learned with guidance. Adaptive systems attempt to stay in each learner’s ZPD by analysing data in real-time.

Data-driven personalisation also extends to using analytics from assessments, quizzes, and even student behaviour (e.g. time spent on tasks) to inform instruction. Teachers can use dashboards to identify which students need extra help on which topics, enabling targeted interventions. The rise of learning analytics and AI in education has provided tools to implement personalised pathways at scale, something not feasible in traditional classrooms where one teacher must manage 20–30 students simultaneously.

From a theoretical standpoint, personalised learning aligns with constructivist and learner-centered paradigms. Students can have voice and choice in what or how they learn, pursuing interests (project-based learning tailored to their passions, for instance) which increases motivation. It also connects with self-determination theory: by personalising goals and allowing autonomy, students may feel more ownership (fulfilling needs for autonomy and competence). Moreover, personalised learning can incorporate formative assessment theory – using frequent low-stakes assessments to guide next steps – essentially closing feedback loops quickly for each student.

That said, “personalised learning” is a broad umbrella and can be defined in various ways. It can involve technology (adaptive software) but also non-tech methods (individualised projects, differentiated instruction by teachers). As Education Week noted, proponents have struggled to define it and implementations vary widely (Herold, 2016). For clarity, this review focuses on approaches that explicitly use adaptive or individualised instruction strategies, often supported by digital tools, to cater to student needs.

Adaptive Technologies and Data-Driven Personalisation

Modern classrooms use several adaptive and data-informed tools, such as:

• Intelligent Tutoring Systems (ITS): These are computer programs that provide step-by-step tutoring in subjects like math, science, or language. Examples include Carnegie Learning’s

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Cognitive Tutor or ASSISTments. They pose problems, give feedback, hints, and adapt the sequence of problems based on student responses. ITS are designed based on cognitive science models of how students learn specific skills. Studies have shown they can achieve similar outcomes to human tutoring in certain constrained domains. For instance, some algebra ITS have been found to significantly improve problem-solving skills compared to regular practice, by giving immediate feedback and targeted hints. (Koendinger & Alaven, 2016)

- Adaptive Practice Apps: Many educational apps (for math fact practice, vocabulary, etc.) have built-in adaptivity. If a student is excelling, the app might skip ahead to more advanced material; if a student is struggling, it will review prerequisite skills. This ensures each student is appropriately challenged. Platforms like Khan Academy also adapt by recommending specific videos or exercises based on a learner's past performance (Khan's mastery system requires answering a certain number of questions correctly before moving on).

- Personalised Learning Platforms: Some schools have implemented comprehensive software that orchestrates a personalised schedule for each student. For example, the Summit Learning Platform (used in some U.S. schools) provides personalised learning plans where students progress through content at their own pace, with teachers acting as mentors. These platforms often use data from assessments to generate daily or weekly "playlists" of tasks for each student, mixing individual practice with teacher-led workshops on topics the student hasn't mastered. (Reddy et al., 2015)

- Learning Analytics Dashboards: Even when students learn in traditional settings, teachers can use data dashboards from LMS or assessment tools to personalise support. For instance, after an online quiz, a dashboard might show which questions a particular student got wrong, allowing the teacher to assign a review activity specifically addressing that misconception. Over time, analytics can profile learning patterns, helping educators intervene early (e.g., identifying a student who consistently struggles with reading comprehension and providing targeted literacy support). (Ramaswami et al., 2019)

Research in low- and middle-income countries (LMICs) provides compelling evidence for the effectiveness of tech-supported personalised learning. A meta-analysis by Major et al. (2021) spanning 16 studies in countries such as China, India, and Malawi found that technology-supported personalised learning has a statistically significant positive effect on learning outcomes for school-aged children. The overall effect size was modest (one analysis reported an average effect size ~0.18) but meaningful. Notably, the benefits were observed in both math and literacy, and it didn't matter whether teachers played an active personalising role or if the software handled personalisation – both models yielded improvements. The meta-analysis also found that adaptive or "responsive" personalisation led to significantly greater gains than more basic forms of personalisation (Major et al. 2021). In other words, programs that dynamically adjusted content to the learner (rather than just offering a menu of choices) produced larger learning improvements. This aligns with intuition: a system that continuously targets a student's current level can push their learning more effectively.

Interestingly, the study noted that interventions of moderate duration and intensity were about as effective as very long or intensive ones (Major et al., 2021). This suggests that one does not need

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endless hours of personalised software use to see results; even moderate use, integrated thoughtfully, can benefit students. It also implies diminishing returns beyond a certain point, and that personalized learning can be balanced with other methods.

Academic Outcomes: Personalised learning, when well-implemented, can improve academic achievement, especially for students who might be behind. In the RAND Corporation's studies of U.S. schools adopting personalised learning, students made greater gains in math (and to some extent reading) compared to similar students in traditional schools (Pane et al., 2015) In one analysis of 11,000 students across 62 schools, those in personalized learning environments progressed faster, and the longer they experienced personalized practices, the larger their growth (Pane et al., 2015). These gains were modest on average but consistent, with some schools seeing quite substantial improvements, particularly in mathematics. Personalised approaches can be particularly beneficial for struggling learners – by meeting them at their level, these students can make catch-up gains. At the same time, high-achieving students are not held back and can advance to more challenging work, which keeps them engaged. This ability to differentiate effectively is why personalisation is viewed as a promising strategy for equity; it aims to give each student what they need to succeed.

However, it's important to temper expectations. As of the mid-2010s, the overall research base was still emerging and results were mixed, leading some experts to caution against viewing personalised learning as an educational panacea (Pane et al., 2015). Implementation details greatly influence outcomes. Many of the successful cases involved charter schools or well-resourced programs with flexibility to redesign schedules, train teachers, and adopt new curricula – conditions that may not exist everywhere.

Learner Engagement and Autonomy: Beyond test scores, personalised learning often yields improvements in student engagement and ownership of learning. When students have individualised goals and can see their progress (e.g., via gamified progress dashboards or weekly mentoring sessions to review their learning plan), they tend to develop greater intrinsic motivation. In one study, increased student engagement was identified as the key mechanism behind improved classroom climates in schools using personalised/SEL approaches (Elmi, 2020). Students in personalised settings often report feeling more supported and capable, as the work is neither too easy nor too hard. Additionally, personalisation can incorporate student interests (for example, letting a student interested in sports read articles about athletics to practice literacy skills), making learning more relevant and enjoyable.

Equity and Differentiation: Personalised learning can help address diverse learning needs in a classroom – including those of students with learning disabilities or those who need enrichment. Adaptive systems don't judge; they simply respond to performance, which can build confidence in students who might feel embarrassed to ask for help in a full class setting. Moreover, by analysing data without bias, these systems can sometimes catch issues teachers might miss (e.g., a quiet student who is falling behind). That said, equitable personalisation requires ensuring all students have access to the technology and support needed – otherwise it could widen digital divides. It also requires culturally responsive content; personalised learning isn't just about pacing, but also about connecting to students' lives.

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Implementation Challenges and Considerations

While the promise is high, implementing personalised learning comes with challenges:

• Defining Personalised Learning: As mentioned, the term covers many practices (Herold, 2016). Schools must clarify their model – is it primarily driven by adaptive software? Daily individualised learning time? Project-based learning choices? Without a clear vision, efforts can become disjointed.

• Teacher Role Shift: In personalised models, teachers often move from whole-group instructors to facilitators or coaches. They may run small-group workshops, analyse data, and mentor students individually. This shift requires training and mindset changes. Some teachers struggle to "let go" of control, while others struggle to manage a classroom where different students may be doing different tasks simultaneously. Successful models (e.g., in some charter networks) usually provide extensive teacher training and coaching on how to manage personalised learning classrooms and use data effectively.

• Quality of Content: Not all adaptive software is pedagogically sound. There's a risk of "drill and kill" software that personalises in a narrow sense (simply cycling through rote problems). High-quality personalised learning still needs rich tasks, critical thinking, and opportunities for discussion and collaboration. Schools need to vet tools carefully to ensure they align with deeper learning goals.

• Data Privacy and Monitoring: Personalised learning generates a lot of student data. Ensuring privacy and using data ethically is paramount. Additionally, data is only useful if someone monitors and acts on it. Teachers can be overwhelmed by data overload. Effective implementations often designate times for teachers to review data (professional learning community meetings) and have easy-to-use dashboards that highlight key insights rather than raw numbers.

• Equitable Access: If personalised learning relies on technology at home (e.g., homework on adaptive software), students without reliable internet or devices at home could be disadvantaged. Programs must strive to provide access (through school devices or offline options) to all students.

Case Example – Schoolwide Personalised Learning: A notable example of personalised learning in practice is the case of C Summit Public Schools (a charter network in the U.S.) which worked with the Chan Zuckerberg Initiative to develop a Personalised Learning Platform. Summit schools restructured their model such that students spend part of the week on self-directed learning through the platform and part in project-based learning. An evaluation by RAND found that Summit students made gains above national averages in some subjects, and students reported learning how to learn – e.g., setting goals and managing their time. Another example is Carpe Diem schools, which had a "learning center" with rows of computers where each student worked through a personalized curriculum at their own pace, combined with breakout sessions with teachers. These schools reported high test score improvements initially, although sustaining the model proved challenging when scaling up.

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On the international front, in India, a program called Mindspark (an adaptive learning software for math) was used in after-school centers for low-income students. A randomised controlled trial showed that students using Mindspark significantly outperformed the control group in math and Hindi after 4.5 months – essentially bridging a gap of several months of learning (Major et al., 2021). This study, published in 2021, highlighted how a well-designed adaptive software, when used regularly, can directly impact learning outcomes in a developing country context. The success was attributed to the software's fine-grained alignment with the curriculum and immediate feedback and remediation for each student, which is something regular classes struggled to provide.

These case studies illustrate both the potential and the intricacies of personalised learning. Where it works, it can accelerate learning and engage students; where it falters, it often ties back to issues of implementation, support, or clarity. Schools and systems venturing into personalisation should do so with a commitment to continuous improvement, monitoring outcomes, and being ready to iterate on their approach.

Effectiveness and Outlook of Personalised Learning

The evidence thus far suggests that personalised learning can be effective in improving outcomes, but typically requires a supportive ecosystem. The 2021 meta-analysis (Major et al., 2021) concluded that personalised learning had a significant positive effect, answering in the affirmative that tailoring instruction can indeed boost achievement. These effects applied across subjects and student demographics, indicating broad utility.

However, researchers caution against hype. A 2016 review by Education Week, after surveying dozens of studies, noted that while there are "bright spots" with promising results, these are often context-dependent and not easily generalised (Herold, 2016). The field still lacks definitive evidence on which specific personalised practices work best and how to implement them cost-effectively at scale (Pane et al., 2017). There are also critical voices arguing that resources might yield better returns if invested in proven methods like smaller class sizes or more teachers, rather than unproven tech-driven personalisation (Herold, 2016).

In conclusion, personalised learning is a compelling approach with a growing evidence base behind it. Adaptive learning technologies and data-driven methods offer a way to make the ambitious goal of educating every child at their level more feasible. The theoretical ideal (Bloom's 2-sigma tutoring effect) shows what's possible; actual programs have inched closer to that ideal, but with effect sizes more modest than one-on-one tutoring. The key is to treat personalised learning not as a silver bullet but as one strategy among many – to be integrated with solid teaching practices, SEL support, and a rich curriculum. When done thoughtfully, it can lead to more engaged, self-directed learners who achieve academically and carry forward the skills to be lifelong learners (Major et al., 2021).

4. Socio-Emotional Learning (SEL) Strategies

Cognitive development and academic achievement in children are deeply intertwined with their social and emotional well-being. Social and Emotional Learning (SEL) refers to the process through which students (and adults) acquire and effectively apply the knowledge, attitudes, and

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skills necessary to understand and manage emotions, set and achieve positive goals, feel and show empathy for others, establish and maintain positive relationships, and make responsible decisions. This section explores methods for incorporating SEL in schools, the impact of SEL on mental health and social skills, and evidence of its effect on academic outcomes. We also examine theoretical frameworks like the CASEL model and real-world implementation examples of SEL programs.

Importance and Frameworks of SEL

Educating the "whole child" involves nurturing not just academic abilities but also emotional intelligence, character, and interpersonal skills. Over the past two decades, SEL has gained prominence globally as essential for positive youth development. In fact, a council of scientists concluded that social-emotional competencies are "essential to learning, positive development, and success in school, careers, and life" (Greenberg, 2023). This broad consensus is reflected in the uptake of SEL standards: more than half of U.S. states, for example, have adopted SEL competencies or standards for schools, and many countries have integrated SEL or "life skills" into their curricula (Greenberg, 2023).

The most influential SEL framework is that of the Collaborative for Academic, Social, and Emotional Learning (CASEL). The CASEL framework identifies five core competency clusters: Self-Awareness, Self-Management, Social Awareness, Relationship Skills, and Responsible Decision-Making (Collaborative for Academic, Social, and Emotional Learning, n.d.). These competencies encompass skills like recognising and regulating one's emotions, setting goals, showing empathy and respect for others, teamwork, and making ethical, constructive choices. SEL programs and curricula are often structured around fostering these five areas in developmentally appropriate ways. For instance, self-awareness in early elementary might involve identifying basic emotions, whereas in high school it might involve reflecting on personal strengths and values.

The CASEL framework also emphasises that SEL doesn't happen in isolation – it should be integrated across classrooms, schools, families, and communities to be most effective. This systemic approach means creating a supportive school climate and culture that reinforces social-emotional skills throughout the day (not just in a once-a-week lesson). Theoretically, SEL draws on psychology fields such as developmental psychology (e.g., Erikson's stages of socio-emotional development), emotional intelligence theory (Salovey & Mayer, 1990), and prevention research (resilience, anti-bullying, etc.). It aligns with Maslow's hierarchy in that a child's sense of safety, belonging, and esteem are foundational for higher-order learning.

Furthermore, follow-up research indicates that personalised interventions can have lasting benefits. In one follow-up study of an early Social and Emotional learning program, students not only improved academically in the short term but were also more likely to graduate high school on time and showed better social-emotional outcomes years later (Taylor et al., 2017). The idea is that personalisation and socio-emotional learning strategies build academic foundations and confidence that carry forward in a student's educational trajectory.

SEL Implementation Strategies

Schools implement SEL through various methods:

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- Standalone SEL Curriculum: Many evidence-based programs offer a scripted curriculum taught during a dedicated time (e.g., 30 minutes a week). Examples include Second Step, PATHS (Promoting Alternative THinking Strategies), and MindUp. These curricula use stories, role-plays, discussions, and activities to teach specific skills like emotion regulation or problem-solving. For younger children, lessons might involve puppets and songs; for older students, perhaps group discussions on ethical dilemmas. Standalone curricula ensure explicit teaching of SEL skills.

- Integration into Academic Instruction: Some schools integrate SEL objectives into regular academic lessons. For example, while teaching literature, a teacher might have students reflect on characters' emotions and perspectives (building social awareness and empathy). Math teachers might emphasise goal-setting and resilience when solving challenging problems. This approach normalises SEL as part of everyday learning and shows students how these skills apply in all contexts. Teachers using this approach often receive training on how to incorporate SEL "moments" into their subject teaching.

- Schoolwide Practices and Routines: Building a positive school climate is crucial. Strategies include morning check-ins or circles where students can share how they're feeling, mindfulness exercises to start the day, having a "peace corner" or calm-down space in classrooms for emotion regulation, and establishing school norms like respect and inclusivity. Older students might participate in advisory periods focusing on SEL or mentorship programs. Additionally, restorative justice approaches to discipline (as opposed to punitive measures) align with SEL by teaching conflict resolution and empathy.

- Teacher Modeling and Training: Teachers and staff are frontline implementers of SEL. Training educators in SEL not only equips them to teach skills but also often improves their own well-being and teaching practice (Greenberg, 2023). Adults model SEL competencies – e.g., a teacher openly acknowledging stress and demonstrating coping strategies can model self-management for students. Some programs focus on adult SEL, helping teachers develop mindfulness or emotional intelligence, under the logic that teachers with strong SEL skills foster better classroom climates and student outcomes (Greenberg, 2023).

- Family and Community Engagement: Effective SEL initiatives often involve parents and the community. Parent workshops might inform families about the skills being taught and suggest activities to reinforce them at home (like family discussions using "feeling" words). Community service projects conducted by students can build empathy, social awareness, and relationship skills in real-world settings and also demonstrate these values outwardly.

Regardless of method, research highlights that SAFE practices – Sequenced, Active, Focused, and Explicit skill training – are important for successful SEL (Durlak et al., 2011). Sequenced means there is a logical progression of skills; Active means engaging students in forms of learning like role-play or practice rather than passive listening; Focused refers to dedicating time specifically to SEL goals; and Explicit means targeting specific social-emotional skills rather than hoping they are an indirect byproduct.

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Impact on Student Well-Being and Social Skills

Decades of research, synthesised in multiple meta-analyses, provide robust evidence that SEL programs have wide-ranging benefits. A landmark meta-analysis of 213 school-based SEL programs by Durlak et al. (2011) found that, compared to control groups, students who participated in SEL significantly improved in their social and emotional skills, attitudes, and behaviour. These students also showed an 11-percentile-point gain in academic achievement on average relative to peers. In other words, SEL not only enhanced soft skills and reduced problem behaviours, but also translated into better grades and test scores – affirming the connection between emotional well-being and cognitive performance. The analysis also noted that programs were effective when run by regular school staff (not just outside experts) and that proper implementation (following recommended practices and ensuring program fidelity) led to better outcomes. (Durlak et al., 2011)

Subsequent research has reinforced and extended these findings. A review of 12 meta-analyses by the Learning Policy Institute concluded that SEL programs show medium to large effect sizes on various student outcomes (Greenberg, 2023). Specifically, SEL promotes positive social behaviours and relationships, reduces disruptive behaviour and emotional distress, and increases students' engagement in learning. For example, students in SEL programs tend to exhibit more kindness and cooperation and less aggression or bullying. They are also less likely to experience depression, anxiety, or behaviour problems, as numerous studies have documented decreases in conduct problems and internalising issues (like stress) among SEL participants (Greenberg, 2023).

By fostering skills like empathy and conflict resolution, SEL creates a more positive peer environment. Classrooms that implement SEL with fidelity often see improved classroom climate. One study found independent observers rated classrooms using the RULER SEL approach as having more positive emotional climate and better organisation than non-SEL classrooms (RULER Approach, n.d.). The improvement was attributed to higher student engagement and more emotional support in those classrooms. In essence, when students learn to manage their emotions and work well with others, the entire class functions more smoothly, which further supports learning.

Crucially, SEL skills are linked to long-term outcomes. A follow-up meta-analysis by Taylor et al. (2017) looked at studies with outcomes 6 months to 18 years after SEL intervention. It found that benefits endured over time – SEL students still fared better than controls in social-emotional competencies, attitudes, and well-being years later. They also had on average higher high school graduation rates and healthier behaviours (such as lower likelihood of drug use or mental health issues in later years). The lasting impact is likely because SEL imparts fundamental life skills; improvements in self-control, for instance, can affect one's trajectory in education and beyond. Notably, these benefits held across demographic groups – SEL was effective for students of different races, socioeconomic backgrounds, and in different countries, indicating a universal human relevance of these skills.

One area of growing interest is SEL's role in supporting mental health. Given rising concerns about student anxiety, depression, and suicide, many schools look to SEL as a preventive measure.

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Research supports that SEL programs, by teaching coping strategies and providing social support, help reduce symptoms of stress and emotional distress in children (Greenberg, 2023). For example, teaching a child how to recognise when they are getting upset, and to use a calming strategy (deep breathing, taking a break, talking to someone), can mitigate anxiety. Building a sense of belonging at school through SEL initiatives can protect against feelings of isolation. While SEL is not a replacement for clinical interventions when needed, it forms a first line of defence in creating resilient, emotionally healthy students.

Academic Outcomes: Students with better SEL skills tend to do better academically. Because skills like self-management and responsible decision-making mean students can focus better, persist through challenges, and organise their work. Improved relationship skills lead to better student-teacher and peer relationships, contributing to a more supportive learning environment. A review summarising multiple meta-analyses noted that by increasing engagement in learning, SEL subsequently improves cognitive and academic performance (Greenberg, 2023). Indeed, many educators now see SEL as not ancillary but foundational to academic success: a child not burdened by unmanaged stress and who knows how to seek help is more ready to learn reading, math, and science.

SEL Case Studies and Programs

Case Example – The RULER Program: One well-studied SEL program is RULER, developed at the Yale Center for Emotional Intelligence. RULER is an acronym for five emotion skills (Recognising, Understanding, Labeling, Expressing, Regulating emotions). It provides training for school leaders, teachers, students, and families to create an emotionally intelligent school culture. In a controlled study at the late elementary level, classrooms were randomly assigned to implement RULER or not. After one year, students in RULER classrooms had higher academic grades in English and better work habits than those in non-RULER classrooms (RULER Approach, n.d.). Teachers also rated RULER students as having better social skills. Additionally, independent observers found that after two years, RULER classrooms showed more emotional support and better classroom organisation compared to control classrooms (RULER Approach, n.d.). The increased student engagement in RULER classes was identified as key to these improvements. This case demonstrates how a structured SEL program can tangibly enhance both the learning environment and academic performance. It also highlights the importance of sustained implementation; many SEL programs show stronger effects after the first year, once the practices take root.

Case Example – Districtwide SEL (Anchorage, Alaska): Anchorage School District implemented a comprehensive SEL initiative across all its schools in the 2000s. They provided a district SEL curriculum, teacher training, and measured school climate regularly. Over several years, the district reported a steady increase in academic achievement (state test scores) concurrently with improved student behaviour and reduced disciplinary incidents. While causation is complex, analysis by CASEL indicated that the SEL focus likely contributed to these positive trends. For instance, suspension rates declined as students learned conflict resolution skills, which meant more instructional time for those students. Teachers reported that with SEL, students were more ready to learn and cooperative, allowing them to cover material more effectively.

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Global example: In the UK, a nationwide initiative called Social and Emotional Aspects of Learning (SEAL) was introduced in most schools in the late 2000s (Department for Education, 2010). It provided a whole-school framework for teaching SEAL themes (self-awareness, managing feelings, empathy, etc.). While early evaluations of SEAL showed mixed quantitative results (possibly due to inconsistent implementation), qualitative feedback from schools was that it helped create a more caring ethos and improved student-teacher relationships. Some schools saw reduced bullying and improved attendance associated with their SEAL work. The lesson was that implementation fidelity and integration into school policies (as opposed to one-off lessons) were crucial for success.

Integration with Technology: A modern development is the use of digital tools to support SEL. For example, some schools use apps where students can daily check-in their mood (creating a quick way for teachers to gauge who might need support) or use online platforms for mindfulness exercises. During remote learning phases, educators had to find ways to do SEL virtually – such as virtual circle time or using video discussions for students to share feelings. Initial studies suggest SEL can be adapted to online environments, though in-person interaction remains very important.

Overall, these case studies illustrate that SEL is versatile – it can be adapted to different age groups (pre-K through high school) and cultural contexts, and it can be delivered at the classroom, school, or district level. The common thread in success stories is a strong commitment to creating a positive environment and explicit teaching of skills, supported by training and leadership.

Recommendations from SEL Research

Given the strong evidence base, experts widely recommend making SEL a standard part of education. The 2011 Durlak meta-analysis ended with a clear call: policymakers, educators, and the public “can contribute to healthy development of children by supporting the incorporation of evidence-based SEL programming into standard educational practice.” (Durlak et al., 2011). In practice, this means SEL should not be seen as an optional add-on or a one-time initiative, but as an integral component of schooling – akin to how we view literacy or math instruction. Many suggest starting SEL in early childhood and continuing through graduation, as each developmental stage offers opportunities to deepen these competencies.

For effective SEL implementation, research points to the need for ongoing professional development for teachers (Greenberg, 2023). Teachers and principals benefit from coaching in SEL practices and how to embed them in academics and school operations. Additionally, aligning SEL with other priorities (equity, trauma-informed practices, academic improvement) can create synergy. For example, SEL supports equity by teaching respect and empathy across differences, and by helping underrepresented students gain voice and agency in the classroom.

In summary, SEL strategies yield measurable improvements in students’ social skills, emotional well-being, behaviour, and academic success. The theoretical frameworks like CASEL’s provide a roadmap, and myriad programs have shown positive results when well-implemented. As the push for student mental health support grows, SEL stands out as a proven, proactive approach that schools can take. By helping students develop self-awareness, resilience, empathy, and

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responsible decision-making, we not only improve the immediate classroom environment but also equip young people with skills for success and fulfilment far beyond school.

5. Biophilic Learning Environment Design

The design of physical learning spaces has a profound impact on student engagement, well-being, and cognitive function. Biophilic design is an innovative approach that integrates natural elements into the built environment, capitalising on humans' innate affinity for nature (the biophilia hypothesis). In educational settings, biophilic design can manifest as green schoolyards, indoor plants, natural light and ventilation, nature-inspired materials and shapes, and even outdoor classrooms. This section defines biophilic learning environments, outlines their theoretical foundations and key components, and examines research on how such environments affect student mental health, attention, and academic performance. We also provide case examples of biophilic design in schools and discuss the measured impacts.

Definition and Theoretical Foundations

Biophilia, a term popularised by biologist E.O. Wilson, refers to the innate human tendency to seek connections with nature and other forms of life. The concept was initially introduced by psychoanalyst Erich Fromm in 1964 as "the passionate love of life and all that is alive," and later expanded by Wilson in 1984 who described it as humans' inherent inclination to focus on and affiliate with nature (Leif & Loftness, 2024). This idea suggests that because humans evolved in close contact with natural environments, our minds and bodies are optimised when we are in or around natural elements. Prolonged disconnection from nature, conversely, might have negative effects on well-being (a concept sometimes referred to as "nature-deficit disorder").

Building on this, Stephen Kellert and others in 2008 laid the foundation for biophilic design – deliberately designing buildings and spaces to reconnect people with nature (Leif & Loftness, 2024). Biophilic design applies biophilia as a strategy for architecture and sustainability, going beyond aesthetics to actively support occupants' health and performance. Kellert et al. (2008) identified elements and principles (such as incorporating natural materials, dynamic light, organic forms, and opportunities for interaction with nature) that can be translated into design practice. Another influential guide is Terrapin Bright Green's 14 Patterns of Biophilic Design (2014), which distilled biophilic design into patterns like Visual Connection with Nature, Non-Rhythmic Sensory Stimuli (e.g. breezes, bird sounds), Thermal & Airflow Variability, Presence of Water, Prospect & Refuge, etc. These frameworks provide a vocabulary and set of goals for architects and educators aiming to create nature-rich environments.

In the context of schools, biophilic design is seen as a way to create learning spaces that are not only more enjoyable but also healthier and cognitively restorative for students. Theoretical support comes from environmental psychology:

• Attention Restoration Theory (ART): Kaplan and Kaplan's (1989) theory posits that exposure to natural environments helps restore our directed attention capacities which get fatigued by prolonged concentration. A classroom with a window view of greenery or an outdoor break area can allow students' minds to recover from mental fatigue, leading to improved focus when they return to task.

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• Stress Reduction Theory: Ulrich and colleagues (1991) work suggests that natural views and elements can reduce stress and physiological arousal. In schools, lower stress levels can translate to better behaviour and concentration. There's a parallel to healthcare design: studies showed hospital patients with window views of nature recover faster and require less pain medication; similarly, students in biophilic spaces might experience less stress and anxiety.

• Sensory Stimulation and Neurodiversity: Biophilic environments provide varied sensory inputs (soft light, natural textures, ambient nature sounds) that can be soothing or gently stimulating in contrast to the often a monotonous fluorescent lighting and barren walls of traditional classrooms. This can particularly help students who are neurodiverse or prone to sensory stress – a natural palette is generally calming.

In sum, the theory is that by aligning school environments with humans' natural predispositions like providing daylight, fresh air, plants, organic forms, and access to the outdoors, we support students' mental and physical well-being, which in turn supports learning.

Key Components of Biophilic Learning Environments

A biophilic learning environment can be conceptualised through various elements and design choices. Based on biophilic design taxonomies and research on school spaces Leif & Loftness (2024), it is possible to propose key components for designing biophilic learning environment:

• Natural Light and Views: Maximising daylight in classrooms (through large windows, skylights) and providing views of natural landscapes or green spaces outside. Views of nature can capture attention in a positive way; even a tree outside or a school garden visible from class can have benefits.

• Indoor Greenery and Natural Elements: Incorporating plants inside classrooms and common areas. Indoor plants improve air quality by reducing CO_2 and pollutants, and research suggests they can reduce stress and increase attentiveness. Natural materials (wood, cork, bamboo) and nature-inspired textures/patterns (like fractal patterns that resemble those found in nature) also bring a biophilic touch. Even representations of nature (murals of landscapes, nature photography) can have positive effects.

• Outdoor Learning Spaces: Dedicated outdoor classrooms, school gardens, or semi-outdoor spaces (like courtyards) where classes can be held or students can engage in experiential learning. Outdoor education has long been championed in approaches like forest schools, and it aligns with biophilic design by directly immersing students in nature. Lessons in a school garden not only teach science or nutrition but also have been observed to boost engagement and teamwork. Outdoor play areas with natural features (trees, logs, sand, water) encourage imaginative play and physical activity more than flat asphalt yards.

• Natural Shapes and Forms / Biomorphic Design: Avoiding overly sterile, rectangular layouts in favour of more organic shapes, curves, and varied spaces. The example of the Ecokid Kindergarten in Vietnam illustrates this. The building features curvilinear forms and circular windows, creating a playful, less formal atmosphere (Morley, 2024). Such forms, along with

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colours and patterns inspired by nature (e.g., leaf motifs, fractal wall designs), subconsciously echo natural environments, which can feel more inviting and comfortable.

- Natural Color Palette and Lighting: Using calming earth tones or sky tones as opposed to harsh synthetic colors can set a soothing mood. Lighting that varies and mimics natural rhythms (such as bright blue-white light in the morning, softer warm light in the afternoon) might help regulate student energy levels, though this is an emerging area of research in schools.

- Ventilation and Air Quality: While not “biophilic” in a narrow sense, fresh air and comfortable temperatures are related. Operable windows, good cross-ventilation, or even outdoor hallways (common in some tropical school designs) can keep students connected to the outside air. Better air quality has been linked to improved concentration and lower absenteeism (poor ventilation leads to high CO_2, which makes students drowsy).

- Elements of Water or Animals: Some advanced designs incorporate aquariums, small ponds, or even school pets/animals as part of the environment. The presence of water (through sight or sound) can be calming and captivate attention gently. Contact with animals (like a class pet rabbit or visiting farm animals) can teach empathy and reduce stress, although such elements require care and are less common inside typical schools.

A recent study compiling evidence from various biophilic retrofits in schools summarised significant connections between these design elements and human outcomes: lower anxiety and stress levels, improved attention, enhanced cognitive function, greater student engagement, and even higher test scores (Leif & Loftness, 2024). For instance, simply adding more plants and improving views in a school was associated with reductions in students’ stress and improvements in their reported concentration. Also, schools that underwent greening projects (like adding gardens) sometimes reported increased science test scores, possibly due to both direct learning in the garden and the general cognitive benefits of a greener setting (Leif & Loftness, 2024).

Ecokid Kindergarten in Vietnam exemplifies biophilic school design: its organic, curving structures with circular windows and abundant outdoor play spaces keep children connected to nature. Such designs aim to reduce stress and uplift mood by ensuring nature is “never far from view,” whether students are indoors or outside (Morley, 2024).

Impact on Student Engagement, Mental Health, and Performance

An increasing body of empirical research points to tangible benefits of biophilic learning environments on students’ well-being and learning. A 2019 integrative review by Kuo, Barnes, and Jordan concluded that “converging evidence strongly suggests that experiences of nature boost academic learning, personal development, and environmental stewardship”. This review noted hundreds of studies across various contexts demonstrating positive effects of nature contact on youth. Specifically in academic contexts, they found that nature-based instruction tends to outperform traditional instruction, with evidence including improved standardised test scores and even graduation rates in schools that integrated nature significantly into their curriculum. Mechanisms identified include improved attention, reduced stress, greater interest and enjoyment in learning, increased physical fitness, and a “calmer, quieter, safer” context for learning (Kuo, Barnes & Jordan, 2019). In essence, nature acts as a buffer and enhancer – calming

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students and at the same time invigorating them in healthy ways, leading to better focus and persistence.

Attention and Cognitive Function: Natural settings have been shown to replenish directed attention. One experimental study had students complete cognitive tasks after a walk in either an urban setting or a park; those who walked in the park performed better on tasks of attention and memory. In classrooms, even the presence of plants or the colour green has been linked to small improvements in creative thinking and concentration. A literature review in 2021 found significant connections between biophilic design features and improved attention and cognitive function in learners (Leif & Loftness, 2024). Green schoolyards, for example, provide children with opportunities for imaginative play and exploration, which can enhance executive function and problem-solving skills.

Stress Reduction and Mental Health: Many studies document that students in greener environments show lower stress levels. Measurements of cortisol (a stress hormone) in students have found healthier diurnal patterns when schools have more exposure to nature (e.g., one study in Finland showed that students who experienced nature in their schoolyard had lower stress indicators). Biophilic design elements like natural light and wood have been associated with reduced anxiety in students (Leif & Loftness, 2024). In one pilot study, middle school students in a classroom enhanced with biophilic features (plants, nature views, natural materials) reported feeling significantly less stressed than their peers in a standard classroom (Browning & Determan, 2024). Another study used biometric measures (blood pressure and heart rate) to confirm lower physiological stress responses in the biophilic classroom (MD Sakip et al., 2024). Lower stress and anxiety can translate to better mood, fewer disciplinary issues, and a more positive attitude towards school.

Engagement and Behaviour: Biophilic environments tend to be more engaging and stimulating in the right ways. Features like gardens or aquariums naturally draw student interest and can spark curiosity (e.g., observing a butterfly life cycle in a school garden can enthral a child more than reading about it in a book). Classrooms with varied sensory elements (like a mix of indoor and outdoor spaces) may better hold students' attention. The toolkit study we referenced found improved student engagement in class linked to biophilic design interventions (Leif & Loftness, 2024). Teachers in greener classrooms often report that students are calmer and more on-task. Also, physical activity tends to increase with biophilic design. Schools that have outdoor learning or natural playgrounds see more movement, which can improve student focus when back in class (active bodies, active minds). A systematic review noted that greater access to green space was associated with higher physical activity and less time spent in sedentary screen-based activities for children (Byrd-Williams, Dooley & Thi, 2019), indirectly supporting healthier behaviours and readiness to learn.

Academic Performance: Some studies have directly measured academic outcomes in relation to biophilic elements. A remarkable case is a pilot study of a biophilic classroom in an urban middle school (Baltimore, USA) which compared one class that received a "biophilic makeover" to a control class without changes. The biophilic classroom had features like nature-inspired wall art, potted plants, a water feature, improved natural lighting, and furniture made of natural materials.

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Over the school year, the students in the biophilic classroom had math test score gains more than 3 times greater than those of students in the standard classroom (Determan et al., 2019). All assessment measures: surveys, interviews, cognitive tests, indicated the biophilic space was associated with reduced stress and enhanced learning outcomes. While this was a pilot (one school, relatively small sample), it provides proof of concept that altering the physical environment can significantly affect learning.

Not every study finds dramatic test score jumps, but the trends are consistent. For instance, research summarised in the MDPI Architecture special issue noted improved standardised test scores in several instances after biophilic interventions (Leif & Loftness, 2024). Even graduation rates have been tentatively linked: one cited study found a correlation between incorporating nature and higher graduation rates for high schoolers. These outcomes make a strong case that biophilic design is not just about aesthetics or student preference; it's about measurable educational benefits.

Health and Attendance: Biophilic design can also improve physical health factors (better indoor air quality reduces asthma triggers, natural light can lessen headaches and eye strain) which in turn reduce absenteeism. A longitudinal study in Canada (Jarvis et al. 2021) found that for every 10% increase in neighbourhood vegetation around a child's home, there was a small but significant increase in kindergarten developmental scores. Presumably because greener environments at home and school support healthier development. If students are healthier and more present in school, their learning naturally benefits.

Case Studies and Examples

Several real-world examples illustrate biophilic design in education:

- "Forest Schools" and Outdoor Education: In countries like Denmark, Sweden, and some U.S. contexts, forest kindergartens or nature schools conduct large parts of the day outdoors, year-round. Children in these programs often show advanced motor skills, high levels of creativity, and low stress. While fully outdoors might not be feasible everywhere, many schools have adopted elements like weekly outdoor lessons or creating "outdoor classrooms" with log seating in a wooded area on campus.

- Green School, Bali: The Green School in Indonesia is an international example of biophilic design taken to an extreme. Classrooms are open-air bamboo structures, there are gardens and animals integrated into campus, and much of the learning is project-based with sustainability themes. Students reportedly are highly engaged and develop strong environmental stewardship (as expected), and the unique environment is a big part of the school's identity, though formal studies of academic outcomes aren't widely published.

- Singapore's School Rooftop Gardens: In land-scarce Singapore, many schools have created rooftop or courtyard gardens, not only as aesthetic features but as functional learning spaces (for biology lessons, etc.). The Ministry of Education found that these green spaces improved students' attitudes towards learning science and provided calming breaks in the day. Singapore also emphasises natural ventilation in many school designs, making the climate comfortable and reducing energy use.

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- Biophilic Retrofits in North America: The Green Schoolyards for Healthy Communities initiative in several U.S. cities (like Chicago, Philadelphia) has transformed asphalt playgrounds into green oases with trees, gardens, and permeable surfaces. Evaluations of these retrofits found that students in schools with green schoolyards had increased physical activity, more positive feelings about school, and teachers noted improved focus after recess in the green yard versus the old concrete yard. In one Chicago school, reading scores rose in the years following the yard greening, though many factors could contribute to that.

- Case: James L. Capps Middle School (Oklahoma, USA): This school undertook a biophilic redesign of certain areas (as documented by a design firm Interface). They added features like a living plant wall, nature-themed carpeting, and murals of local landscapes. Students reported feeling more relaxed in those spaces, and teachers said it sparked more student curiosity (e.g., asking about the plants). While quantitative data wasn't immediately available, the school saw this as part of improving student well-being in tandem with an SEL program.

The adoption of biophilic design in schools is still an emerging trend, but momentum is growing. Organisations and researchers are actively showcasing exemplary "green" school designs and compiling evidence. For instance, the Children & Nature Network regularly shares research digests indicating benefits of nature engagement in educational settings. One digest highlighted that even mediated nature experiences (like virtual reality nature or indoor simulations) are better than none. Children using a VR nature therapy reported decreased pain and anxiety after surgery (Kucher et al., 2020). This hints at possibilities to combine technology with biophilia, which we will explore in the next section.

In conclusion, biophilic learning environment design aligns the school setting with students' biological and psychological needs. The research to date suggests it can play a significant role in improving student well-being (less stress, more joy), sharpening focus, and bolstering academic success. As one special issue editorial put it, nature provides a calm and safe context for learning by improving attention, reducing stress, and increasing curiosity. By taking nature seriously as a resource for learning, schools can tap into an often an underutilised avenue for enhancing education. The next frontier is to integrate these principles with other innovations leading us to a question, how do digital technology and nature-based design interact? The final thematic section examines the interplay between digital and biophilic approaches.

6. Interplay Between Digital Innovations and Biophilic Environments

At first glance, technology-enhanced learning and nature-based learning might seem to pull in opposite directions – one keeps students at screens, the other urges them outdoors. However, modern educational thought is increasingly about finding synergy between these domains rather than choosing one over the other. This section explores how digital innovations and biophilic design can complement each other, and what potential tensions exist. We discuss integrated approaches (like using technology in outdoor learning, or virtual nature experiences) as well as the importance of balancing "screen time and green time." The goal is to understand how schools can leverage both technology and nature to support student well-being and skill development in tandem.

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Synergies Between Technology and Nature in Education

Emerging research suggests that blending digital tools with natural environments can create enriched learning experiences that harness the benefits of both. An integrative approach recognizes that children are growing up in a digital world and that they need nature for healthy development – so the ideal is to give them ample opportunities for both, sometimes simultaneously.

One way technology and nature intersect is through outdoor experiential learning enhanced by tech. For example, students might use tablets or smartphones during field work: taking photos of plant species for a biology project, recording data on water quality in a stream, or using a GPS-based app for a geocaching treasure hunt that teaches mapping skills. Far from detracting from the nature experience, these technologies can engage students more deeply. A study in Canada followed early childhood educators who initially were hesitant to allow iPads during outdoor play. Over a three-year period, the teachers observed that when children did use tablets outside (for taking pictures of insects, making short videos of their play, etc.), it inspired more physical activity, creativity, and nature connectedness rather than less (McGlynn-Stewart et al., 2020). The educators found that technology, when used appropriately outdoors, actually encouraged children to explore their environment (e.g., "let's go find more leaves to photograph") and then reflect or create something with what they found. This case indicates that the binary of "screen vs. nature" can be broken, tech can be a tool to engage with nature.

Another synergy is using virtual reality (VR) or augmented reality (AR) to bring nature into the classroom when real nature access is limited. For urban schools with few green spaces or during seasons when outdoor time is impractical, VR can simulate natural environments providing students with an immersive pseudo-nature experience. Preliminary research on VR nature experiences, even in medical settings, shows they can induce some of the same benefits as real nature. One small study cited in a research digest had pediatric patients use a 3D nature VR therapy after surgery, and all reported it was enjoyable and helped reduce their pain and anxiety (Kucher et al., 2020). In an educational context, while VR isn't a replacement for touching and smelling real plants, it can spark curiosity and learning about the natural world (imagine a virtual field trip to the Amazon). AR can also be used in nature education. For instance, an AR app might overlay information on a leaf when viewed through a tablet, teaching students about that tree species on the spot.

Technology can also facilitate environmental monitoring and citizen science projects in schools. Students can use digital sensors to track weather, air quality, or bird populations in their schoolyard, contributing data to real scientific databases. This not only teaches STEM skills but deepens their connection to local ecology, blending digital literacy with environmental literacy. Such projects have been reported to increase student engagement in science and their sense of making a meaningful contribution.

Blended Learning and Biophilia: One interesting pedagogical approach is to take typically indoor, screen-based tasks and occasionally move them to outdoor settings. For example, a teacher might conduct a writing lesson under a tree in the schoolyard. Students could draft their essays on laptops while sitting in nature. The laptops provide the modern tool for writing and research

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(perhaps connected to Wi-Fi if needed), but the environment is biophilic. Anecdotally, teachers who try this note students often find it novel and enjoyable, and some students concentrate better in the fresh air. As long as glare or battery life isn't an issue, there's little downside. A balanced schedule might include a mix of indoor tech-rich time, outdoor tech-free time (recess or outdoor exploration), and hybrid time (using tech outdoors or using nature indoors via plants and natural decor).

Digital Nature Content: Another synergy is using the vast digital content available on nature to support learning. There are countless high-quality documentaries, interactive simulations (e.g., virtual lab of an ecosystem), and games about environmental conservation that can supplement real experiences. These can prepare students for outdoor learning (by giving background knowledge) or deepen it afterwards (by analysing data collected outdoors using computer software). A review by Siskind et al. (2020) provides an overview of benefits of both technology and outdoor learning for young children and explicitly argues for an integration of the two. They offer recommendations for teacher educators on how to guide teachers in balancing tech and nature in practice, highlighting that the two need not be at odds.

Balancing "Screen Time" and "Green Time"

While synergy is possible, there is also a real need to balance the time students spend in front of screens with time spent in natural, physical play and exploration. Concerns about excessive screen time include potential impacts on attention, sleep (especially blue light exposure), social skills (if screen displaces face-to-face interaction), and physical health (sedentary behaviour). On the other hand, as we have discussed, a lack of nature exposure can contribute to stress, attention fatigue, and diminished mental health. Therefore, educators and parents increasingly talk about balancing screen time and green time.

Research suggests that currently, many children do not get enough outdoor time, whereas screen use (for entertainment) is at an all-time high. However, one interesting historical analysis found that children today actually have more nature experiences than children in the year 1900 – but those experiences often include "mediated" experiences (e.g., via media or organised activities) rather than free play (Novotny et al., 2020). Still, the consensus is that deliberate efforts are needed to maintain a healthy balance.

Some guidelines that have emerged from studies and expert recommendations:

- Set aside tech-free nature time: Schools can ensure that recess is outdoors and screen-free, and perhaps institute "outdoor learning" periods where devices stay in pockets unless needed for a specific activity. Some educators use a "nature hour" approach, encouraging at least 60 minutes of outdoor time daily for younger students (which aligns with physical activity guidelines as well). In early childhood settings, a cross-sectional study in Texas found that while most centers met basic physical activity requirements, many did not meet recommended limits on screen time for 3–5 year olds, and very few fully utilised their outdoor environment (Byrd-Williams, Dooley & Thi, 2019). This indicates room for improvement: limiting non-educational screen time and maximising outdoor play opportunities.

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- Use screens as a gateway, not a wall: Encourage students to apply what they learn on screens in the real world. For example, if they research about butterflies online, follow it up by observing butterflies outside or creating a butterfly garden. If they play a nature-themed game, have a discussion about the real ecosystems or animals in the game. This way, screen activities feed into nature engagement rather than replace it.

- Green the screen time: Not all screen time is equal. Content matters. Time spent on creative, educational activities (like coding, digital art, or virtual science experiments) is generally more enriching than passive consumption. Similarly, content that encourages movement or interaction with surroundings (like an AR scavenger hunt) can blur the line – you're using a device but also moving through physical space. Educators can favour digital activities that have these qualities.

- Monitor and reflect: Teachers and parents can help students become aware of how they feel after too much screen time versus after time in nature. By guiding reflection, students might self-regulate – noticing, for instance, that after a long computer session they feel tense or tired, but a 10-minute walk outside makes them feel refreshed. This kind of self-awareness ties into SEL and can foster lifelong healthy habits.

The interplay of screen and green also has a societal equity dimension: not all students have safe parks or backyards to play in after school, and not all families can afford lots of technology at home. Schools might actually be the primary provider of both rich tech access and rich nature access for many children. A balanced school program ensures that students from all backgrounds get to build digital skills and experience the outdoors.

Potential Conflicts and Mitigations

There are potential conflicts between digital and biophilic initiatives if not carefully managed. One concern is that heavy emphasis on technology could further reduce time spent outdoors. Studies have indeed found that higher use of television or video games correlates with less time in outdoor play (though cause and effect can go both ways). A systematic review across nine countries found that greater access to green space is associated with less TV watching and healthier weight in youth (Jia et al., 2021), suggesting that when kids have enticing outdoor options, they naturally opt for less sedentary screen use. Conversely, if school programs inadvertently encourage students to do everything on a device, they might lose interest in non-digital activities.

Another issue is the philosophical difference in pace and stimulation. Nature often works slower, teaching patience and observation, whereas digital media often operate on fast feedback loops and instant gratification. Students used to constant stimulation from apps might find quiet observation in nature "boring" at first. Educators need to scaffold experiences so students appreciate different modes of engagement. For example, a teacher might integrate photography (instant gratification) with nature journaling (patient observation) to bridge the two.

Physical side effects of screen overuse (eye strain, poor posture) might also negate some benefits of a biophilic environment. It would be ironic to have a classroom full of plants and sunlight but all students hunched over tablets for hours, barely noticing their surroundings. To avoid this, scheduling and pedagogy must ensure that tech use is purposeful and interspersed with breaks

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and off-screen work. Classroom layouts could mix tech stations and non-tech, nature-oriented zones.

There can also be practical conflicts: electronic devices generally don't like water, dirt, or extreme temperatures, whereas nature can be full of those. Schools trying outdoor tech use need robust, perhaps rugged devices or simple ways to protect them (umbrellas for sun and rain, cases for tablets). Planning is needed so that the outdoor tech-enhanced lesson doesn't fail due to glare on screens or a lack of Wi-Fi. However, these are surmountable with current technology (e.g., anti-glare screen covers, offline apps, outdoor routers).

Despite these challenges, the solution is not to swing the pendulum to either extreme but to mindfully integrate the two. A research digest by the Children & Nature Network titled "Technology and Nature: A research-based overview" argues that finding an appropriate balance and integration can enhance early childhood education (Siskind et al., 2020). It acknowledges that while screen media are ubiquitous, "research on green time consistently demonstrates positive outcomes for children" and thus the aim should be to get the best of both. Some researchers propose the concept of "Screen-time, Green-time balance" as a new health recommendation.

Integrated Vision for Future Learning Environments

Imagine a "smart green school": Classrooms have living walls and natural light, and also interactive smartboards and VR corners. A lesson on ecosystems might start with a VR exploration of the Amazon, then move to the school's native plant garden for hands-on observation, and conclude with students using tablets to log their findings and share a multimedia presentation. Students might have personal devices, but they use them to document and analyse the real world (e.g., measuring the growth of their class greenhouse plants with sensors and apps). The school schedule alternates between on-screen and off-screen learning in a natural rhythm – perhaps even using outdoor time as a reward or respite after intensive screen work.

In such an environment, digital literacy and environmental literacy grow together. Students might use an app to identify bird calls on their campus, fostering both tech skills and nature knowledge. Or they might code a simple program that maps the micro-climates in different parts of the schoolyard, combining computer science with biology and geography.

There are also thematic overlaps: both digital and ecological literacy are critical for future citizens. Environmental issues like climate change often intersect with technology (think of sensor networks for climate monitoring, or the power of social media in environmental activism). Educators can design project-based learning that addresses real problems, for example, students design (using CAD software) a green roof for their school, calculating both the tech and ecological benefits, and perhaps even implement it. This gives a sense of empowerment and relevance.

Policy and Research Integration: Some educational policies and grants now encourage both ICT in education and outdoor learning, but often separately. A more integrated approach at the policy level would fund innovations that combine them, such as outdoor learning labs with technological tools. Further research is encouraged on questions like: Does an outdoor environment improve outcomes of computer-based learning (for instance, if students do an online lesson in a garden vs. in a standard lab, do they perform or feel better)? What is the optimal ratio of outdoor to indoor

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tech time for maximizing student health and achievement? How can virtual nature be used in schools that truly have no access to real nature (e.g., inner-city schools surrounded by concrete)?

In summary, the interplay between digital innovation and biophilic design is not a zero-sum game. When thoughtfully integrated, technology can encourage students to engage with nature, and nature can provide a healthier context for technology-enhanced learning. Achieving the right balance is key. Schools should ensure students get plenty of "green time" to complement their "screen time," leveraging each to amplify the other's benefits (Siskind et al., 2020). This holistic approach can produce learners who are both digitally savvy and deeply connected to the natural world – exactly the kind of well-rounded, resilient individuals needed in the future.

Case Studies of Innovative Implementations

To illustrate how the above methodologies come together in practice, we highlight a few notable real-world implementations where schools or programs have integrated digital tools, personalised learning, SEL, and/or biophilic design to improve outcomes. These case studies demonstrate challenges and successes, providing practical insights for educators and policymakers.

Case Study 1: Summit Sierra High School (Seattle, USA). Summit Sierra is part of the Summit Public Schools network known for pioneering personalised learning. Students there follow a personalised learning plan through the Summit Learning Platform (a digital tool that organises their goals and playlists of content). What sets Summit apart is the heavy emphasis on mentoring and SEL alongside the tech. Each student has a mentor teacher they meet with weekly to discuss goals not just academically but personally, building self-management and relationship skills. Classrooms are flexible spaces with laptops available, but you'll also see students working in small groups or one-on-one with teachers. The school reported that in its first few years, over 99% of students graduated and were accepted to college, crediting the personalised approach for meeting students where they are academically, and the mentoring approach for keeping them motivated and supported. One student who struggled in a traditional school thrived at Summit, saying, "I learned how to set my own goals and the teachers really knew me here." However, Summit also faced challenges with student screen fatigue and ensuring all students stayed on track without constant teacher-led classes. They addressed this by scheduling "project time" (without computers, hands-on collaborative projects) and by closely monitoring student progress data to intervene early. Summit Sierra's experience shows a model of integrating personalised digital learning with strong human support (SEL/mentoring) to achieve excellent academic results and student growth in autonomy.

Case Study 2: Coombes Primary School (England). Coombes Primary is famous in the UK for its innovative use of the outdoor environment as a "third teacher." The school's expansive grounds include woodlands, ponds, and gardens which classes use daily across subjects. What's interesting is Coombes also embraces technology where useful – students have access to tablets to document their outdoor investigations or to create digital stories about what they find. In one project, Year 3 pupils learning about life cycles raised butterflies: they observed caterpillars in the classroom, used iPads to record their growth (making time-lapse videos), released the butterflies in the school's butterfly garden, then used a simple animation app to illustrate the life cycle,

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combining art, science, and ICT. Teachers at Coombes report high engagement especially among boys who elsewhere might be restless. The freedom to move and explore channels their energy productively. Academic performance in science and writing at Coombes has been strong, often attributed to the tangible experiences, children have which then translate into richer understanding and vocabulary. One challenge has been weather. They commit to outdoor learning even in less-than-ideal weather, which required investing in proper outdoor gear for kids and creative shelters. Also, not all teachers initially felt comfortable teaching outside the classroom or integrating tech outside; the school provided peer mentoring to share practices. Coombes exemplifies biophilic design meets curriculum integration, with technology acting as a tool to enhance and document learning rather than being the center of it.

Case Study 3: New Tech High, Zion-Benton East (Illinois, USA). New Tech High is part of the New Tech Network, focusing on project-based learning with technology. They also undertook a redesign of their physical space to break away from a traditional classroom model. The school features open, flexible commons with natural light and student work displayed, giving a more informal and creative vibe (somewhat biophilic in using daylight and student-friendly design). All students have laptops and all coursework is through a digital platform (Echo). Projects often involve real-world community issues. In one interdisciplinary project, students studied local water quality – they went out to test nearby water sources (engaging with nature directly), then used sensors and software to analyse data (technology integration), and finally presented solutions to local officials (building SEL skills like communication and responsible decision-making for community benefit). The school has shown good outcomes: high student attendance and lower disciplinary issues, and students outperform district peers on state tests. They attribute this to high engagement and the culture of trust and responsibility. The case illustrates blending PBL, tech, and a bit of biophilic principle (by not confining learning within four walls). One notable aspect: students reported learning how to collaborate and resolve conflicts (SEL) because projects forced them to team up and the school explicitly coaches them on collaboration tools and norms. Thus, it's a holistic approach – technology + PBL + SEL, in a student-centered space. A lesson learned was the need for sufficient training: in the first year, some teachers struggled to adapt to the open environment and new tech, but mentoring from experienced New Tech Network coaches helped them find balance between guiding students and letting them be self-directed.

Case Study 4: Riverbank Academy (Coventry, UK). Riverbank Academy is a secondary school for students with special educational needs. They implemented a comprehensive program emphasising student well-being through multiple innovations. Digitally, they use assistive technologies and interactive apps tailored to students' needs (e.g., communication apps for non-verbal students, virtual reality for safely experiencing new situations to reduce anxiety). They also created a sensory garden and outdoor learning area as a calming space – a clear biophilic element to reduce stress. SEL is embedded through a daily "morning nurture" session where students express how they feel using digital mood boards and emoticons if they can't articulate it, and staff help them with strategies (like breathing exercises in the garden). This triple integration has led to observable improvements: students are more regulated emotionally, incidents of meltdowns have decreased, and academic participation is up. One student with autism who used to refuse to enter class found solace in tending the sensory garden; teachers then gradually introduced a

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tablet for him to document plant growth, bridging to doing assignments on the tablet in the garden, and eventually being comfortable in the classroom. Riverbank's approach shows how combining assistive tech, SEL practice, and therapeutic natural spaces can dramatically improve outcomes for vulnerable learners. It also underscores the importance of personalisation. Every student's plan might look different (some need noise-cancelling headphones and a quiet corner with plants to focus, others use movement breaks outdoors). The school's flexible and caring ethos is key.

These case studies, diverse in context, all share a commitment to reimagining traditional schooling. They demonstrate that innovation is not about one thing, but the orchestration of multiple elements – technology, pedagogy, environment, social support – to better serve students. Educators in these cases often speak of increased student ownership of learning, better teacher-student relationships, and a school climate that embraces change and creativity. For policymakers, the takeaway is that supporting such multifaceted innovation (with funding, training, and freedom from restrictive rules) can yield schools that truly meet 21st-century needs.

7. Recommendations for Educators and Policymakers

Drawing from the extensive research and examples above, we offer evidence-based recommendations to enhance student well-being, digital competence, and academic success through innovative educational methodologies. These recommendations are aimed at educators implementing changes in classrooms and schools, as well as policymakers at the district, state, or national level who shape the conditions for innovation.

1. Invest in Teacher Training and Support for Innovation: Teachers are the key of all these innovations, whether it's technology integration, personalised learning, SEL, or creating a nature-rich classroom. Provide ongoing professional development focused on these areas. For digital tools, train teachers not just in using the hardware/software, but in effective pedagogical strategies (TPACK framework, blended learning models). Evidence shows that teachers' technical and instructional mastery of ICT correlates with better student outcomes (Timotheuou et al., 2022). For SEL, offer workshops and coaching on integrating SEL into academic content and modeling SEL skills; teachers with strong SEL competencies foster better student outcomes (Greenberg, 2023). Likewise, for outdoor and biophilic education, many teachers benefit from training on outdoor classroom management and how to link experiences to curriculum. Allocate time for teachers to collaborate, plan interdisciplinary projects, and visit model schools. Avoid one-off trainings; instead, create learning communities and mentoring systems so teachers can share successes and troubleshoot challenges in implementing these innovations.

2. Blend Digital and In-Person Learning Thoughtfully (Hybrid Models): Take advantage of what technology does best (personalising pace, providing rich media, connecting learners) and what live teachers and environments do best (emotional connection, hands-on exploration, social interaction). Implement blended learning models where students might rotate between online learning, teacher-led instruction, and collaborative or outdoor activities. This keeps students engaged and caters to different learning preferences. Ensure that screen time during school is purposeful and interactive, not passive. Policies should encourage a mix of modalities – e.g., a district might set guidelines that every class should have some form of interactive group work or discussion to balance individual device time, and that students spend a certain minimum time

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outdoors or in physical activity each week. Monitor the balance of screen/green time: schools could track how much of the day students spend seated at screens and strive to reduce it if it's excessive. A balanced approach addresses both digital literacy and physical/mental health (Siskind et al., 2020).

3. Implement Evidence-Based SEL Programs Schoolwide: The research is unequivocal that SEL improves academics, behaviour, and well-being (Durlak et al., 2011; Greenberg, 2023). Adopt an SEL framework (such as CASEL's) and integrate it into the school's fabric. This means scheduling regular SEL lessons or circles, training all staff in SEL principles, and engaging families. Use programs proven by research (meta-analyses show benefits from structured SEL curricula (Durlak et al., 2011). Additionally, make SEL a priority in strategic plans, for example include SEL indicators in school evaluations (like student self-report of feeling safe and supported). Encourage practices like mindfulness breaks, conflict resolution exercises, and mentoring that reinforce SEL daily. Policymakers should support SEL by funding counselor and psychologist positions, promoting lower student-counselor ratios, and incentivising schools to use resources for SEL training. Emphasise that SEL is not a "soft" add-on but a foundation for academic excellence (as reflected in the 11 percentile point academic gain found in SEL participants (Durlak et al., 2011). In short, embed SEL into standard practice, as recommended by experts.

4. Personalise Learning with a Human-Centered Approach: Embrace personalised and mastery-based learning, but do so in a way that keeps human connection at the core. Use adaptive learning technologies to differentiate tasks and provide data on student progress (Durlak et al., 2011) but complement them with one-on-one coaching, peer learning, and project-based learning that builds social skills. Start small with personalisation: for example, allow students some choice in assignments or the order in which they tackle tasks, then gradually incorporate more adaptive software in subjects where it's proven (math practice, reading practice). Ensure that every student has an adult mentor or advisor monitoring their personalised plan. Technology can't replace the encouragement and guidance that teachers provide. Also, consider equity in personalisation: provide additional support to students who might struggle with self-pacing (such as executive function coaching or structured check-ins). From a policy perspective, move away from rigid lockstep curricula; allow flexibility in pacing and demonstrate trust in teacher judgment to adjust instruction for individual needs. Fund pilot programs for personalized learning and study their results, focusing on both test scores and metrics like student agency and motivation. Include adaptive features in learning environments to maximise gains (Durlak et al., 2011), but assess their impact and cost-effectiveness carefully – research suggests moderate personalization can yield rewards without excessive cost.

5. Enhance Learning Spaces with Biophilic Elements: School facilities (new or existing) should incorporate nature for the benefit of students and staff. Policymakers and school leaders should prioritise funding for green schoolyards, natural light improvements, and indoor air quality upgrades. Even low-cost steps like adding plants in classrooms, creating window seating near views, or taking some classes outside can make a difference in stress and engagement (Leif & Loftness, 2024). Use Biophilic design guidelines and resources when renovating or building schools. There is growing evidence that such investments pay off in terms of student performance

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and well-being – for instance, improved test scores and reduced stress have been linked to biophilic classroom designs (Browning & Determan, 2024; MD Sakip et al., 2024). Therefore, advocate for capital investment in school infrastructure: better lighting, ventilation, acoustics, and green spaces. Partner with local organisations or volunteers to develop gardens or outdoor classrooms. Encourage teachers to use outdoor areas for instruction regularly, and provide storage for outdoor equipment and appropriate clothing for students if needed. At the policy level, update building codes or guidelines to reflect the importance of natural light and outdoor access in schools (not just minimum space requirements). A healthy physical environment is part of educating the whole child. Educational authorities should “embrace biophilic design as another example of how space design contributes to student well-being and success”.

6. Provide Adequate IT Infrastructure and Pedagogical Support: Ensure that the technology in schools is reliable and accessible to all students. There’s nothing more counterproductive than trying to integrate tech and having constant technical failures, it frustrates teachers and students. Invest in robust internet connectivity, device maintenance, and IT support staff. Also, consider equity: lend devices or provide internet access to students who don’t have them at home so personalized or digital learning can continue after school. However, as the OLPC Peru case taught, simply handing out devices isn’t enough – pair technology deployment with comprehensive pedagogical support (Cueto et al., 202. Train teachers on how to incorporate devices into lessons effectively, and train students on how to use devices responsibly for learning (digital citizenship). Use data from digital platforms to inform instruction. For example, have regular data team meetings where teachers review learning analytics to identify who needs help or enrichment. Policymakers might allocate funds specifically for tech integration coaching roles or require that any 1:1 initiative plan includes a professional development component. The aim is to avoid “technology-rich but innovation-poor” scenarios; tech should transform pedagogy, not just layer onto old practices. Encouragingly, research shows when teachers receive support and learn to use tech in learner-centered ways, student outcomes improve (Timotheuou et al., 2022).

7. Encourage Interdisciplinary, Project-Based Learning: Many of the benefits discussed engagement, real-world skills, SEL and deeper understanding come to life during interdisciplinary projects that often integrate tech and hands-on learning (sometimes in nature). Restructure curricula to allow for project blocks or inquiry-driven units. For example, implement a capstone project each semester where students solve a community problem or explore a personal interest, using both digital research and field work. Provide teachers with planning time to collaborate across subjects (so a project can merge science, art, and literacy objectives, for instance). Projects can easily incorporate SEL (group work, communication) and can be done in flexible environments beyond the classroom. Schools that have done this (like many New Tech network schools) see strong results in student engagement. To support this, policymakers should consider assessments that value project outputs and presentations, not just standardised tests. Create room in standards or graduation requirements for demonstration of skills via portfolios or project exhibitions. This shifts the focus from memorisation to applying knowledge, aligning with the competencies needed in higher ed and the workforce.

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8. Monitor and Evaluate Holistically: When implementing these innovations, use a broad set of success metrics. Track not only test scores, but also student attendance, engagement surveys, SEL skill growth, mental health indicators, and digital skill competency. For example, use tools to measure school climate or student stress levels before and after a biophilic intervention. If rolling out personalised learning, compare cohorts on academic growth but also on motivation and ownership of learning through surveys or interviews. Policymakers should support research-practice partnerships to rigorously evaluate new programs (perhaps funding pilot studies or collaborating with universities). By collecting evidence, schools can refine their approaches and make the case for continued or expanded support. Share success stories with data e.g., if a district sees a decrease in discipline referrals and an increase in reading scores after introducing SEL and tech-assisted reading practice, publicize that to build momentum. Conversely, be honest about what isn't working and why, and be prepared to iterate. This culture of continuous improvement and learning from evidence is crucial.

9. Foster a Visionary Leadership and Culture: School leaders and policymakers should articulate a clear vision that well-being and learning outcomes are mutually reinforcing goals. Communicate that, innovative methods like SEL and outdoor learning are part of a strategy to produce better academic results, citing research (Durlak, 2011; Greenberg, 2023). Leadership should model the importance of these areas (e.g., principals attending SEL training alongside teachers, superintendents championing green school designs in bond measures). Remove unnecessary barriers for instance, if policies inadvertently discourage going outside (due to strict class period schedules or liability fears), find ways to enable it safely. Celebrate teachers who try new methods, even if the first attempt isn't perfect. Also, involve students in the vision. Student voice can guide what technologies or SEL approaches work best for them. A student tech team, for example, could help train peers and teachers, empowering students and improving implementation. On a larger scale, policymakers should create innovation funds or "innovation lab schools" to experiment and showcase what the future of education can look like, which others can then learn from.

10. Collaborate and Share Resources: No school needs to do this alone. Encourage collaboration between schools, perhaps a traditional public school pairs with an innovative magnet or a nature-focused charter to share practices. Use online communities of practice for teachers to exchange lesson plans for outdoor STEM or how they've integrated a particular app with SEL. Policymakers can support networks or hubs (like an EdTech innovation hub, or a Forest School network) to disseminate research and provide training. International exchanges of ideas are also beneficial; for instance, a policymaker could draw inspiration from Finland's holistic approach (which includes phenomenon-based learning and student welfare services) or Singapore's marriage of tech and academic rigor, and adapt these ideas locally.

Implementing these recommendations requires resources and commitment, but the research indicates the payoff is worthwhile: students who are healthier, happier, more competent with technology, socially and emotionally skilled, and achieving academically. In a world where change is constant – technologically, socially, environmentally – such students will be better prepared to adapt and thrive. As one set of researchers noted, we should "take nature seriously as a resource

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for learning” (Kuo, Barnes & Jordan, 2019, while also taking advantage of the tremendous opportunities technology affords – and importantly, recognise that these can be pursued together. By following the above recommendations, educators and policymakers can create learning environments that truly nurture the whole child and equip the next generation with the knowledge, skills, and mindsets to succeed in school and in life.

8. Conclusion

Education in the 21st century is undergoing a dynamic transformation, driven by a recognition that academic success is deeply interconnected with student well-being and real-world competencies. This comprehensive review has examined four major innovation strands, like digital tool integration, personalised learning, socio-emotional learning, and biophilic design and how they collectively enhance student outcomes. The evidence from global research is clear: when thoughtfully implemented, these methodologies lead to engaged, motivated learners who perform better academically, are more adept with technology, and exhibit healthier social and emotional behaviours.

Key insights include: Digital integration yields small-to-moderate learning gains and can vastly improve digital literacy, especially when teachers are well-trained and when tools are used to actively involve students in learning. Personalised learning, empowered by adaptive technology, can meet students at their level. Boosting achievement across diverse contexts provided it’s coupled with strong teacher guidance and does not sacrifice the social aspects of learning. Socio-emotional learning stands out as a foundational element that not only improves behaviour and mental health but also lifts academic performance, and its benefits endure over time. Biophilic learning environments tap into our innate need for nature, with studies showing reductions in stress and improvements in attention, engagement, and even test scores when schools incorporate natural elements.

Perhaps most importantly, these approaches are not siloed. They work best in combination: a school that uses adaptive math software (digital) during the day might also ensure students spend time in the school garden (biophilic) and have class meetings to discuss feelings and teamwork (SEL), all the while letting students progress at a pace right for them (personalisation). Such an ecosystem of learning addresses the whole child. The case studies illustrated that synergy – from Summit Sierra’s mix of personalised learning and mentoring to Coombes Primary’s blend of outdoor education and technology – and showed that innovation is context-specific but guided by common principles of student-centered design.

For policymakers and educators, the path forward is to embrace these innovations systematically. This means reimagining teacher training, curricula, assessment, and school design through a holistic lens. It involves breaking down silos (e.g., “ed tech” separate from “counseling” separate from “facilities”) and pursuing a cohesive strategy that places students’ needs at the center. Equity must remain a focus – ensuring every student, regardless of background, has access to supportive relationships, modern learning tools, and healthy environments.

There will undoubtedly be challenges: securing funding for infrastructure, overcoming resistance to change, and learning from trial and error as new models are refined. However, the well-

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documented successes provide a roadmap and justification. As research continues (for example, into long-term impacts of these innovations and how best to integrate them at scale), schools can iterate and improve. The COVID-19 pandemic accelerated some changes (like digital learning adoption) and underscored others (students' need for social connection and mental health support) in its wake, the importance of resilient, flexible, and human-centric education has never been clearer.

In conclusion, the vision of education that emerges from this review is one of balance and richness. Students toggling between immersive digital worlds and the calming presence of real nature; between individualised learning tasks and collaborative group endeavours; between rigorous academic challenges and reflective SEL dialogues. Such an education not only produces higher test scores or better tech skills as isolated outcomes, but cultivates young people who are capable, caring, creative, and connected to the world around them. Achieving this at scale will require continued commitment and innovation from all stakeholders – teachers, administrators, policymakers, communities, and students themselves. The evidence and examples compiled here make a compelling case that these efforts are well worth it. By implementing the recommendations and learning from both research and on-the-ground practice, we can create learning environments that truly nurture the mind, heart, and spirit of every student, preparing a generation that is both high-achieving and well-rounded.

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