1102 ADMISSIONS AND ENROLLMENT POLICY

DEFINITIONS
Sibling Preference: Sibling preference will be extended to all siblings (including step-siblings) residing in the home of a student enrolled in Lincoln Academy, and this shall include and extend to all children residing in the home of a student enrolled in Lincoln Academy who are under legal guardianship of the parent or stepparent of such student enrolled in Lincoln Academy.

In the event of legal Guardianship sibling preference will be extended to an applicant if they: (a) have been continuously residing in the home of a student enrolled in Lincoln Academy for the previous 12 months, (b) reasonably anticipate continuing to reside in the same home with the student enrolled in Lincoln Academy for the next 12 months, and (c) can provide written proof that an adult with legal custody of the applicant is the legal guardian or legal custodian of a student currently enrolled at Lincoln Academy.

Lottery: Random drawing of students for enrollment.

POLICY
A. General Enrollment Information
Lincoln Academy is chartered to enroll up to 905 students in Kindergarten through ninth grade. In accordance with state law, entering students must have turned five years old on or before September 1st of the year in which they are starting school. Except for a limited number of priority slots (see below), enrollment in Lincoln Academy is open to any interested student in the state of Utah. If the number of applicants exceeds the number of available spaces in a given grade level, a lottery will be held to determine who will be admitted. Once enrolled in Lincoln Academy, students retain their enrollment until they graduate or officially withdraw.

B. Open Enrollment and Lottery
During the open enrollment period, Lincoln Academy will accept applications (Intent to register forms) for the following school year from families of prospective students. The application must be received by the final day of the open enrollment period to be included in the lottery.
After this period of open enrollment, a lottery (random drawing) will take place, if necessary. A lottery is legally necessary when the number of applicants for a given grade level exceeds the grade's capacity (based on numbers of returning students and students granted priority admission). For each grade with fewer applicants than positions available, all students will be admitted.

The lotteries for each grade will take place at the school at a date and time, duly announced to the public. Names will be chosen randomly and assigned numbers corresponding to the order of selection. Once a student is selected from the lottery, siblings of that selected lottery student will be given priority in their respective grades. For each grade level, after all available slots have been filled; the remaining students will be entered on the lottery list for that grade in the order in which they were selected. Those families whose admission was based upon the lottery-selected child in the lottery process must keep that lottery-selected student enrolled at the school in order to maintain their position. If a lottery-selected student withdraws from Lincoln Academy, all other siblings will be placed back on the lottery list according to their random order number assigned during the lottery process. Applications received after the open enrollment period will be added to the lottery list for each grade level in the order the applications are received.

C. Priority Enrollment

Utah Code Section 53A-1a-506 gives charter schools the right to offer preference in enrollment to certain parties. In accordance with its charter and with state law, Lincoln Academy will, offer preferential enrollment for the next school year to the following parties, in this order and subject to available openings:

- Priority #1. Children of the Board of Trustees and the Founding Council (parents who actively participated in the development of the school)
- Priority #2. Classroom teachers
- Priority #3. Advisory Board Members,~~ and~~ Parent Council Leadership Positions, and Board Sub-Committee Members.
- ~~Priority #4 Grandchildren of classroom teachers and staff~~
- Priority #5. Lincoln Academy Staff
- Priority #6 Siblings of students currently enrolled at Lincoln Academy

Each family who qualifies for preferential enrollment must fill out a form stating if they plan to return to Lincoln Academy, and submit it by the time designated, indicating the category/ies of preference for which they qualify. All slots not filled during the preferential enrollment period will be filled by Open Enrollment applicants according to the lottery procedures outlined. In the situation where there are more applicants than open positions, Lincoln Academy will award open positions based on priority. If there are multiple requests for priority enrollment form the same priority level Lincoln will award positions according to the longevity of the family or employee at Lincoln Academy.

Individual teachers and staff members may not have more than 10 students preferentially enrolled.

Students who are required to leave the United States for visa or passport renewal can remain enrolled in the school for 45 days. During this time, they must work actively with their teachers to turn in work electronically. No live online instruction is provided. Students who are gone more than 45 days are removed from the school and added to the top of the sibling list for up to 180 days. Re-enrollment and placement is contingent upon availability and student performance on placement assessments. After 180 days the student must be removed from the school and preferential enrollment.

If a family decides to take a vacation and be gone from school for more than 30 days students must be unenrolled from the school.

D. Advisory Board Members and Parent Council Leadership Positions

Those advisory board members and parent council leaders who demonstrate a willingness to assist the board in their area of expertise on an as-needed basis receive preferential enrollment status. Advisory Board members and parent council leaders, and board sub-committee members only receive preferential status while actively serving. Advisory board members and board sub-committee members are selected by the board of trustees. Parent council leaders who receive preferential enrollment are also selected by the board of trustees after a recommendation from the Parent Council President.

E. Staff

Staff members at Lincoln Academy may request preferential enrollment upon being hired. The staff member's student retains their status while the staff member is employed by the school. However, if a staff member's employment with the school terminates, their child shall be withdrawn from the school, unless their child was accepted through the lottery process. Regardless of staff status, a staff parent is still encouraged to complete their annual service hours.

F. Notification of Admission

Families will receive an email or be contacted by phone notifying them of their child's enrollment status. Parents/guardians will be given a specific timeframe to accept the position for their student(s). This will be done by signing and returning the acceptance letter as indicated thereon. If parents/guardians fail to claim the space(s), their student(s) will lose their allotted space(s). If these parents thereafter desire to enroll their student(s) at Lincoln Academy, their application will be placed at the end of the appropriate lottery lists.

Within a reasonable amount of time, as determined and publicized by the school, parents who have claimed a spot or spots for their child(ren) will need to actually enroll their child(ren) by submitting certain required forms, including the School Records Transfer Form.

H. Required Forms

Per state law, upon notification of a student's acceptance to Lincoln Academy and prior to the first day of school, parents must:

1. Complete and submit the School Records Transfer Form authorizing the transfer of school records from the student's previous school to Lincoln Academy.
2. Provide a complete immunization record copy or a signed Immunization Waiver form. Complete and submit the Free/Reduced School Lunch form, if applicable. This information allows the school to receive additional services, funding and potentially grant money on behalf of its student body.
3. Provide a copy of the student's birth certificate.
4. Fill out all other necessary paperwork required by Lincoln Academy.

All records should be brought to the main office during announced business hours or mailed to:

Lincoln Academy
Student Records
1582 West 3300 North
Pleasant Grove UT 84062

I. Withdrawal from the School

Parents who wish to withdraw their student(s) from Lincoln Academy must submit a withdrawal form (available at the office) and return it to the office at the address above. Students who have been absent from school for more than 10 days without notifying the school will be considered withdrawn. Please ensure that library books and all school textbooks and materials are returned on or before the student's last day at the school. If school materials have not been returned within two weeks of a student's withdrawal, the family will be billed at replacement cost.

Revised Feb 17, 2015
Modified May 2021
Modified June 2022
Modified April 2023
September 2023

First read; out for 30-day review. Will approve in June

- Should the board approve the new books selected for Junior High and the Battle of the Books for next year?

- All books added to the curriculum must be reviewed by the board, approved for parent review, reviewed by parents for 30 days, and then approved again by the board.
- Book list for the Battle of the Books are:
- Holm, Jennifer "Our Only May Amelia"
- May Amelia, the only girl in a Finnish immigrant family in 1899 Washington State, faces challenges with courage and humor.
- https://www.commonsensemedia.org/book-reviews/our-only-may-amelia
- Korman, Gordon "The Unteachables"
- A group of misfit students and a burned-out teacher are thrown together in a classroom. Their unlikely bond leads to personal growth and redemption.
- https://www.commonsensemedia.org/book-reviews/the-unteachables
- Patterson, James "Middle School: The Worst Years of My Life"
- Rafe, a middle-schooler, rebels against school rules with hilarious and sometimes touching results, learning about consequences and friendship.
- https://www.commonsensemedia.org/book-reviews/middle-school-the-worst-years-of-my-life-middle-school-book-1
- Sloan, Holly "Counting by 7s"
- Willow, a gifted but misunderstood girl, must rebuild her life after the loss of her parents. She finds unexpected friends and a new sense of belonging.
- https://www.commonsensemedia.org/book-reviews/counting-by-7s
- Van Draanen, Wendelin "Sammy Keys and the Hotel Thief"
- Sammy, a smart and spunky girl, witnesses a crime from her grandmother’s window and sets out to solve the mystery.
- https://www.goodreads.com/book/show/361587.Sammy_Keyes_and_the_Hotel_Thief
- Woodson, Jacqueline, "Feathers"

- Set in the 1970s, this novel explores hope and acceptance as Frannie’s class welcomes a new, mysterious boy who is different from everyone else.
- https://www.commonsensemedia.org/book-reviews/feathers
- Books for Junior High:
  - "A Monster Calls" to 8-9.
- https://www.commonsensemedia.org/book-reviews/a-monster-calls

  - Ghost by Jason Reynolds
- https://www.commonsensemedia.org/book-reviews/ghost-track-book-1

BUSINESS PLAN Lincoln Academy

Future Focus

CORE VALUES

1. Student Focused
2. Growth Mindset
3. Automatic Optimism
4. Loyalty
5. Own It!

FOCUS

Purpose/Cause/Passion Produce students that are capable of fully contributing to society and work. Do this by getting over 80% of students to be learning at grade level, improving retention rates to 90%+ and expanding this success to a high school model.

Niche Low educator to student ratio (12 to1) in a protected & supportive community

BHAG

Be the #1 School in Utah: Grade Level Learning, Student & Faculty Retention, & Parent Satisfaction

Marketing Strategy 1

Target Market:
Families invested in their children's education

Differentiators:
1. Low Educator to Student Ratio
2. High caliber Educators
3. Lincoln Community

Proven Process:
High Quality Tier 2 Intervention

Guarantee:
Students are always ready for the next level. Someone will always know your child's name.

3-YEAR VISION

Future Date: 08-19-2024
Fundraising: build out
Students at Grade Level: 75%
Parent Satisfaction: Find national norms
Student Retention: 90%
FT Employee Retention: 90%

What does it look like?
1. Improve Educator ratio to 12 to1 in Secondary. 9 more than current.
2. Increased hourly rate and benefits to TA's
3. Opening High School
4. Increase Teacher Salaries

BUSINESS PLAN

Short-Term Focus

1-YEAR GOALS

Future Date: 08-19-2024
Fundraising: need more info
Students at Grade Level: 65%
Parent Satisfaction: need more info
Student Retention: 85%
FT Employee Retention: 85%

Goals for the year:

1.	Structuring a PCBL rollout plan
2.	Adopting new student information system
3.	Implement new Financial system
4.	Adopting Reading Curriculum
5.	Determine Expansion or no expansion
6.	Create Uniform Benchmark & Grading systems

QUARTERLY GOALS

Future Date: 08-19-2024
Revenue:
Profit:
Measurables:

Quarterly Goals:

1.	Do 1 school visit and pull actionable step
2.	Identify 3 curriculums to review
3.	Administer 1 benchmark for each core subject and evaluate data

LONG-TERM ISSUES

No Long-Term Issues.

;

Lincoln Core Values

Lincoln Student Focused- Student growth, well-being, and achievement are paramount. All decisions are based on what is in the best interest of Lincoln students. All Lincoln employees strive to get to know all students, build meaningful relationships, and develop instructional delivery models that reach the individual student. Employees have shared responsibility for all students at the school.

Growth Mindset- Collaboration is the key to our success. Employees continually seek out ways to improve their practice and develop their skill sets both individually and as a team. All employees can learn new skills and are willing to implement new initiatives that are asked of them. Employees understand the power of yet. Discussion and disagreement are a healthy part of the growth mindset; however, if you see a problem, bring a potential solution and be willing to support the final outcome.

Automatic Optimism- Always look for the bright side of any situation. Employees assume positive intent in all interactions. Look for reasons why something will work out instead of the reasons it won't. Maintaining an "I Can" attitude will drive progress.

Loyalty- Professional interactions create a safe environment for all stakeholders. Employees are loyal to the goals of the school, co-workers, students and families. Employees support the school in conversation with community members and each other. Concerns about co-workers, school practices, or other issues are addressed directly and vertically, not horizontally. The names and issues of students and families are protected by Lincoln employees. FERPA is not optional–it is the law!

Own it- Integrity means prioritizing doing the right thing over personal gain. Without integrity, Lincoln Academy will fail to SOAR. If it is your job, do it. Mistakes are a part of growth and learning. Taking responsibility for mistakes accelerates growth. Self-reflection is an essential part of resolution.

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Executive Function and Screen Time in Kids

This meta-analysis examines the relationship between screen time exposure and executive functions in children under 6 years old. Fifteen studies with a total of 6922 participants were includ... **Full description**

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Written Testimony

Dr. Jared Cooney Horvath, PhD, MEd

Neuroscientist and Educator

Before the U.S. Senate Committee on Commerce, Science, and Transportation

Executive Summary

Over the past two decades, the cognitive development of children across much of the developed world has stalled and, in many domains, reversed. Literacy, numeracy, attention, and higher-order reasoning have declined despite increased school attendance and expanded public investment.

One major structural change distinguishes today's classrooms from those of prior generations: the rapid and largely unregulated expansion of educational technology (EdTech). Digital devices now occupy a significant share of instructional time, assessment, homework, and student attention.

The available evidence (from international assessments, large-scale academic studies, and meta-analyses) shows that increased classroom screen exposure is generally associated with weaker learning outcomes, not stronger ones. In narrow circumstances (e.g., tightly constrained adaptive practice and remediation), digital tools can support surface-level skill acquisition, but in most core academic contexts screens slow learning, reduce depth of understanding, and weaken retention.

This is not primarily a question of teacher quality, student motivation, or access to devices. It reflects a structural mismatch between how human cognition develops and how digital platforms are engineered to capture attention, fragment focus, and accelerate task switching.

If federal policy continues to incentivize large-scale digital adoption without demanding independent efficacy evidence, privacy protections, and developmental safeguards, it risks compounding long-term educational and workforce harm.

1. What Has Changed

For most of the twentieth century, cognitive performance steadily improved across generations, driven largely by expanding access to formal education and improved instructional quality[1]. Beginning in the mid-2000s, this trend plateaued then reversed in many Western nations. Multiple indicators now show stagnation or decline in literacy, numeracy, problem solving, creativity, and general cognitive performance among adolescents[2-6].

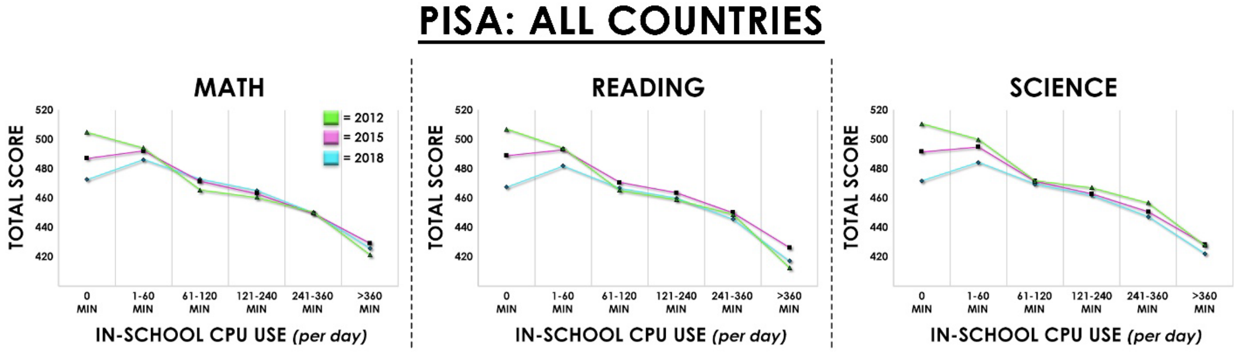
At the same time, classroom environments underwent a rapid digital transformation. One-to-one device programs, cloud platforms, online assessments, adaptive software, and constant connectivity became standard practice in many districts - often without independent longitudinal validation.

Over half of our children now use a computer at school for one to four hours each day, and a full quarter spend *more than* four hours on screens during a typical seven-hour school day[7]. Unfortunately, studies suggest that less than half of this time is spent actually learning, with students off-task for up to 38 minutes of every hour when on classroom devices[8].

2. Evidence from International Assessments

PISA

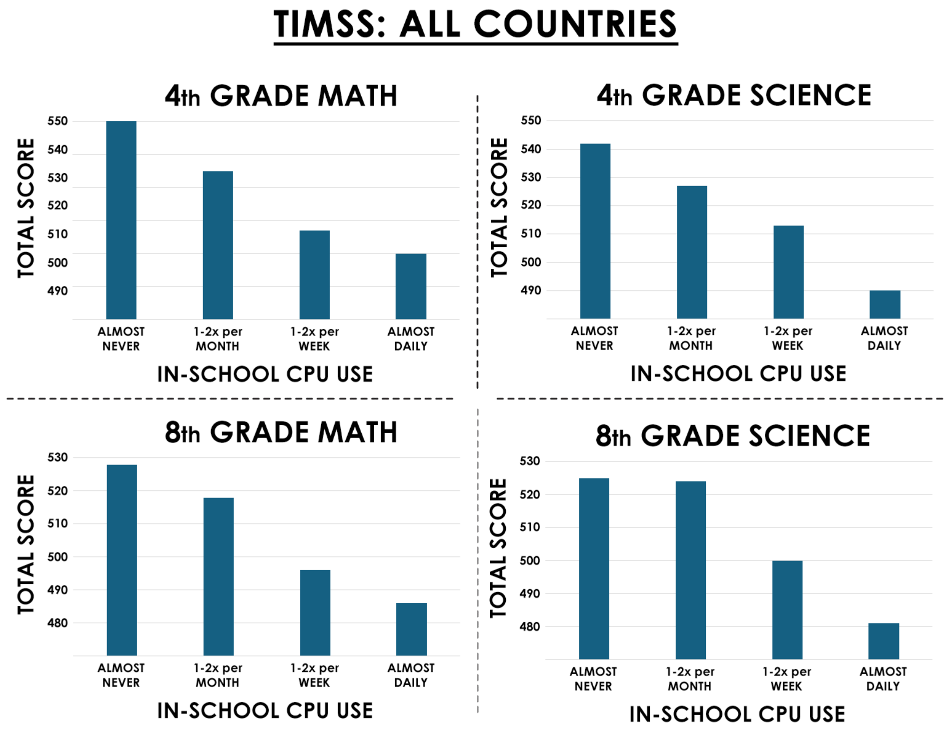
The Programme for International Student Assessment (PISA) tracks the academic performance of 15-year-olds across dozens of countries. When students self-report classroom computer use, higher daily screen exposure consistently corresponds to lower scores in reading, mathematics, and science. The relationship is monotonic: more screen time, lower performance.



Apparent small advantages sometimes reported for minimal computer exposure disappear once test mode effects are accounted for. When assessments shifted from paper to digital delivery, students with limited device familiarity experienced artificial score penalties, creating the illusion of benefit for moderate screen users rather than genuine learning gains[9].

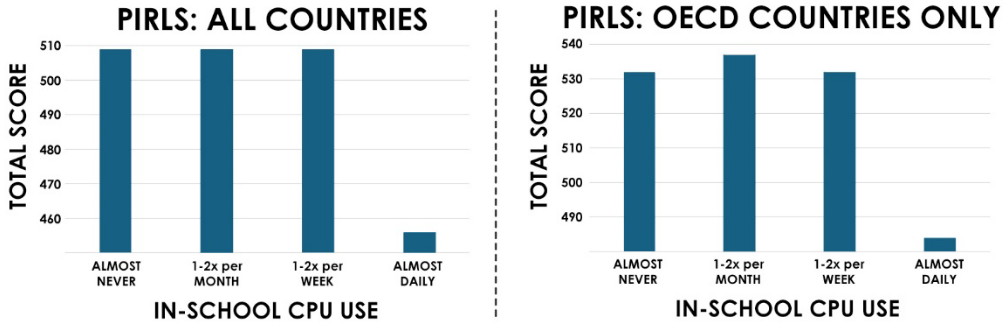
TIMSS

The Trends in International Mathematics and Science Study (TIMSS) shows a similar pattern among younger students. Frequent in-class computer use correlates with significantly lower math and science performance across both high-income and middle-income countries.



PIRLS

The Progress in International Reading Literacy Study (PIRLS) historically shows weaker reading performance among students with high classroom computer use. More recent U.S. data confirm that even modest daily digital exposure is associated with lower reading comprehension[10].



Collectively, these assessments involve millions of students over decades and converge on the same conclusion: heavy classroom screen exposure is not improving learning outcomes at scale.

3. Evidence from Meta-Analysis

Meta-analyses aggregate hundreds of individual studies to estimate overall impact. Most EdTech meta-analyses report small positive effect sizes. However, education research systematically inflates positive effects because comparison conditions vary widely and often lack rigorous baselines.

When educational interventions are benchmarked against established instructional methods, meaningful impact typically begins around moderate effect thresholds (approximately 0.40 – 0.50)[11]. Most digital interventions fall below this range, particularly in:

- One-to-one device programs
- Fully online instruction
- General classroom technology integration
- Programs targeting disadvantaged populations

Only narrowly constrained tools (such as adaptive drills for foundational skills and targeted remediation) consistently approach meaningful gains. These tools succeed because they automate repetition in well-defined domains, not because they enhance deep learning.

To assess practical significance, effect sizes must be interpreted relative to a meaningful benchmark rather than an arbitrary zero. Large-scale syntheses of education research indicate that the average impact of ordinary classroom instruction is approximately +0.42[11]. An intervention that falls below this threshold does not meaningfully outperform standard practice, even if its effect size is technically positive. In practical terms, schools should not invest in tools that perform worse than the average classroom already does without them.

For clarity, the table below presents effect sizes re-centered against this instructional benchmark to show whether each category of educational technology exceeds or underperforms typical instructional impact[11, 12].

	# Of Meta-Analyses	*# of Research Studies*	*Effect Size (Cohen's D)*
General Learning	398	21,155	-0.13 *(SE=0.09)*
SPECIFIC MODERATORS			
Online/Distance Learning	42	1,767	-0.22 *(SE=0.06)*
Primary Years	27	781	*-0.03 (SE=0.04)*
Secondary Years	10	745	-0.11 *(SE=0.05)*
Intelligent Tutoring Systems	5	283	+0.10 *(SE=0.03)*
1-to-1 Laptops	3	162	*-0.30 (SE=0.07)*
Disadvantaged Students	4	195	-0.26 *(SE=0.02)*

Literacy	31	1,109	-0.09 *(SE=0.15)*
Mathematics	41	3,479	-0.09 *(SE=0.13)*
Science	10	547	-0.18 *(SE=0.19)*
Learning Disorders	9	245	+0.05 *(SE=0.08)*

NOTE: Reported effect sizes from published meta-analyses have been re-centered relative to the estimated average impact of typical classroom instruction (+0.42). Values shown represent the difference between each intervention's effect and this instructional benchmark (Adjusted Effect = Reported d – 0.42). This does not alter the underlying study results; it clarifies whether an intervention meaningfully exceeds, matches, or underperforms ordinary instructional impact.

Interpreted this way, most general-use educational technologies perform below the effectiveness of ordinary classroom instruction, while only narrowly constrained adaptive tools modestly exceed baseline impact.

4. Mode Effects: Reading and Writing

Independent research consistently shows that reading comprehension and retention are stronger on paper than on screens, particularly for complex or extended texts. Spatial stability, reduced scrolling, and embodied interaction support memory formation and comprehension[12].

	# Of Meta-Analyses	*# of Research Studies*	*Effect Size (Cohen's D)*
Reading Comprehension	10	377	-0.16 *(SE=0.05)*
SPECIFIC MODERATORS			
Adult Supports	1	7	-0.22 *(SE=0.22)*
Adult vs Digital Supports	1	10	-0.22 *(SE=0.07)*

NOTE: All studies compare screens to hard-copy texts, meaning the baseline of 'reading from paper' is 0.00.

Similarly, handwritten note-taking reliably outperforms laptop note-taking for long-term learning. Typing encourages verbatim transcription and shallow processing; handwriting forces summarization, organization, and conceptual encoding[12].

	# Of Meta-Analyses	*# of Research Studies*	*Effect Size (Cohen's D)*
General Learning	4	238	-0.21 *(SE=0.04)*
SPECIFIC MODERATORS			
Allowed to Review Notes	1	9	-0.42 *(SE=0.07)*
Class Length: >30min	1	5	-0.58 *(SE=0.01)*

NOTE: All studies compare typing to handwriting, meaning the baseline of 'handwritten notes" is 0.00.

These effects are not marginal curiosities. They directly affect how students process information across subjects and grade levels.

5. Why Screens Undermine Learning: A Core Mechanism

Human attention systems evolved to sustain focus on a single task at a time. The prefrontal control system cannot reliably manage competing goal states without significant performance costs[13]. When attention is repeatedly interrupted, three predictable costs emerge:

1. Time loss from task switching overhead[14].
2. Higher error rates from cognitive interference[15].
3. Weaker memory formation as learning shifts from deep encoding toward habit-based processing[16].

Digital platforms are optimized for rapid switching, novelty, and continuous engagement capture. Even when used for academic tasks, they cue the same behavioral patterns students practice during recreational screen use: frequent checking, rapid scrolling, and multitasking.

As a result, screens structurally train attentional habits that conflict with sustained learning. This is not a matter of discipline or willpower; it is a function of repeated conditioning.

6. National Implications

Sustained declines in cognitive skill development have downstream consequences for:

- Workforce adaptability and productivity
- Scientific and technological innovation
- Civic reasoning and institutional trust
- Economic competitiveness[17]
- Public health and wellbeing[18]

Education policy shapes long-term human capital. Decisions made today will influence national capacity for decades.

7. Policy Recommendations

Congress has several practical levers to improve accountability and protect students:

1. Independent Efficacy Standards: Require federally funded EdTech to demonstrate learning benefits through independent, replicated trials before large-scale deployment or renewal.
2. Mode-Equivalence Validation: Mandate validation studies before transitioning high-stakes assessments from paper to digital formats.
3. Student Data Protections: Strengthen limits on behavioral tracking, profiling, and secondary data use involving minors.
4. Procurement Transparency: Require public disclosure of evidence standards, conflicts of interest, and performance claims in district purchasing.
5. Developmental Screen Exposure Guidelines: Establish age-appropriate limits for screen exposure in federally supported early education programs.
6. Federal Evidence Clearinghouse: Create a centralized repository of independently replicated EdTech research to guide districts.
7. Research Funding for Longitudinal Outcomes: Prioritize long-term cognitive and academic impact studies rather than short-term engagement metrics.

Conclusion

This is not a debate about rejecting technology. It is a question of aligning educational tools with how human learning actually works. Evidence indicates that indiscriminate digital expansion has weakened learning environments rather than strengthened them[12].

Federal policy can restore balance by demanding evidence, protecting children's developmental needs, and ensuring that innovation serves learning rather than attention capture.

Our responsibility is not to maximize screen exposure, but to maximize the cognitive capacity and long-term flourishing of the next generation.

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Lincoln Academy Incorporated

Account Level Balance Sheet As of 03/31/2026

Fiscal Year: 2025-2026

Year To Date

Undefined Fund Type

ASSET

		YTD
10.000.0000.0000.8111.8012.00.0	Cash in Banks-Lincoln Lunch Checking	$81,250.21
10.000.0000.0000.8111.8013.00.0	Cash in Banks-Lincoln Main Checking	($16,920.70)
10.000.0000.0000.8111.8014.00.0	Cash in Banks-Lincoln Parent Council	$27,324.72
10.000.0000.0000.8111.8015.00.0	Cash in Banks-Lincoln Sweep Savings	$3,127,574.24
10.000.0000.0000.8120.8021.00.0	Investments-Bond Expense Fund	$32,220.96
10.000.0000.0000.8120.8022.00.0	Investments-Bond Interest Fund	$286,169.46
10.000.0000.0000.8120.8023.00.0	Investments-Bond Principal Fund	$424,637.68
10.000.0000.0000.8120.8024.00.0	Investments-Debt Service Reserve Fund	$951,412.50
10.000.0000.0000.8120.8025.00.0	Investments-Repair & Replacement Fund	$200,000.00
10.000.0000.0000.8120.8026.00.0	Investments-PTIF-Public Treasurers' Invest. Fund	$3,401,471.65
10.000.0000.0000.8131.8032.00.0	Local Receivables-SCH Invoiced Fees	$2,490.70
10.000.0000.0000.8131.8034.00.0	Local Receivables-Sales Tax Reimb.	$1,431.92
10.000.0000.0000.8131.8037.00.0	Local Receivables-Workers Comp	$1,227.75
10.000.0000.0000.8150.0000.00.0	Prepaid Expenditures	$55,170.02
ASSET		$8,575,461.11

LIABILITY

		YTD
10.000.0000.0000.9510.0000.00.0	Accounts Payable	($58,644.75)
10.000.0000.0000.9561.0000.00.0	Unearned Revenue-Local-Lunch Super Hero	($302.29)
10.000.0000.0000.9563.0000.00.0	Unearned Revenue - State	($220,000.00)
LIABILITY		($278,947.04)

FUND BALANCE

		YTD
10.000.0000.0000.9860.0000.00.0	Nonspendable - Inventories & Prepaid Expenditures	($155,451.20)
10.000.0000.0000.9872.0000.00.0	Restricted - Food Service	($111,419.73)
10.000.0000.0000.9899.0000.00.0	Unassigned Fund Balance	($7,099,737.41)
FUND BALANCE		($7,366,608.34)

Total Liability & Fund Balance	($7,645,555.38)
Total (Income)/Loss	($929,905.73)
Total Liability and Equity	($8,575,461.11)

End of Report

Lincoln Academy Incorporated

Board P&L For the Period 03/01/2026 through 03/31/2026

Fiscal Year: 2025-2026

	03/01/2026 - 03/31/2026	Year To Date
INCOME		
Income		
1000 Local Funds (+)	$68,724.85	$682,625.80
3000 State Funds (+)	$822,079.64	$8,042,564.74
4000 Federal Funds (+)	$14,387.63	$187,128.17
Sub-total : Income	$905,192.12	$8,912,318.71
Total : INCOME	$905,192.12	$8,912,318.71
EXPENSES		
Expenses (Objects)		
100 Salaries (-)	$518,986.46	$4,755,454.96
200 Benefits (-)	$158,540.64	$1,380,212.28
300 Purch/Prof Services (-)	$22,442.12	$219,452.19
400 Purch Property Services (-)	$22,667.95	$259,463.97
500 Other Purchased Services (-)	$6,825.18	$205,855.57
600 Supplies & Materials (-)	$74,339.66	$802,069.83
700 Property (-)	$0.00	$27,539.01
800 Debt & Miscellaneous (-)	$2,679.95	$332,365.17
Sub-total : Expenses (Objects)	($806,481.96)	($7,982,412.98)
Total : EXPENSES	($806,481.96)	($7,982,412.98)
NET ADDITION/(DEFICIT)	$98,710.16	$929,905.73

End of Report

Lincoln Academy Incorporated

Profit and Loss Financial Statement For the Period 03/01/2026 through 03/31/2026

Fiscal Year: 2025-2026

	03/01/2026 - 03/31/2026	Year To Date
INCOME		
Local Sources		
1510 Interest on Investment (+)	$24,036.24	$212,395.15
1610 Sales to Students (+)	$22,416.35	$171,181.58
1620 Sales to Adults (+)	$1,350.00	$4,629.65
1690 Other Local Revenue (+)	$46.75	$272.50
1710 Admissions (+)	$0.00	$1,353.91
1743 Curricular Activity Fees (+)	$64.00	$30,695.00
1744 Curricular Activity Fee Waivers (+)	($37.50)	($1,777.50)
1747 Extra-Curricular Activity Fees (+)	$18,624.00	$105,578.40
1748 Extra-Curricular Activity Fee Waivers (+)	($6,667.50)	($7,872.50)
1760 Fines (+)	$120.00	$2,518.45
1770 Fundraisers (+)	$1,887.53	$51,567.51
1780 Non-Waivable Charges (+)	$745.00	$11,338.00
1910 Rentals (+)	$6,150.00	$35,637.00
1920 Contributions and Donations From Private (+)	($20.02)	$62,202.69
1990 Miscellaneous (+)	$10.00	$2,905.96
Sub-total : Local Sources	$68,724.85	$682,625.80
State Sources		
3810 School Meal Program Reimbursement (+)	$0.00	$824.40
3805 State Liquor Tax (+)	$6,717.75	$44,559.00
3815 School Fees Distribution (+)	$0.00	$17,612.84
3005 Kindergarten (+)	$23,231.08	$209,079.71
3010 Regular School Programs K-12 (+)	$308,790.72	$2,779,116.55
3100 Restricted Basic School Program (+)	$92,937.21	$916,484.70
3200 Related to Basic Programs (+)	$311,021.45	$2,799,193.04
3400 Educator Supports (+)	$56,094.60	$723,517.95
3500 Statewide Initiatives (+)	$23,286.83	$468,672.72
3800 Non-MSP State Revenue (via USBE) (+)	$0.00	$83,503.83
Sub-total : State Sources	$822,079.64	$8,042,564.74
Federal Sources		
4522 IDEA - B -- Pre-School Disabled (Sec 619) (+)	$0.00	$846.86
4524 IDEA - B -- Disabled (PL 101-476) (+)	$0.00	$68,594.36
4560 Federal Child Nutrition Prog (+)	$14,387.63	$91,623.88

Profit and Loss Financial Statement For the Period 03/01/2026 through 03/31/2026

Fiscal Year: 2025-2026

	03/01/2026 - 03/31/2026	Year To Date
4800 Federal Elementary and Secondary (+)	$0.00	$26,063.07
Sub-total : Federal Sources	$14,387.63	$187,128.17
Total : INCOME	$905,192.12	$8,912,318.71
EXPENSES		
BLDG Acquisition & Construction SVCS		
400 Purch Property Services (-)	$5,000.00	$5,000.00
Sub-total : BLDG Acquisition & Construction SVCS	($5,000.00)	($5,000.00)
Instruction		
100 Salaries (-)	$374,287.32	$3,328,306.65
200 Benefits (-)	$101,340.51	$893,174.81
300 Purch/Prof Services (-)	$2,200.00	$10,600.00
400 Purch Property Services (-)	$1,961.98	$11,976.35
500 Other Purchased Services (-)	$1,283.30	$97,416.05
600 Supplies & Materials (-)	$17,566.15	$298,119.19
800 Debt & Miscellaneous (-)	$0.00	$6,761.18
Sub-total : Instruction	($498,639.26)	($4,646,354.23)
Support Services - Students		
800 Debt & Miscellaneous (-) (-)	$0.00	$298.00
100 Salaries (-)	$17,514.44	$175,332.63
200 Benefits (-)	$3,834.77	$34,771.90
300 Purch/Prof Services (-)	$11,772.00	$83,661.30
500 Other Purchased Services (-)	$0.00	$393.16
600 Supplies & Materials (-)	$1,187.29	$2,884.12
Sub-total : Support Services - Students	($34,308.50)	($297,341.11)
Support Services - Staff Assistance		
100 Salaries (-)	$20,953.68	$193,220.18
200 Benefits (-)	$10,479.53	$98,622.33
300 Purch/Prof Services (-)	$100.00	$15,722.40
500 Other Purchased Services (-)	$2,153.52	$7,950.74
600 Supplies & Materials (-)	$2,020.06	$24,878.79
Sub-total : Support Services - Staff Assistance	($35,706.79)	($340,394.44)
Support Services - General Dist Admin		
100 Salaries (-)	$17,837.00	$188,529.99
200 Benefits (-)	$5,230.59	$48,649.22
300 Purch/Prof Services (-)	$5,000.00	$65,200.00
500 Other Purchased Services (-)	$157.00	$1,411.12
600 Supplies & Materials (-)	$68.67	$32,986.29
800 Debt & Miscellaneous (-)	$0.00	$18,090.12

Profit and Loss Financial Statement For the Period 03/01/2026 through 03/31/2026

Fiscal Year: 2025-2026

	03/01/2026 - 03/31/2026	Year To Date
Sub-total : Support Services - General Dist Admin	($28,293.26)	($354,866.74)
Support Services - School Admin		
100 Salaries (-)	$44,380.91	$439,517.80
200 Benefits (-)	$19,000.45	$159,870.00
300 Purch/Prof Services (-)	$0.00	$5,262.50
400 Purch Property Services (-)	$270.06	$1,491.37
500 Other Purchased Services (-)	$1,902.86	$12,821.37
600 Supplies & Materials (-)	$3,967.14	$42,202.67
Sub-total : Support Services - School Admin	($69,521.42)	($661,165.71)
Support Services - Central Services		
100 Salaries (-)	$20,742.60	$212,935.66
200 Benefits (-)	$9,484.31	$70,195.92
300 Purch/Prof Services (-)	$3,354.12	$38,229.19
400 Purch Property Services (-)	$0.00	$124.20
500 Other Purchased Services (-)	$1,228.50	$84,634.88
600 Supplies & Materials (-)	$3,874.07	$65,370.77
800 Debt & Miscellaneous (-)	$449.36	$8,063.06
Sub-total : Support Services - Central Services	($39,132.96)	($479,553.68)
Operation & Maintenance of Plant		
100 Salaries (-)	$11,065.33	$96,274.58
200 Benefits (-)	$3,919.34	$33,262.68
300 Purch/Prof Services (-)	$0.00	$514.80
400 Purch Property Services (-)	$14,575.99	$236,215.67
500 Other Purchased Services (-)	$50.00	$450.00
600 Supplies & Materials (-)	$16,320.95	$115,543.79
700 Property (-)	$0.00	$23,940.01
Sub-total : Operation & Maintenance of Plant	($45,931.61)	($506,201.53)
Food Services		
100 Salaries (-)	$12,205.18	$121,337.47
200 Benefits (-)	$5,251.14	$41,665.42
300 Purch/Prof Services (-)	$16.00	$262.00
400 Purch Property Services (-)	$859.92	$4,656.38
500 Other Purchased Services (-)	$50.00	$778.25
600 Supplies & Materials (-)	$29,335.33	$220,084.21
700 Property (-)	$0.00	$3,599.00
800 Debt & Miscellaneous (-)	$230.59	$2,246.56
Sub-total : Food Services	($47,948.16)	($394,629.29)
Debt Service		
800 Debt & Miscellaneous (-)	$2,000.00	$296,906.25

Profit and Loss Financial Statement For the Period 03/01/2026 through 03/31/2026

Fiscal Year: 2025-2026

	03/01/2026 - 03/31/2026	Year To Date
Sub-total : Debt Service	($2,000.00)	($296,906.25)
Total : EXPENSES	($806,481.96)	($7,982,412.98)
NET ADDITION/(DEFICIT)	$98,710.16	$929,905.73

End of Report

ELA

K-5 (meets 3 out of the 4 indicators below) Current: 65%

- On Grade Level or higher on EOY iReady Diagnostic
- At Benchmark or Above Benchmark on Acadience Reading
- Proficient or Above Proficient on RISE
- 80% or higher on 80% of grade level benchmark assessments

6-9 (meets 3 out of the 5 indicators below) Current: 60%

- On Grade Level or higher on iXL EOY Diagnostic
- Proficient or Above Proficient on MOY Full Class Period Interim/RISE Summative
- 80% or higher on 80% of grade level common assessments
- Earned a B or higher in Language Arts class
- Meets proficiency on CommonLit Reading Comprehension

MATH

K-2 (meets 2 out of the 3 indicators below) Current: 70%

- On Grade Level or higher on EOY iReady Diagnostic
- At Benchmark or Above Benchmark on Acadience Math
- 80% or higher on 80% of grade level benchmark assessments

3-5 (meets 2 out of the 3 indicators below) Current: 60%

- On Grade Level or higher on EOY iReady Diagnostic
- Proficient or Above Proficient on RISE
- 80% or higher on 80% of grade level benchmark assessments

6-9 (meets 3 out of the 4 indicators below) Current: 55%

- On Grade Level or higher on iXL EOY Diagnostic
- Proficient or Above Proficient on RISE
- 80% or higher on 80% of grade level common assessments
- Earned a B or higher in Math class

Science (Secondary only)

- 80% or higher on Rise Benchmarks
- Earn a B or higher in Science class
- 80% or higher on common assessments
- End of year RISE score

ELA

	On Grade Level	Total #	Percentage
Kindergarten	67	74	90.54%
1st Grade	55	75	73.33%
2nd Grade	52	77	67.53%
3rd Grade	47	79	59.49%
4th Grade	40	81	49.38%
5th Grade	59	81	72.84%
Elementary	**320**	**467**	**68.52%**
6th Grade	52	109	47.71%
7th Grade	75	120	62.50%
8th Grade	74	117	63.25%
9th Grade	58	97	59.79%
Junior High	**259**	**443**	**58.47%**
Whole School	**579**	**910**	**63.63%**

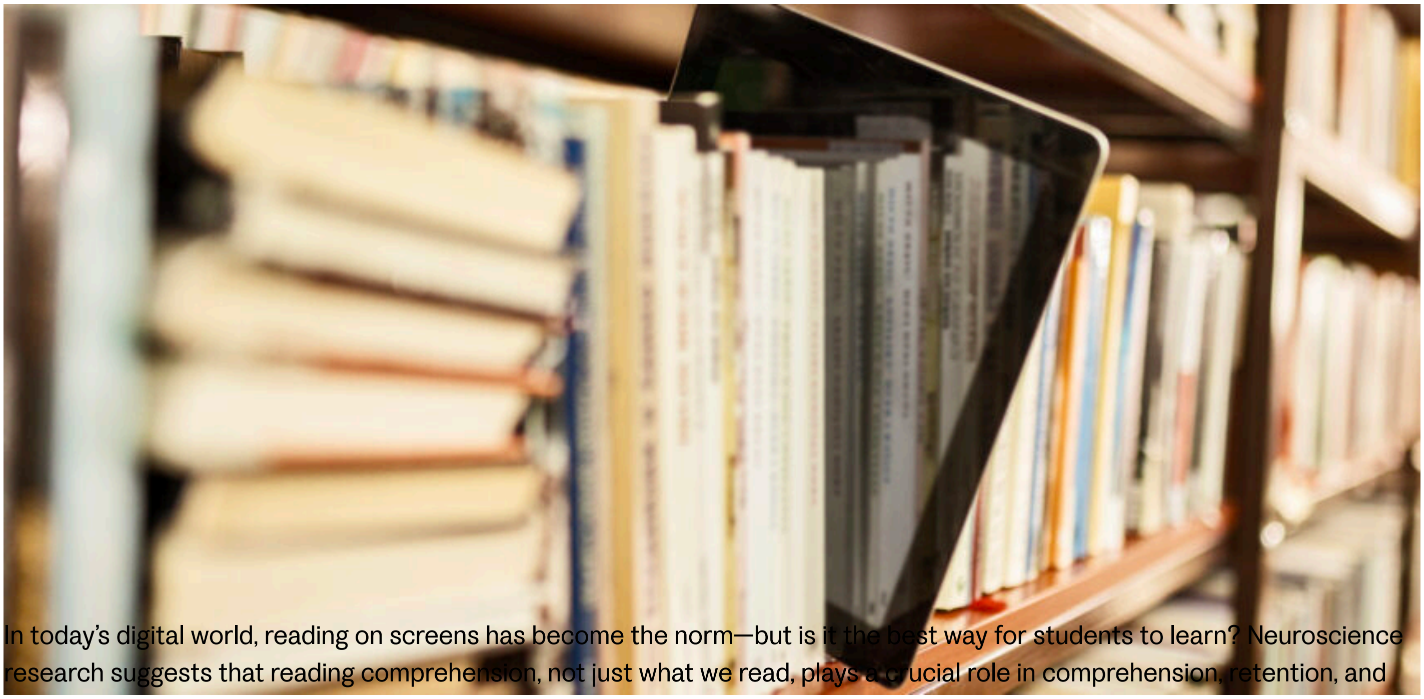
MATH

	On Grade Level	Total #	Percentage
Kindergarten	65	73	89.04%
1st Grade	44	75	58.67%
2nd Grade	48	76	63.16%
3rd Grade	54	77	70.13%
4th Grade	45	81	55.56%
5th Grade	47	81	58.02%
Elementary	**303**	**463**	**65.44%**
6th Grade	48	99	48.48%
7th Grade	75	120	62.50%
8th Grade	62	111	55.86%
9th Grade	34	88	38.64%
Junior High	**219**	**418**	**52.39%**
Whole School	**522**	**881**	**59.25%**

Notes: Missing 5th Grade Benchmark Data for 1 class; Secondary ELA missing Common Lit Data and benchmark data- adjusted to meeting 2/3 requirements

Screen vs. Paper: Which One Boosts Reading Comprehension?

March 14, 2025 • Reading (https://oxfordlearning.com/category/reading/)



In today's digital world, reading on screens has become the norm—but is it the best way for students to learn? Neuroscience research suggests that reading comprehension, not just what we read, plays a crucial role in comprehension, retention, and overall academic success. When we swap pages for pixels, we're changing the way our brains process information. For students, this can make a significant difference in their ability to absorb and retain what they read.

The Print Advantage: What Science Says

Studies show that reading print books leads to better reading comprehension and deeper learning compared to digital reading. A 2024 meta-analysis of 49 studies (https://phys.org/news/2024-02-screens-paper-effective-absorb-retain.html) found that students who read on paper consistently scored higher on comprehension tests than those who read the same material on screens. Researchers call this the "screen inferiority effect"—meaning that digital reading leads to lower information retention and understanding.

The Screen Inferiority Effect

The Screen Inferiority Effect refers to the phenomenon where people tend to comprehend and retain less information when reading on screens compared to reading on paper. It has been widely found that screen readers consistently score lower on reading comprehension tests than paper readers.

Why Does This Happen?

The three main reasons why this happens are:

- Cognitive Overload – Screens encourage multitasking and scrolling, which can disrupt deep comprehension.
- Lack of Mental Mapping – Physical books provide spatial cues (e.g., turning pages and text placement) that help with memory and information recall.
- Tendency to Skim – Readers on screens are more likely to scan text instead of engaging in careful, analytical reading.

Who Is Most Affected?

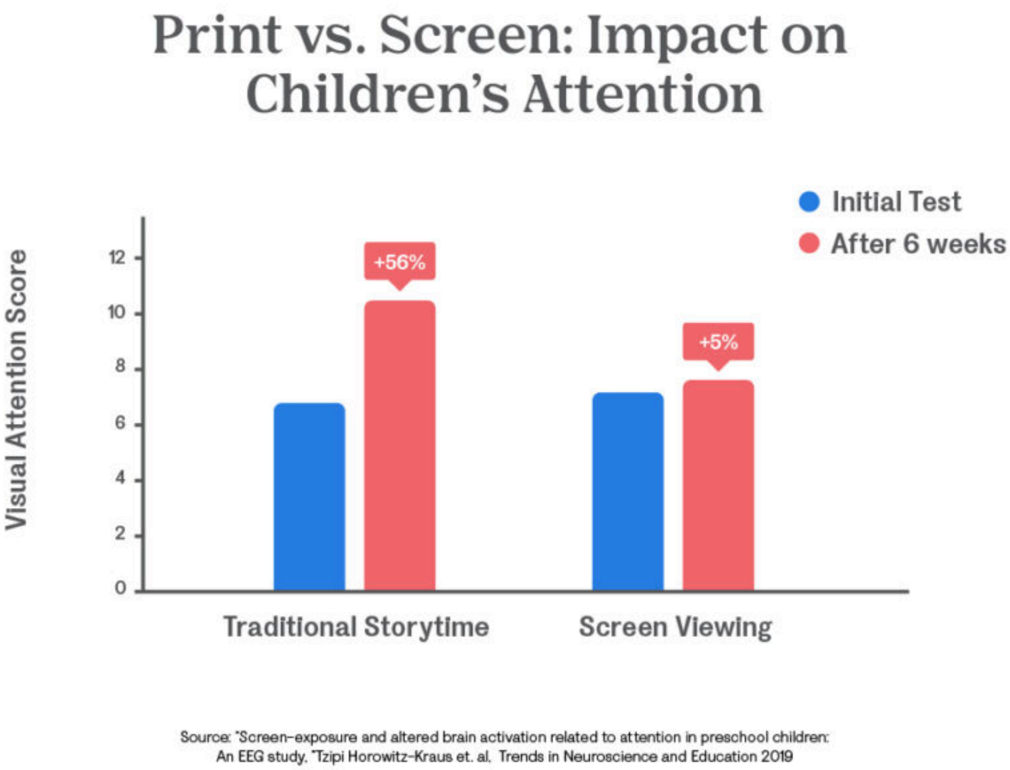
While this effect impacts all age groups, younger readers are particularly vulnerable. Studies show that children who primarily read on screens develop weaker reading comprehension skills compared to those who engage with print books.

The Impact on Young Readers

The way children read has an even bigger impact. Research (https://pubmed.ncbi.nlm.nih.gov/30410746/) shows that children who grow up with access to physical books complete an average of three additional years of education compared to those who do not. In contrast, studies have found no such correlation between e-books and academic success.

Additionally, an MRI study (https://www.researchgate.net/publication/321656566_Brain_connectivity_in_children_is_increased_by_the_time_they_spend_re
based_media) found that children who spend more time reading books have stronger brain connections in areas related to language and cognitive control. Meanwhile, children who spend more time using screens show fewer of these crucial connections.

Screens and Attention—A Hidden Challenge


Print vs. Screen: Impact on Children's Attention

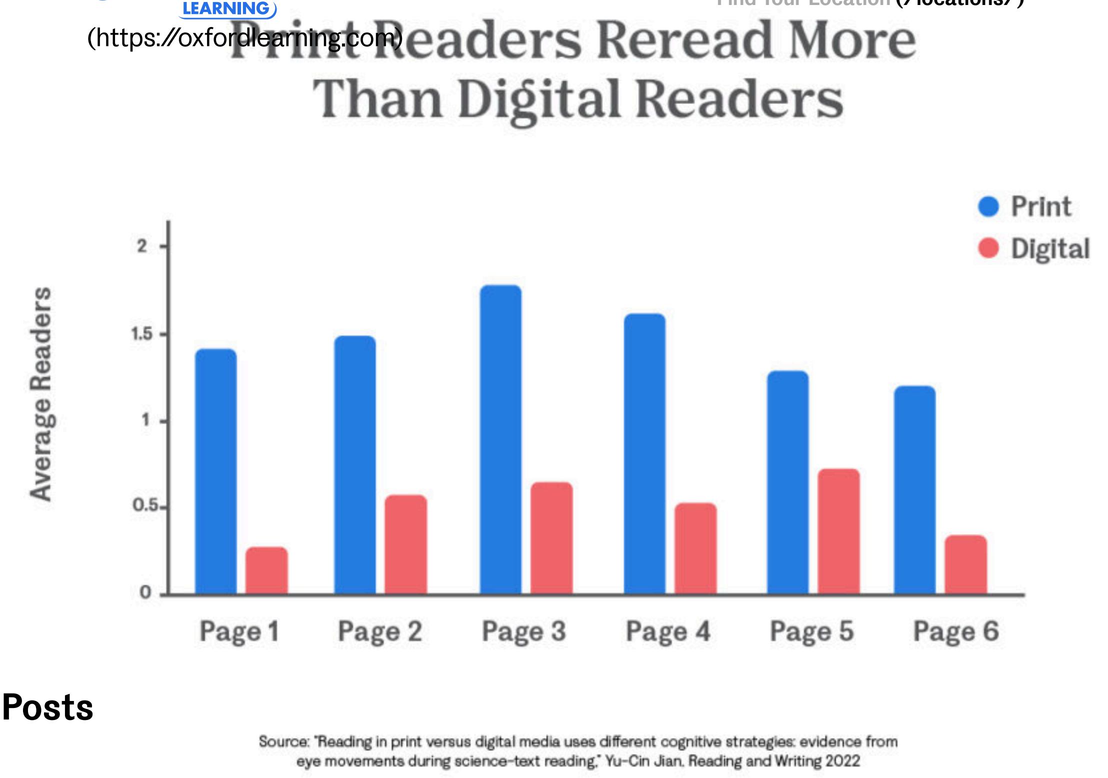
Source: "Screen-exposure and altered brain activation related to attention in preschool children: An EEG study, "Tzipi Horowitz-Kraus et. al, Trends in Neuroscience and Education 2019

Screens can also impact students' attention spans. A study (https://www.sciencedirect.com/science/article/abs/pii/S0193397319300425) of preschoolers compared two groups:

- Group A) Listened to a story read from a physical book with an adult
- Group B) Watched the same story on a screen with audio narration

Six weeks later, the children who watched the story on screen performed significantly worse on attention tests and exhibited brain wave patterns similar to children with ADHD.

For older students, research (https://pmc.ncbi.nlm.nih.gov/articles/PMC3563053/) using eye-tracking technology revealed that those reading print texts approached the material more carefully, frequently re-reading important details. In contrast, students reading on screens tended to skim, leading to lower reading comprehension scores.



Source: "Reading in print versus digital media uses different cognitive strategies: evidence from eye movements during science-text reading," Yu-Cin Jian. Reading and Writing 2022

What Can Parents Do?

Given the overwhelming evidence in favour of print reading, how can you, as a parent, help your child build better reading comprehension habits? Here are some tips to use:

- Encourage print reading at home: Having physical books readily available encourages deeper reading and better retention.
- Balance screen time with paper reading: While screens are unavoidable, setting aside daily time for print reading can reinforce strong literacy skills.
- Use print materials for studying: Students should opt for printed study guides and notes whenever possible when preparing for exams to improve their reading comprehension.
- Model print reading: When children see parents reading physical books, they are more likely to develop the same habit.

The Role of Tutoring in Building Strong Reading Comprehension Skills

We understand the importance of developing strong reading comprehension skills. Our tutors incorporate research-backed cognitive strategies to help students improve their reading abilities, whether it's through guided reading sessions, print-based study materials, or customized learning plans that reinforce deep reading habits.

While we believe that technology has its place in education, research shows that reading on paper is still the best way to support lasting learning and academic success. By making small shifts toward print reading, students can build stronger literacy skills. They can also improve reading comprehension and set themselves up for long-term success.

Want to help your child develop better reading comprehension skills? Contact us today to learn how our tutoring programs can support their learning journey!

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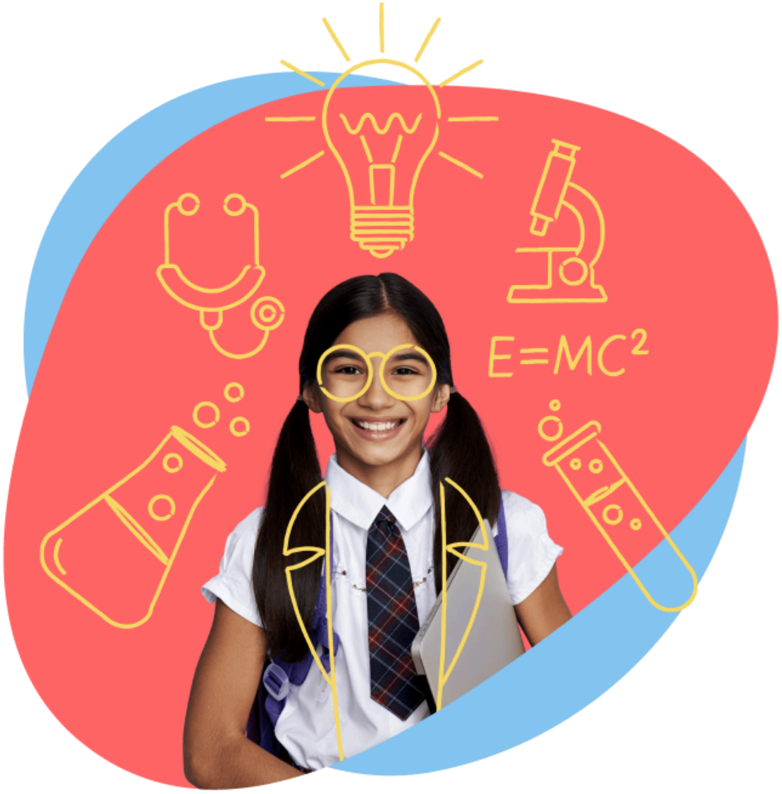

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Research Stories

A new study finds that the effectiveness of edtech products for early literacy varies considerably, depending on particular features of the interventions and the skills they target. (Photo: Shutterstock)

K-12 | LANGUAGE AND LITERACY | TECHNOLOGY

New study explores what makes digital learning products more – or less – effective

Research led by Stanford Professor Rebecca Silverman analyzes studies on edtech interventions for early reading skills.

August 5, 2024 By Carrie Spector

SHARE:

Educational technology has become a fixture in the U.S. classroom, but scholars continue to debate its effectiveness – some even arguing that the products might deter learning by taking students' time and attention away from more powerful supports.

What does research show about the effectiveness of edtech? Does the impact vary when it comes to teaching certain skills and student populations? How can schools determine which products are most useful for their own setting and purposes?

A new Stanford-led study sheds light on the value of edtech interventions, with a focus on products aimed at helping elementary school students develop early reading skills. In a meta-analysis of studies conducted over the past two decades, the researchers found that the effectiveness of tech products varied considerably, depending on particular features of the interventions and the skills they targeted.

"When we talk about digital learning products, they're really not all the same – there's a wide range," said Rebecca Silverman, the Judy Koch Professor of Education at Stanford Graduate School of Education (GSE), a faculty affiliate of the Stanford Accelerator for Learning, and the study's lead author. "There isn't a single answer to whether digital technologies support literacy. The question is much more complex: Which products, with which characteristics, under which conditions?"

The paper, published July 31 in the peer-reviewed journal *Review of Educational Research*, was co-authored by Elena Darling-Hammond, a doctoral student at the GSE; Kristin Keane, a postdoctoral scholar at the GSE; and Saurabh Khanna, PhD ’23, who is now an assistant professor at the University of Amsterdam.

Stanford GSE Professor Rebecca Silverman

Accounting for variability

For the meta-analysis, the researchers drew on 119 studies published between 2010 and 2023 to examine the use of various digital interventions in kindergarten through fifth grade, including computer programs, e-books, online games, and videos.

The study is unique, they said, in its focus on edtech at the elementary school level and its review of interventions across four skills: decoding (the ability to read words quickly and accurately), language comprehension (understanding the meaning of words), reading comprehension (processing the meaning of a passage), and writing proficiency (the ability to convey ideas in writing).

Their analysis found positive effects on elementary school students' reading skills overall, indicating that generally, investing in educational technology to support literacy is warranted. But when the researchers isolated particular learning outcomes to measure effectiveness, they found wide variability, suggesting that the effectiveness of a particular edtech product can depend on different factors, including features of the tool and characteristics of the users.

The authors observed that most studies – and the majority of products in the marketplace – focused on basic decoding, where students use phonetic skills to understand the relationship between written letters and their sounds. Relatively few studies considered language and reading comprehension, and only a handful looked at writing proficiency.

"Decoding is a fairly constrained construct involving a relatively circumscribed set of skills," Silverman said. "There are only so many letters and sounds and letter-sound combinations that kids need to learn, so it's generally easier to teach and see change over time."

Language comprehension is a more complex construct, she said, involving a vast number of concepts, word meanings, and sentence constructions and the ability to make connections and build knowledge. "Its complexity makes it harder to teach and see progress. But it's a crucial skill to be able to access texts and content, so we need more tools and research focused on that piece."

Product features that appeared to account for some of the variability in effectiveness included the type of technology, the duration of the intervention, and the instructional approach (that is, whether it emphasized repetition and facts, strategies to organize and process information, or open-ended tasks).

The analysis found, for example, that certain personalization, gamification, and interactive feedback features, like pop-up questions and clickable definitions, were not effective for supporting more complex skills like reading comprehension.

Where student characteristics were concerned, socioeconomic status surfaced as one factor moderating effectiveness: With decoding as an outcome, for example, studies with a substantial percentage of students from low socioeconomic backgrounds tended to have larger effects compared with other studies, which Silverman said could be due to the programs they used being more geared toward their needs.

The researchers suspected that disability and language status would also emerge as a factor in the variability they uncovered, but few studies disaggregated findings based on these backgrounds.

“A program might not benefit some kids as much as others, and if we don’t track that in a systematic way, we’re not going to know,” Silverman said. “Right now, it’s not being systematically captured in the research, and that’s a problem.”

The researchers also noted that few studies addressed edtech’s impact on students’ motivation or engagement, and few included follow-up over time, to assess whether the effects lasted months or even years after the intervention.

Considerations for school leaders

The findings point to several directions for educators and policymakers, the researchers concluded. For one thing, Silverman said, districts contemplating a particular product should carefully consider whether it’s appropriate for their population of students, and whether the content and approach aligns with the curriculum and classroom teaching.

She advised that, rather than taking marketing claims at face value, districts conduct a critical analysis of any program before deciding whether to adopt it for their schools. “Is it following the principles of effective practice for the skills you’re targeting with that program?” she said. “What studies have been done on it? How strong is the company’s own research? Has anybody done any independent research?”

Districts can also generate their own data, for example, by running a pilot program in which some schools or classrooms implement an edtech intervention, comparing their outcomes against the schools that don’t. “You may not be able to isolate [the effects of the program] completely,” Silverman said, “but an analysis can suggest whether this product is helpful.”

If a product doesn't appear to produce positive effects, districts can partner with researchers to try to figure out why — or they can move on to trying other tools and evaluate those, she said. “We don’t want kids to keep using products that aren’t helpful.”

Faculty mentioned in this article: Rebecca Silverman

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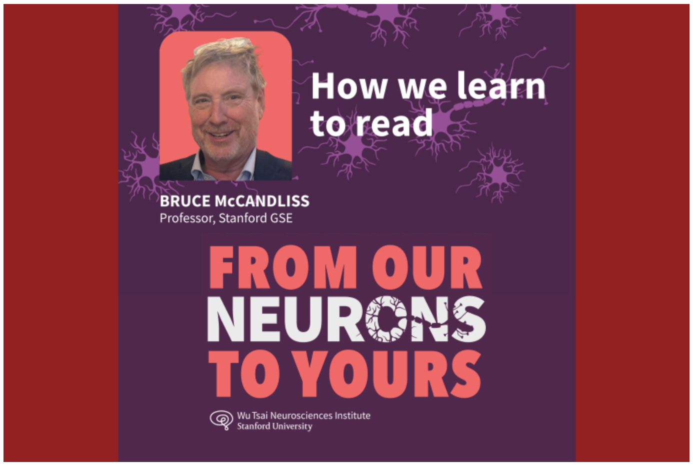

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ELA

Grade	iREADY	Acadience	RISE	Benchmark	
Kindergarten	81.08%	95.77%	NA		
1st	49.32%	76.19%	NA		
2nd	80.43%	73.44%	NA		
3rd	46.48%	67.16%	Pending		
4th	45.33%	80.70%	Pending		
5th	27.54%	48.44%	Pending		

	iXL	RISE	COMMON Assessments	Grade	Common Lit
6th	73.60%	Pending		56.40%	64.28%
7th	59.50%	Pending	64.40%	80.30%	41.30%
8th	56.90%	Pending		64.70%	53.33%
9th	75.25%	Pending		75.50%	50%

MATH

Grade	iREADY	Acadience	Benchmark	
Kindergarten	81.08%	95.77%		
1st	34.72%	97.26%		
2nd	23.61%	94.59%		

	iREADY	RISE	Benchmark	
3rd	24.68%	Pending		
4th	32.05%	Pending	83%	
5th	28.77%	Pending	44.80%	

	iXL	RISE	COMMON Assessments	Grade
6th	63.10%	Pending	34.30%	68.62%
7th	50.87%	Pending	59.15%	80.03%
8th	57.02%	Pending	51.92%	76.66%
9th	29.59%	Pending		84.78%

OECD Education Working Papers No. 335

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Abstract

This working paper shares findings of a literature review examining the impact of a range of digital tools on student outcomes. Drawing on systematic reviews, meta-analyses and empirical studies, this working paper delivers a balanced assessment of major digital tools, highlighting both their benefits and the challenges they present. The evidence shows that access to technology alone does not guarantee educational gain. Rather, successful digitalisation also requires pedagogical, not solely technical, solutions.

This working paper was prepared as part of the *Resourcing school education: Policies for the digital transformation of education and future-readiness of teachers* project, which is included in the 2025-26 Programme of Work of the OECD's Education Policy Committee. It was commissioned by the Irish Department of Education and Youth to the OECD to investigate the impact of digital tools on education. This work was developed by the University of Stavanger under the guidance of the OECD Secretariat.

Acknowledgements

This working paper is one of two companion working papers focused on the impact of digital technologies on students' learning. It provides a granular review of the impact of various categories of digital tools on student learning and motivation in primary and secondary education. Its companion working paper ("Key findings and integration strategies on the impact of digital technologies on students' learning: Results from a literature review", Forsström et al., 2025[1]) complements it by synthesising key findings of the review and looking across the various categories of digital tools to explore integration strategies more holistically. The working papers were prepared as part of the *Resourcing school education: Policies for the digital transformation of education and future-readiness of teachers* project, which is included in the 2025-26 Programme of Work of OECD's Education Policy Committee, and developed thanks to the financial support of Ireland's Department of Education and Youth.

The development of this working paper was undertaken by the Knowledge Centre for Education (KCE) of the University of Stavanger, Norway, and guided by the OECD Secretariat. Sanna Forsström, Morten Njå and Elaine Munthe (University of Stavanger) led the preparation of the paper and Serap Keres (KCE) provided support.

Jose-Luis Alvarez-Galvan (OECD) guided the paper's development and Lawrence Houldsworth (OECD) provided analytical support to the paper's final development. Karine Tremblay (OECD) led the initial stages of this work, including the definition of its scope. The overall guidance and feedback on drafts provided by Andreas Schleicher (Director of Education and Skills) and Paulo Santiago (Head of Division, Policy Advice and Implementation) are gratefully acknowledged. Christina Mitrakos (OECD) supported the paper's preparation for publication, supported by Rachel Linden (OECD) who also oversaw communication efforts. Beatrice Bottura (OECD) provided additional technical assistance. Susan Mulhall, Clare Connolly, and Edel Martin (Digital Policy for Schools, Department of Education and Youth, Ireland) provided valuable input throughout the paper's conceptualisation and development. The paper has also benefited from the valuable input from delegates to the OECD Group of National Experts on School Resources (GNE-SR), which oversees the OECD project.

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1 Introduction

The integration of digital technologies in primary and secondary education holds significant potential for enhancing teaching and learning processes, fostering student engagement, collaboration and self-regulated learning. While digital tools can improve engagement, offer personalised learning and develop key digital skills, their successful use depends on thoughtful pedagogical alignment, teacher and student digital competencies and careful planning. Challenges – including distractions, cognitive overload and digital inequity – must also be addressed for digitalisation to benefit all students.

This working paper builds on the GrunnDig project (Munthe et al., 2022[1]), extending its foundational systematic review by incorporating newer systematic reviews and primary studies. It provides an updated overview of various categories of digital tools – including programming and robotics, media production, gaming, extended reality simulations, assessment tools and learning analytics – and how they impact students' motivation and learning. Drawing on systematic reviews, meta-analyses and recent primary studies, it identifies effective practices, discusses challenges and highlights trends and gaps in current research.

As highlighted in the GrunnDig project, tools alone do not transform education (Munthe et al., 2022[1]). The impact of digital tools on students' learning and motivation relies heavily on teachers' practices, choices and competencies, specifically the purposes for which the tools are used, the timing of their use and the educational objectives they support. Effective education continues to depend on competent teachers who can guide students and make thoughtful choices regarding the integration of digital tools. Their role is crucial in navigating the opportunities and risks associated with digitalisation.

To provide a clear, evidence-based overview of these dynamics, this working paper addresses the following guiding questions:

- What is the impact of different types of digital tools on student learning and motivation in primary and secondary education?
- For what purposes, when and how are digital tools used in successful learning processes, and what challenges are identified in their integration into primary and secondary classrooms?

Key findings

This working paper explores digital tools and their impact on student learning and engagement across various subjects. It synthesises findings from meta-analyses, systematic reviews and primary studies to highlight effective practices, challenges and emerging insights, focusing on programming, media literacy, gaming, extended reality and artificial intelligence and learning analytics.

Programming and robotics

Programming education significantly develops computational thinking, creativity and problem-solving skills. In primary education, visual, block-based tools (e.g. Scratch Blocks™) effectively introduce students to programming concepts, reducing cognitive load and allowing students to focus on logical reasoning and problem decomposition. For secondary students, transitioning to text-based languages like Python or Java introduces greater complexity and real-world application opportunities, though it poses cognitive challenges. Hybrid programming environments that combine block- and text-based approaches can facilitate this transition. Effective programming education depends on collaborative environments and strategies encouraging students to reflect on their learning processes. Teachers play a crucial role in managing cognitive demands and guiding exploration, emphasising the importance of professional development to equip educators with the necessary technical and pedagogical skills.

Media production and literacy

Media production and literacy tools can substantially enhance language and literacy development, particularly benefiting students from less stimulating home environments. Multimedia platforms such as digital storytelling tools and podcasting can boost comprehension, vocabulary and collaborative learning. These tools should be carefully aligned with educational objectives, balancing engaging multimedia integration against potential cognitive overload. Social media platforms (e.g. instant messaging applications or video streaming services) offer environments for communication and collaboration but pose challenges like distraction and cyberbullying. Computer-assisted instruction supports foundational literacy by providing personalised feedback, enhancing students' writing and reading skills. A balanced approach that combines digital and analogue reading methods promotes deeper comprehension and sustained engagement. Teachers' careful selection of tools, strategic use of digital and analogue methods, and ongoing professional development significantly influence successful media literacy integration.

Gaming

Game-based learning (GBL) enhances motivation, engagement and critical skills development such as problem-solving and collaboration. Serious games support deeper cognitive engagement across disciplines like mathematics, science and social studies. Exergames combine physical activity with cognitive tasks, benefiting both physical fitness and cognitive skills. Role-playing games (RPGs) foster critical thinking, empathy and social skills, while sandbox games (e.g. Minecraft) encourage creativity, self-directed learning and teamwork. Challenges in GBL integration include aligning games with learning objectives, ensuring equitable access to technology and managing varying student engagement levels. Teachers play a pivotal role in selecting suitable games, scaffolding learning experiences and addressing technical barriers.

Extended reality and simulations

Extended reality (XR) – including augmented (AR), virtual (VR) and mixed reality (MR) – offers immersive learning experiences that enhance conceptual understanding, especially in STEM (Science, Technology, Engineering and Mathematics) subjects. Augmented reality (AR) promotes spatial reasoning, while virtual reality (VR) and MR support problem-solving through interactive simulations. Dynamic Geometry Software (DGS) and Computer Algebra Systems (CAS) improve mathematical skills through real-time interactions. XR technologies facilitate collaboration, creativity and inclusivity, particularly benefiting students with special needs. Virtual laboratories allow safe, interactive experimentation. However, challenges like high costs, unequal technology access, cognitive overload and technical issues persist. Effective XR integration requires teacher training, infrastructure investment and pedagogical alignment to maximise educational benefits.

Artificial intelligence and learning analytics

Artificial intelligence (AI) and learning analytics can transform education through personalised feedback, formative assessment and targeted interventions. AI-powered tools, such as intelligent tutoring systems and natural language processing, provide immediate feedback, reduce teacher workload and foster student engagement. Learning analytics helps identify students at risk, enabling timely interventions. AI-enhanced collaborative tools (e.g. chatbots) support balanced group participation and communication. AI applications also support inclusivity, offering tailored accommodations for students with disabilities. Despite these benefits, issues like high implementation costs, limited digital access, ethical concerns and cognitive load require careful management. Successful AI integration relies on infrastructure investment, teacher training and ethically-sound, pedagogically-informed implementation. Combined effectively with traditional teaching methods, AI and learning analytics can create personalised, inclusive and efficient learning environments.

Structure of this working paper

The main body of the paper is divided into five self-contained chapters. Each one is designed to be read as a standalone review, allowing a reader to focus on a single type of digital tool without needing to read the others.

The chapters are:

- Programming and robotics: Explores how tools like Scratch and educational robots impact computational thinking and problem-solving skills.
- Media production and literacy: Analyses how digital storytelling, multimedia tools and social media affect skills in reading, writing and communication.
- Gaming: Discusses how game-based learning, serious games (e.g. Minecraft) and exergames influence student motivation and critical thinking.
- Extended reality (XR) and simulations: Examines the use of augmented reality (AR) and virtual reality (VR) to create immersive learning experiences, especially in STEM.
- Artificial intelligence (AI) and learning analytics: Reviews how AI enhances personalised feedback, formative assessment and collaborative learning.

Every chapter follows the same consistent format: a summary of key findings, a detailed analysis and a final summary table that covers both benefits and challenges of using such a digital tool.

An accompanying working paper, “Key findings and integration strategies on the impact of digital technologies on students’ learning: Results from a literature review” (Forsström et al., 2025[2]), looks across these findings to consider some of the integration strategies for tools as well as associated risks or challenges to realising this integration in classrooms.

2 Methodology

This working paper presents key findings from central systematic reviews, meta-analyses, and recent primary studies examining how the integration of various digital tools in primary and secondary education impacts students' learning and motivation. It identifies effective practices and challenges associated with digitalisation in education and synthesises insights from these different study types to explore the role of digital technologies in education.

Meta-analyses discussed in this working paper aggregate data from multiple primary studies to assess the overall effectiveness of tools – such as extended reality (XR) on student motivation – to offer a broad, quantitative perspective. Systematic reviews synthesise the existing literature and identify trends, best practices and challenges by combining the findings from numerous primary studies. Primary studies provide specific contextual insights by addressing research questions related to the central theme of digital tool integration in education, such as examining the effects of virtual reality within a single classroom environment.

Each study type uniquely contributes to the understanding of the educational impact of digitalisation. Primary studies are foundational, generating firsthand evidence through original research designed to answer specific research questions. In contrast, systematic reviews offer a comprehensive summary or synthesis of the existing primary studies on a given topic. They follow a rigorous, pre-defined methodology to search for, select, and evaluate studies, aiming to provide an unbiased overview of the current evidence. Meta-analyses take this process a step further by statistically combining results from multiple primary studies, typically those identified in systematic reviews, to yield a single effect size or overall conclusion. While systematic reviews synthesise qualitative insights, meta-analyses deliver quantitative precision by pooling data and offering more accurate effect estimates across studies.

Interpretation of effect sizes

In a meta-analysis, *effect size* is a standardised measure that quantifies the overall magnitude of an effect across multiple studies on a topic of interest. This enables researchers to synthesise findings from different studies and determine a more accurate estimate of the true effect, accounting for variations in study designs, sample sizes and measurement tools.

Effect sizes are essential in medical research because they provide a standardised measure of the impact of treatments or interventions, enabling direct comparisons across studies. Medical research outcomes, such as survival rates or symptom reduction, are typically well-defined and consistent, making effect sizes a reliable indicator of clinical relevance. This, in turn, helps to inform evidence-based practice.

In contrast, the effect sizes in educational research are often context-dependent. Educational outcomes can vary due to factors such as student demographics, instructional context and individual differences in learning. An effect size indicating a "small" impact on an outcome may still hold value if it benefits a specific group of students or supports incremental learning gains. Moreover, the practical significance in education is not solely about the magnitude of the effect but also about how it contributes to student growth and classroom dynamics. Thus, interpreting effect sizes in education requires considering the broader context and educational objectives.

The most common effect sizes used in meta-analyses to compare two groups (intervention versus control) are Cohen’s *d* and Hedges' *g.* Cohen’s *d* measures the difference between two group means in standard deviation units and is used in many studies for effect size calculation without a small sample adjustment. Hedges' *g* is a variation of Cohen's d but adjusted for small sample sizes. Some frameworks categorise the magnitude of these measures as follows: an effect size of 0.2 is considered small, 0.5 medium and 0.8 large. However, it is important to appropriately contextualise these effect sizes, as they should not be used in isolation as the only indicator of how well a specific tool or intervention works in specific educational settings.

While calculating the mean effect size can help summarise the overall impact across studies, this measure may be less meaningful if there is substantial variation among the included studies. When effect sizes differ significantly due to variations in study populations, methodologies, or other contextual factors, a single mean effect size might not accurately represent the full range of observed outcomes. This is why examining the factors that contribute to this variation – known as moderators – is crucial. Analysing these moderators allows for a more nuanced interpretation of the results, helping identify the conditions under which interventions are more or less effective.

Reporting on grades and students’ ages

In this working paper, some systematic reviews and meta-analyses employ school-level terminology that is not used within the Irish education system. Additionally, some studies do not specify participant age but instead refer to broader educational levels. In these cases, we use the terms used by the authors of the included reviews. The table below provides an overview of how these general terms correspond to the Irish system.

Table 2.1. Overview of education levels

General terms	Irish system equivalent	Irish years/classes	Typical age range
Pre-school/ Early years	Pre-school (or early years)	Pre-school	3 – 4/5
Primary school	Primary school	Junior infants, Senior infants, 1st class – 6th class	~4/5 – 12/13
Middle school	(No distinct stage)	4th, 5th and 6th class	~10/11 – 12/13
Lower secondary	Secondary school – Junior cycle (and optionally part of TY)	1st year, 2nd year, 3rd year (+ optional transition year)	~12/13 – 15/16
Upper secondary	Secondary school – Senior cycle	5th Year, 6th year	~16 – 18
Higher education	Higher education (University/College, Undergraduate & Postgraduate)	(Not broken down by “years/classes” in the same way as primary/secondary)	18+

Relevant theoretical concepts

The working paper primarily emphasises practical exploration over theoretical analysis, focusing on the impact of digital technologies on students' learning and motivation. It focuses mainly on empirical findings rather than theoretical frameworks. However, in instances where specific studies are grounded in theory, these theories are brought up to provide additional context and depth. While theories are not the main focus, the concepts of cognitive load and motivation theories emerged across the studies examined.

Digital literacy in education

In this working paper, digital literacy is highlighted at several points, particularly when discussing benefits and challenges related to the digitalisation of primary and secondary education, as well as when exploring solutions to the identified challenges. The discussion addresses the digital literacy of students, teachers and school leaders. This section defines digital literacy and outlines its core components.

Digital literacy refers to the ability to locate, evaluate, use and create information using digital tools and platforms. It includes several interconnected competencies essential for the effective use of technology in educational contexts. Technological comprehension is fundamental, as it enables teachers and learners to effectively understand and use digital tools to achieve their objectives (Kohnke, Moorhouse and Zou, 2023[3]). In the report "Ireland's Literacy, Numeracy and Digital Literacy Strategy 2024-2033: Every Learner from Birth to Young Adulthood" (Developed by the Irish Department of Education and Youth and the Irish Department of Children, Equality, Disability, Integration and Youth), digital literacy is defined as

> *the ability to access, explore, manage, understand, integrate, communicate, evaluate, create and disseminate information safely and appropriately through digital technologies. It includes critical thinking, using ICT (Information and Communications Technology) safely, responsibly and ethically, collaboration and creativity, finding real information and respectful online communication.*

These definitions illustrate the broad scope of digital literacy, encompassing technical skills, critical thinking, ethical awareness and effective communication.

Another core component is information manipulation, which involves the ability to evaluate, organise and apply digital information in meaningful ways (Yazon et al., 2019[4]). Critical thinking is crucial as it supports the ability to assess the credibility, relevance and accuracy of digital content, allowing users to make informed decisions about its application (Muñoz-Basols et al., 2023[5]). Additionally, ethical awareness is integral to digital literacy, addressing the importance of recognising and navigating the ethical dimensions of technology use, including issues of privacy, security and academic integrity (Dempere et al., 2023[6]).

Digital literacy plays a key role in both teaching and learning. For teachers, this involves designing, implementing and evaluating technology-enhanced learning experiences. For students, it supports self-directed learning, critical engagement with resources and effective collaboration and communication in digital environments. Emphasising effective digital communication can help learners collectively identify and counter misinformation and disinformation by promoting collaborative dialogue and the sharing of reliable information. Dianova and Schultz (2023[7]) emphasise the necessity of interdisciplinary digital literacy, which fosters adaptability and comprehensive knowledge across various educational contexts. A detailed discussion of teachers' and students' digital literacy can be found in the accompanying working paper, "Key findings and integration strategies on the impact of digital technologies on students' learning: Results from a literature review" (Forsström et al., 2025[2]).

Although digital literacy is widely recognised as important, its development can face challenges. The rapid evolution of technology means that tools and platforms frequently change and require continual adaptation to new systems and features (Johinke, Cummings and Di Lauro, 2023[8]). Ethical complexities, such as concerns about data privacy, misinformation and misuse, are also associated with using digital tools (Dempere et al., 2023[6]). Furthermore, disparities in access to digital resources contribute to the uneven development of digital literacy, particularly in contexts with a limited technological infrastructure. These factors underline the multifaceted nature of digital literacy and its relevance to diverse educational settings.

Cognitive load theory

Cognitive Load Theory (CLT), as described by Sweller, Ayres and Kalyuga (2011[9]), examines how the human brain processes information, emphasising the limitations of working memory when learning new material. This theory provides a framework for understanding how mental effort is allocated during learning and how it can be optimised to enhance knowledge acquisition and retention. CLT is particularly relevant in the context of digital education, where the design of digital tools and learning environments can significantly influence cognitive load.

Cognitive Load Theory identifies three types of cognitive load:

1. **Intrinsic load**. This refers to the inherent complexity of the material being learned. For instance, the complexity of a mathematical problem or a new programming concept may naturally demand a certain level of cognitive effort. Intrinsic load varies depending on the learner's prior knowledge and the interactivity of the material.
2. **Extraneous load**. This stems from elements that do not directly contribute to learning and can include poorly designed interfaces, unnecessary instructions, or distracting multimedia elements. Reducing extraneous load is critical for ensuring that learners can focus their cognitive resources on the task at hand.
3. **Germane load**. This represents the cognitive effort devoted to processing, organising and integrating information into long-term memory. Germane load is essential for deep learning and understanding, as it supports schema construction and knowledge retention.

In the context of digital technology, understanding cognitive load is essential for designing and using effective learning tools. Well-designed digital resources can reduce extraneous load by presenting information clearly and minimising distractions, allowing learners to allocate more effort toward germane load and the actual process of understanding. On the other hand, poorly designed digital environments can increase extraneous load, overloading working memory and hindering learning.

Motivational theory

Although not a primary focus, 'motivational theory', particularly 'self-determination theory' (Deci and Ryan, 1985[10]), is referenced in this working paper as a theoretical framework for understanding how *digitalisation* can impact motivation in education. This theory explains motivation through three basic psychological needs: autonomy, competence and relatedness. When these needs are met, students are more likely to experience intrinsic motivation and engage in learning for their own sake rather than external rewards.

Digitalisation can support autonomy by offering students opportunities for *personalised learning* and decision-making in their tasks. Competence can be enhanced through digital tools that provide immediate feedback and opportunities for practice, helping students to build confidence in their skills. Digital platforms can also enable meaningful collaboration and communication among students and teachers.

Understanding these dynamics through the lens of self-determination theory provides insights into how digital tools can be integrated into education in ways that foster intrinsic motivation and engagement, aligning with the psychological needs essential for effective learning.

A related concept is 'engagement', which refers to the level of involvement, interest and commitment a student demonstrates in the learning process. This can manifest in various forms, including behavioural engagement (active participation in tasks, such as completing assignments or contributing to discussions), emotional engagement (positive feelings towards learning, such as enjoyment or curiosity), and cognitive engagement (deep involvement in thinking, problem-solving and critical analysis). By meeting students' psychological needs as described by self-determination theory (Deci and Ryan, 1985[10]), digital tools can enhance all these forms of engagement. For example, personalised learning environments foster cognitive engagement by encouraging deep exploration of content, while collaborative platforms promote emotional and behavioural engagement through social interactions and active participation in shared tasks (Fredricks, Blumenfeld and Paris, 2004[11]).

3

Programming and robotics

Key findings

- Programming education can enhance computational thinking by teaching problem-solving and algorithmic reasoning skills, with younger students often showing most consistent gains.
- Collaborative and metacognitive strategies can foster deeper engagement and understanding, while non-collaborative or individualised instruction is generally less effective.
- Skills learned through programming can transfer to other domains (e.g. mathematics, creative thinking), but this depends on context, instructional design and task relevance.
- Programming can foster creativity when students are encouraged to explore and experiment with open-ended tasks.
- Programming can improve mathematical skills, especially in problem-solving and modelling tasks, although the degree of improvement varies depending on task complexity and teaching methods.
- Block-based programming can reduce cognitive load for younger students by simplifying syntax and making tasks more accessible.
- Text-based programming is necessary for advanced learning in older students but can overwhelm younger learners if introduced too early, with the transition to this demanding careful instructional approaches and teacher support to manage cognitive load and maintaining engagement.

Programming education has the potential to foster critical thinking, creativity and problem-solving skills while enhancing students' computational thinking and digital literacy. Introducing programming at an early age allows students to engage with technology meaningfully, making abstract concepts more tangible through hands-on activities, such as robotics. Cross-curricular integration further supports the development of computational thinking, reasoning and problem-solving skills in diverse contexts.

Block-based programming can be particularly effective for younger students in reducing cognitive load and providing an accessible introduction to programming concepts. For older students, text-based programming languages help support more advanced learning and prepare them for real-world applications. Collaborative and creative learning environments also encourage teamwork and allow students to transfer programming skills to other domains, such as mathematics and creative problem-solving, thereby broadening their cognitive abilities.

A clear understanding of key terms is essential for interpreting both research findings and classroom practice in this field. Table 3.1 outlines several important concepts relevant to programming and robotics education.

Table 3.1. Key terms in programming and robotics

Term	Definition	Examples of tools
Block-based programming	Block-based programming uses a visual interface where code elements are represented as interlocking blocks. These blocks are pre-defined chunks of code that can be dragged and dropped to create programmes. This approach is often used in educational settings and for beginners learning to code.	Scratch, Alice
Text-based programming	Text-based programming involves writing code directly using a programming language's syntax. This is the traditional method of coding used by professional developers.	Python, Java, C++ and JavaScript
Educational robots	Educational robotics incorporates programmable robots to engage students in hands-on learning. Robots can be programmed using both block-based and text-based programming, allowing students to apply programming concepts in a physical, interactive environment that makes abstract concepts more tangible.	Lego Mindstorms
Visualisation-based programming	Programming that uses visual elements, such as blocks or graphical interfaces, to help students understand coding concepts by representing code visually, making abstract ideas more accessible.	Scratch
Hybrid programming environments	Educational environments that combine block-based and text-based programming, allowing students to gradually transition from visual, beginner-friendly tools to more advanced, syntax-based coding.	Microbit
Transfer skills	The ability to apply programming knowledge and problem-solving skills learned in one context (such as coding) to other domains, like mathematics, creative thinking, or real-world problem-solving.	N/A
Computational thinking	A structured approach to problem-solving that involves breaking down complex problems, recognising patterns, and developing step-by-step solutions, which can be applied both in programming and other fields.	N/A
Cognitive load	The mental effort required to process and understand information can become overwhelming when students are faced with complex tasks or unfamiliar syntax, especially in programming education.	N/A

Note: N/A refers to Not Applicable where the definitions refer to broader concepts.

Impact of programming education on student learning

This section discusses the impacts of programming education on student learning, focusing on measurable outcomes such as computational thinking, problem-solving, skill development and skill transfer across domains. Meta-analyses have assessed gains in students' ability to break down complex problems, apply algorithmic reasoning and transfer programming skills to areas like mathematics and creative thinking. Moderators, including the instructional approach, educational level and intervention length, offer further insights into the conditions that optimise these outcomes.

Computational thinking and problem-solving

Computational thinking (CT) is a problem-solving approach that draws on concepts fundamental to computer science. This involves breaking down complex problems into smaller, more manageable parts, recognising patterns and developing step-by-step solutions that a computer or human can effectively implement. Meta-analyses by Zhang et al. (2021[12]) and Scherer, Siddiq and Sánchez Viveros (2020[13]) demonstrated varied effects of programming education on CT and problem-solving skills among students of different ages within classroom practices.

Zhang et al. (2021[12]) measured CT as a primary outcome and examined how integrating educational robots into regular classroom instruction improved students' problem decomposition (,i.e. the process of breaking down a complex problem into smaller, more manageable problems), algorithmic thinking and logical reasoning. They found that educational robots moderately impacted student learning outcomes (SMD = 0.46). Furthermore, their study highlights some significant moderating effects.

- **CT and STEM attitudes**. There was a significant difference between outcomes when divided between CT and STEM attitudes: the use of Educational Robots (ER) demonstrated a strong positive impact on students' critical thinking abilities, while their influence on STEM attitudes remained minimal or negligible. This distinct difference in outcomes suggests that robotics education may be more effective in developing analytical skills than in changing attitudes toward STEM fields.
- **Educational level**. The effect size was higher for studies with primary-student samples than for middle school students (see Table 2.1 for definitions of student levels). This suggests that primary students may experience more significant gains in CT through educational robots in classroom settings, whereas middle school students may benefit less from such interventions.
- **Intervention period**. Studies with experimental periods shorter than four weeks showed a slightly larger effect size than those between four and 11 weeks. In contrast, periods of 12 weeks or longer had a lower impact. This suggests that longer use may reduce the effect of ER due to factors such as increased familiarity with robots, reduced novelty, decreased enthusiasm for learning and diminished participation.

Scherer, Siddiq and Sánchez Viveros (2020[13]) explored the effects of programming education in classroom settings, focusing on outcomes such as programming knowledge, problem-solving skills and computational practices, such as debugging, testing and logical reasoning. They reported a large overall effect size (g = 0.81) for the programming interventions. Due to the small number of primary studies explicitly discussing this condition, moderator analyses were deemed insufficient to find any meaningful insights.

Impact of educational robotics on skill development

Sun and Zhou (2023[14]) conducted a meta-analysis of ER to assess its impact on essential and generative skills. Essential skills (e.g. basic programming, debugging) involve acquiring fundamental knowledge and practices necessary to understand and utilise programming and robotics effectively. Generative skills (e.g. computational thinking and creativity) involve applying foundational knowledge to create, innovate and solve problems, showcasing higher-order thinking and collaboration abilities. The overall effect sizes for essential ability (g = 0.539) and generative skills in ER activities were found to be moderate (g = 0.535). Their study identified several significant moderators:

- **Educational level**. This emerged as a significant moderator that influenced both essential and generative skill development. ER was found to be particularly effective in studies of younger students, especially those in kindergartens and primary schools. This suggests that introducing ER at an early educational stage may significantly enhance students' foundational programming abilities and simultaneously foster higher-order thinking skills such as creativity and problem-solving.
- **Intervention length**. The duration of interventions impacted the effectiveness of ER for both skill types. Shorter interventions, specifically those lasting between one and five weeks, yielded the greatest positive effects on essential and generative skills. By contrast, longer durations led to diminished effects. This indicates that brief, focused ER activities might be more effective in promoting both foundational understanding and the ability to creatively apply knowledge.
- **Assessment tools**. Different assessment tools were explored as moderator variables. For essential skills, when the scale evaluation method was used, the greatest impact on enhancing students' abilities was detected. Although the scales proved effective, the evaluation methods of rubrics and tests did not show significant effects on essential ability development. Conversely, the assessment tools were influential overall for generative skills, showing a moderate positive effect.

Within this, studies using scales and rubrics produced the largest effects on enhancing generative skills, while hybrid measurements and tests also exhibited moderate effect sizes.

Managing cognitive load is essential in programming education, particularly for younger students, as the physical manipulation of robots combined with programming tasks can be overwhelming. Block-based programming languages, such as Scratch, help to reduce cognitive load, enabling students to focus on conceptual understanding without being burdened by programming syntax (i.e. writing lines of code). In contrast, text-based programming for younger learners can increase cognitive load and reduce engagement, since they must navigate both syntax and programming logic. This can hinder the ability to grasp foundational concepts effectively. For older students, text-based programming environments introduce the complexity required for continued development. However, ER proved less effective for high school students, showing diminishing returns as task complexity increased.

Transfer of programming skills to other domains

The transfer of programming skills is considered beneficial for enhancing cognitive skills beyond the programming domain. Scherer, Siddiq and Sánchez Viveros (2019[15]) focused on the transfer of programming skills to other cognitive domains, analysing whether learning to programme impacts students' cognitive abilities beyond programming itself. Their meta-analysis demonstrated that programming education improved cognitive skills such as problem-solving, mathematical skills, creative thinking, and metacognition, with an overall moderate effect size for transfer ($g = 0.49$), suggesting that learning programming yields measurable benefits across various cognitive domains, making it a valuable tool for fostering transferable skills in education.

The study also explored the differences between near and far transfer. The study reported that programming interventions had a large effect on near transfer ($g = 0.75$), which refers to the application of programming skills to tasks closely related to programming itself, such as debugging and algorithmic thinking. Far transfer effects, where programming skills are applied to more distantly related tasks (e.g. applying programming skills to non-STEM tasks), were moderate ($g = 0.47$), indicating that students were able to transfer problem-solving skills and logical reasoning to non-programming tasks, such as mathematics and spatial reasoning.

Programming education enhances both skills closely related to programming (near transfer) and various other cognitive domains (far transfer). The most substantial improvements were observed in creative thinking and mathematical skills, indicating that programming is particularly effective in fostering originality and mathematical problem-solving abilities. Moderate gains in metacognition, spatial skills and reasoning skills further underscore the value of programming education in developing a wide range of transferable cognitive skills.

In the following list, the various cognitive domains are further discussed, ranked by their effect size from highest to lowest:

- **Creative thinking**. Programming notably fostered creative thinking, particularly in the originality dimension – the ability to generate unique and novel ideas. Among the cognitive skills examined, programming interventions were particularly effective in enhancing creativity. This suggests that programming develops logical and structured thinking and significantly boosts students' capacity to think outside the box and devise original solutions.
- **Mathematical skills**. Students who participated in programming education showed improvements in their mathematical skills, especially in problem-solving and modelling tasks. The enhancement in mathematical abilities was more pronounced compared to some other domains. This may be attributed to the logical and analytical nature of programming, which closely aligns with mathematical concepts and reasoning.

- **Metacognition**. Programming enhanced students' ability to plan, monitor and evaluate their problem-solving strategies, leading to better self-regulation and reflection on their learning processes. The improvement in metacognitive skills was moderate compared to gains in creative thinking and mathematical skills. Nonetheless, this indicates that programming fosters awareness and regulation of thought processes, which is crucial for effective learning across various disciplines.
- **Spatial skills**. The transfer effect to spatial skills was moderate. Programming activities often include visual and spatial reasoning components that reinforce spatial understanding through problem-solving tasks. While the impact on spatial skills was less pronounced than that on creative thinking or mathematical skills, programming still contributed positively to the ability to understand and manipulate two- or three-dimensional objects and concepts.
- **Reasoning skills**. The impact of programming on reasoning skills, which encompasses logical thought processes, critical thinking, attention, perception and memory, was comparable to its effect on spatial skills. The structured, logical framework that programming provides parallels the reasoning and critical thinking processes. Although the improvement was not as significant as in creative thinking, programming still aided in developing reasoning abilities.

Integrating programming into different subjects

Several countries have integrated programming into their curricula in various ways, either as a standalone subject or embedded within other subjects. For instance, Norway and Finland have incorporated programming into mathematics, science and arts and crafts. However, a meta-scoping review by (Forsström, Bond and Njå, Forthcoming[16]) highlights the lack of high-quality, in-depth systematic reviews specifically examining programming within these subjects. Notably, no systematic reviews or comprehensive primary studies were found on integrating programming into arts and crafts. This observation was based on a manual search for relevant studies rather than a systematic review. Box 3.1 presents an example from a primary study by Olsson and Granberg (2024[17]) to illustrate the potential of programming in mathematics education.

Box 3.1. Transformative potential of programming in mathematics education

Olsson and Granberg (2024[17]) conducted a study with 40 Swedish students aged 10–11 who used Scratch, a block-based programming tool, to solve geometry problems. The study examined how teacher-student interactions support creative mathematical reasoning within programming contexts. Scratch enabled students to experiment with geometric concepts, such as angles and shapes, in a visual, interactive way, promoting deeper learning through immediate feedback and hands-on exploration. Olsson and Granberg's (2024[17]) study shows how programming, with strong teacher support, can create a more exploratory, student-centred learning environment that fosters creativity and enhances students' mathematical understanding.

The transformation in this study was driven by technology, which facilitated deeper learning through experimentation and immediate feedback. The teacher played a key role by guiding students with open-ended questions instead of direct solutions. These interactions encouraged students to initiate, develop, verify and justify their reasoning, helping them connect their code to underlying geometric principles.

The role of Scratch was especially significant. Its visual, block-based environment reduced the complexity of traditional coding and provided immediate feedback, allowing students to test and refine their reasoning iteratively. For example, when programming a sprite to turn and move to form a square, students could visually confirm whether their calculations about angles and distances were correct, leading to an intuitive grasp of geometric concepts.

Mathematics was central to the problem-solving tasks, requiring students to apply concepts such as angles, side lengths and geometric properties. The study found that programming helped students engage more actively with these concepts, as they needed to understand and manipulate mathematical ideas to succeed in the tasks.

However, integrating programming with mathematics presented challenges. While Scratch simplified coding and provided immediate feedback, students sometimes struggled to balance programming with mathematical problem-solving. For instance, focusing too heavily on programming could detract from mathematical reasoning and vice versa. Additionally, some students were unfamiliar with essential concepts like angles, which made the tasks even more difficult (Olsson and Granberg, 2024[17]). To address these issues, structured teacher-student interactions provided targeted guidance through task-specific questions, helping students clarify their understanding, correct mistakes and link programming activities to mathematical concepts. This approach enhanced both their coding skills and mathematical reasoning.

Programming tools and environments

This section examines how programming tools like block-based, text-based and hybrid environments support learning across educational levels.

Block-based and text-based programming

Block-based and text-based programming tools play distinct roles in programming education, each aligning with students' developmental stages. Block-based programming environments, like Scratch and Alice, are particularly effective for younger primary school students. These tools feature a visual, block-oriented interface that minimises syntax errors and fosters creativity, making programming accessible and engaging for beginners (Scherer, Siddiq and Sánchez Viveros, 2020[13]; Zhang et al., 2021[12]).

Hu, Chen and Su (2021[18]) found that block-based programming tools have a small to moderate yet statistically significant positive effect on academic achievement, with a moderate effect size ($g = 0.47$). This effect was particularly strong among studies with younger students, highlighting the importance of the educational stage as a moderator.

Similarly, Scherer, Siddiq and Sánchez Viveros (2020[13]) found that visual programming tools such as Scratch significantly enhance motivation and engagement in primary students, with a moderate to large effect size ($g = 0.51$). Engagement was measured through behavioural indicators, including time on task and students' expressed interest in creating games or animations. The open-ended nature of block-based programming enabled young learners to integrate computational thinking with creative project design, allowing them to build interactive stories, games and animations that reflect their interests. This flexibility in project creation helped sustain students' interest and active involvement in programming (Scherer, Siddiq and Sánchez Viveros, 2020[13]).

For studies with older students, text-based programming tools, such as Python and Java, prove more effective, especially in longer interventions. Text-based programming allows for greater flexibility and control, enabling students to tackle more advanced tasks that reflect real-world applications. Scherer, Siddiq and Sánchez Viveros (2020[13]) reported a moderate effect size ($g = 0.43$) for sustaining motivation and engagement in samples of older students. This suggests that tasks aligned with students' career-related aspirations, such as solving complex, industry-relevant problems, foster investment in their learning.

The role of hybrid programming environments

However, transitioning from block-based to text-based programming can be challenging, as it requires students to shift from a visual, intuitive interface to managing complex syntax and abstract logic. Vinueza-Morales et al. (2021[19]) reviewed various programming tools and pedagogical approaches used across primary and secondary education to support this transition. Their findings suggest that hybrid programming environments offer an effective solution for managing the transition from block-based to text-based programming. These environments allow students to visualise programming logic in a familiar, block-based format while gradually introducing elements of text-based syntax. This helps students build confidence and familiarity with programming concepts without being overwhelmed by syntax-related errors.

Vinueza-Morales et al. (2021[19]) highlight several important design considerations that can support the effective implementation of hybrid programming environments:

- The authors found that introducing text-based programming too early can overwhelm students, while delaying it for too long can hinder their progression into more advanced computational thinking. The study emphasises the importance of incremental learning, where students are introduced to text-based programming one element at a time. This method maintains student engagement by ensuring that the learning process remains accessible and manageable.
- The authors also emphasise the importance of creativity and autonomy in block-based environments. Successful learning in these environments is fostered by providing students with open-ended tasks that encourage experimentation. The study found that when students are given the freedom to create their own solutions to problems, they become more deeply engaged in the learning process. This sense of autonomy is crucial for fostering motivation.
- That said, while creativity is a powerful motivator in block-based environments, Vinueza-Morales et al. (2021[19]) note a risk of disengagement if tasks become too familiar or lose their novelty. As students advance, they require progressively more complex challenges to stay motivated. The study suggests integrating real-world problem-solving tasks into creative programming environments to address this. By connecting programming concepts to real-world applications, students can see the value and relevance of what they are learning.
- As noted earlier, syntax errors and debugging in text-based environments are common sources of frustration for students. Vinueza-Morales et al. (2021[19]) recommend incorporating error-recovery tasks within hybrid environments to address these challenges. These tasks help students identify and correct coding mistakes, encouraging deeper reflection on their learning and strengthening their understanding of both programming modalities.
- Finally, Vinueza-Morales et al. (2021[19]) also identify teacher preparedness as a critical factor in the success of hybrid programming environments. Teachers need to be well-equipped to guide students through the transition, yet many lack sufficient training in both block-based and text-based programming. The study recommends ongoing professional development focused explicitly on hybrid tools and scaffolding techniques, enabling teachers to provide the necessary support for their students.

It is important to note while there is evidence supporting the cognitive benefits of hybrid environments, the specific impact on long-term learning outcomes and adaptability across different educational settings remains unclear.

Pedagogical strategies for programming education

This section explores key pedagogical strategies in programming education, including collaboration, cognitive load management and the teacher’s facilitative role. By examining structured collaboration and scaffolding, along with tools like augmented reality, this section highlights approaches that support student skill development, engagement and effective learning in programming.

Benefits and challenges of collaborative projects

Vinueza-Morales et al. (2021[19]) highlighted the benefits of collaborative projects in block-based programming environments. When students worked together on creative tasks, they gained not only from the social aspects of learning but also from exchanging ideas and approaches to problem-solving. This collaboration fostered a shared sense of accomplishment, enhancing motivation and deepening engagement. The study emphasised that peer-to-peer interaction in creative projects can be an effective way to sustain long-term interest in programming.

Their findings echo those of Scherer, Siddiq and Sánchez Viveros (2019[15]), who explored the transfer effects of computer programming interventions on cognitive skills. They emphasise that collaboration significantly enhances the effectiveness of learning computer programming. The results indicate that studies where students collaborated displayed a larger effect size than those who did not. They note that group work fosters a supportive environment for understanding and problem-solving, while working in pairs improves the transfer of problem-solving strategies through discussion and critique. The analysis underscores the importance of collaboration in improving programming skills and cognitive abilities.

Scherer, Siddiq and Sánchez Vivero (2020[13]) examined the effectiveness of multiple instructional approaches in improving student performance in programming tasks, where collaboration was one such approach investigated. Collaborative environments allow students to share ideas and problem-solve in real time, which is especially effective for boosting computational thinking. This collaborative approach has been noted to encourage deeper engagement, as students are able to resolve issues more quickly than when working individually. They found a moderate effect ($g = 0.56$), which was among the lowest impact of instructional approaches investigated. However, they emphasise that differences here were not significant and should not be interpreted substantially due to the differing nature of effects and experimental conditions across the primary studies. In terms of moderators for collaborative learning environments, they did identify some significant ones:

- **Type of outcome variable**. The impact on student performance was smaller when measured using tests that assessed programming knowledge.
- **Test type**. Studies utilising standardised tests reported significantly larger effects on student performance in programming tasks compared to those using non-standardised tests.
- **Educational level**. Effect sizes varied by educational level samples, with studies with secondary education samples showing the largest effect, followed by a moderate effect in tertiary education. The ones with primary education samples showed a small, non-significant effect with high uncertainty.

Sun and Zhou (2023[14]) also discuss the role of collaboration within the broader context of computational thinking (CT) and programming education. They recognise collaboration as an integral part of the CT self-system, which also includes creativity and self-regulation, and highlight its role in fostering a supportive learning environment where students can exchange ideas and refine problem-solving strategies through peer interaction, ultimately enhancing their understanding and engagement with programming tasks.

This collaborative learning approach can help students not only develop CT skills but also improve their motivation and confidence in programming, aligning with findings from Scherer, Siddiq and Sánchez Vivero (2020[13]) and Vinueza-Morales et al. (2021[19]), who emphasise the motivational and cognitive benefits of collaborative projects.

However, Sun and Zhou (2023[14]) also caution that effective collaboration in programming education requires well-structured instructional design to ensure balanced participation and focus on meaningful engagement. They identify potential barriers in collaborative programming tasks, such as students' struggles with transitioning from visual to text-based programming, which may limit the intended benefits if collaboration is not adequately supported. Similarly, Vinueza-Morales et al. (2021[19]) identified collaborative learning as both an opportunity and a challenge. While peer interaction can enhance engagement, it requires careful structuring to ensure that all students are actively involved and that the collaboration remains focused on creative exploration rather than simply task completion. In sum, researchers caution that without effective facilitation, collaboration may fail to achieve the desired motivational outcomes.

Teacher’s role in successful learning processes

The integration of programming into education, whether in mathematics or science, relies heavily on the role of the teacher in guiding students through complex problem-solving processes. Successful learning in programming-based activities is not just about understanding the technical aspects of programming; it involves deep engagement with subject matter, such as mathematical reasoning or scientific inquiry. Teachers play a key role in facilitating this engagement by providing structure, support and opportunities for exploration.

In the study by Olsson and Granberg (2024[17]) (see Box 3.1), the teacher’s role was central to fostering creative mathematical reasoning (CMR) by using Scratch, a block-based programming tool. The teacher did not provide direct solutions but instead asked open-ended questions that encouraged students to think critically and explore various problem-solving strategies on their own. This approach, where the teacher acted as a facilitator rather than an instructor, allowed students to make connections between programming and the mathematical concepts they were learning. The teacher’s ability to scaffold student thinking and guide them without overtly intervening was essential in supporting independent reasoning and problem-solving. In this case, the success of the learning process depended on the teacher’s ability to balance student autonomy with the right level of guidance.

Olsson and Granberg (2024[17]) underscore the importance of teacher support in successful programming-based learning processes. Teachers are not only responsible for delivering content but also for creating a learning environment that encourages exploration, creativity and independent thinking. The teacher's role in these studies extended beyond traditional instruction, including scaffolding student thinking, fostering engagement and managing the complexities of interdisciplinary projects.

However, Olsson and Granberg (2024[17]) also highlight the challenges teachers face, such as balancing their own technical competence with the demands of programming-based projects and managing the time required for planning and execution. The teachers expressed concerns about their own programming skills and the time-intensive nature of such projects, indicating a need for professional development and collaborative support.

Managing cognitive load in programming education

Managing cognitive load is a key challenge in programming education, especially for novice learners. Several studies have explored strategies for addressing this issue (Berssanette and De Francisco, 2022[20]; Theodoropoulos and Lepouras, 2021[21]; Vinueza-Morales et al., 2021[19]).

In particular, Berssanette and Francisco (2022[20]) conducted a systematic literature review to investigate the application of Cognitive Load Theory (CLT) in programming education. By examining studies that used CLT-based strategies, their review highlights how these approaches help manage extraneous cognitive load, making programming skills easier for students to acquire. They focused on two key strategies: scaffolded instruction and worked examples.

As mentioned earlier in this working paper, CLT distinguishes between intrinsic, extraneous and germane load, with a strong emphasis on minimising extraneous cognitive load to enhance learning (Sweller, Ayres and Kalyuga, 2011[9]). Scaffolded instruction provides structured guidance that gradually decreases as learners gain competence, allowing them to focus on key programming concepts without being overwhelmed. This approach is especially useful for complex tasks, as it allows students to develop skills step by step.

In addition to scaffolding, worked examples are another effective CLT-based strategy. These examples provide fully solved problems, demonstrating each step in the solution process, which reduces extraneous cognitive load and helps students concentrate on core problem-solving techniques. However, Berssanette and Francisco (2022[20]) caution that relying too heavily on worked examples may lead to passivity, as students could depend on the solutions provided. They recommend pairing worked examples with opportunities for students to practice solving problems independently to encourage independent thinking.

Beyond these instructional strategies, Berssanette and Francisco (2022[20]) highlight specific cognitive load challenges unique to programming education. For instance, students often encounter the split-attention effect, where they must divide focus between programming interfaces and instructional texts, which can increase cognitive load. Additionally, the transition from block-based to text-based programming can impose high cognitive demands. To address these issues, they suggest using integrated instructional designs that present all necessary information in a single format, reducing attention shifts and ensuring scaffolded transitions that introduce text-based concepts gradually. These approaches align with CLT's emphasis on structured support, helping students build complex programming skills effectively.

A further solution for managing cognitive load in programming education may be the use of augmented reality. Theodoropoulos and Lepouras (2021[21]) conducted a systematic review examining the use of augmented reality (AR) in programming education, with one focus on how AR environments can reduce cognitive load. In line with cognitive load theory (Sweller, Ayres and Kalyuga, 2011[9]), which emphasises minimising unnecessary cognitive effort, AR in programming education provides visual support that offloads some of the mental demands typical of traditional programming environments. Real-time feedback and visual cues allow students to process information in manageable steps, making AR a powerful complement to scaffolded instruction. Their findings indicate that AR offers unique advantages in teaching programming by creating immersive, hands-on experiences that help simplify abstract concepts and lessen mental demands. By presenting programming tasks through real-time visual and interactive elements, AR enables students to explore and understand complex topics more intuitively, thus lowering extraneous cognitive load.

However, Theodoropoulos and Lepouras (2021[21]) also highlight practical challenges in implementing AR widely, particularly the high technological requirements and the need for teacher training. Effective use of AR in classrooms requires that teachers be equipped with the necessary skills to manage AR tools and environments, ensuring that students can fully benefit from these advanced, interactive resources.

Integrating artificial intelligence literacy with programming

Integrating AI literacy into K-12 education is increasingly recognised as essential for preparing students for a future where AI will play a significant role across various fields. AI education often intersects with programming, computational thinking and robotics, providing students with hands-on opportunities to explore how AI systems work. However, incorporating AI into school curricula presents both opportunities and challenges, from simplifying complex AI concepts to addressing disparities in access to technology and teacher expertise.

Casal-Otero et al. (2023[22]) explore the integration of AI literacy into K-12 education, emphasising its intersection with programming. AI education is frequently taught alongside computational thinking and coding, typically embedded within computer science and robotics curricula. Understanding AI requires grasping the underlying mechanisms of AI technologies, which are rooted in programming and algorithms. This connection enables students to develop insights into how AI systems function and how they can be applied to real-world scenarios. Although AI education is generally introduced at the middle and high school levels, the review highlights growing efforts to incorporate AI concepts at earlier stages, including in primary schools.

In many educational programmes, AI is taught using tools that simplify complex concepts. Block-based programming platforms like Scratch and Google's Teachable Machine are commonly used to help students explore foundational AI principles, such as machine learning, pattern recognition and natural language processing (Casal-Otero et al., 2023[22]). These tools make abstract AI ideas more accessible by enabling students to engage in hands-on coding exercises that demonstrate how AI models work in practical applications, such as image classification or speech recognition.

Project-based learning is a key instructional approach for teaching AI, as it allows students to apply their programming knowledge to real-world problems. In AI education, students often build models or AI-driven robots to perform tasks such as data analysis, navigation, or object recognition. By working on these projects, students develop AI and programming skills while applying their learning in interdisciplinary contexts, integrating AI with subjects like mathematics, ethics and social studies (Casal-Otero et al., 2023[22]).This method also helps students understand the societal impact of AI technologies.

However, their review identifies several challenges in implementing AI literacy in K-12 education. A major obstacle is the lack of teacher expertise in AI and programming. Many teachers lack the background necessary to teach AI effectively and opportunities for professional development in this area are limited. As a result, AI education often relies on pre-packaged curricula that may not be fully aligned with classroom needs. Additionally, access to technology remains a significant challenge, as many schools, particularly those in under-resourced areas, lack the necessary tools – such as computers and AI-specific software – to support effective AI learning. This disparity creates unequal opportunities for students to engage with AI technologies, especially when more advanced AI programming tasks require high-level infrastructure. Furthermore, assessing students' understanding of AI poses another challenge. Current assessment practices often focus on whether students can complete specific tasks rather than on their deeper conceptual understanding of AI, making it difficult to evaluate long-term learning outcomes.

Summary

The findings in this chapter show that programming education can positively influence learning outcomes, though these effects differ across educational stages. Block-based programming tools are especially effective in primary education, reducing cognitive load and encouraging creativity and engagement. As students move into middle and high school, text-based programming becomes more suitable for sustaining motivation and tackling complex tasks. Programming education has also been linked to gains in computational thinking and problem-solving, with the strongest effects observed in younger students using educational robots. Collaborative and metacognitive instructional approaches tend to be particularly effective in secondary education, fostering deeper engagement and understanding. Further, there is evidence that programming skills can transfer to other areas such as mathematics, creative thinking and reasoning, though this depends on instructional design and the similarity between tasks. Despite the benefits, students often face challenges when transitioning from block-based to text-based programming, particularly around syntax and debugging. Hybrid environments can help ease this transition, but teacher professional development remains essential. Table 3.2 summarises the successful processes and challenges associated with programming and robotics tools.

Table 3.2. Summary of programming and robotics activities

Category	Successful processes	Challenges
Sub-tool selection and outcomes	• Use block-based tools (e.g. Scratch) for younger students to reduce cognitive load. • Use text-based languages (e.g. Python) for older students to provide real-world complexity and applications. • Employ hybrid environments to ease the transition between block and text-based coding.	• Abrupt transitions from block-based to text-based programming can overwhelm students with the more complicated rules of coding languages. • Complex syntax and debugging in text-based languages can cause cognitive overload without proper guidance. • The novelty of tools can wear off during long interventions, leading to decreased enthusiasm.
Educational level applications	• Align tools with cognitive stages, using visual and tangible tools like educational robots for primary students.	• Some tools, like educational robots, become less effective for older, high school students as task complexity increases. • Introducing text-based programming too early can overwhelm younger learners.
Subject-specific applications	• Integrate programming into mathematics and science to make abstract concepts tangible through hands-on activities.	• Students may focus on programming mechanics, which can detract from core subject learning (e.g. mathematical reasoning). • There is limited research on integrating programming into subjects like arts and crafts.
Teacher support and role	• Act as a facilitator who guides students with open-ended questions and scaffolds learning. • Structure tasks into smaller, focused steps and integrate real-world problems to maintain engagement. • Use pedagogical strategies like worked examples and pair programming to manage cognitive load and enhance problem-solving.	• A lack of teacher expertise in both technical programming and pedagogical strategies is a primary barrier. • Effective integration requires a significant investment in teacher professional development. • Collaborative work requires well-structured tasks and facilitation to ensure equal student participation.
Equity and diversity considerations	• Access to the right hardware and software is a necessary condition for facilitating effective instruction.	• Unequal access to technology, particularly in under-resourced schools, creates significant learning disparities and unequal opportunities.
Assessment and feedback	• Immediate feedback from running code in visual environments allows for rapid, iterative problem-solving. • Using scales and rubrics can be effective for measuring the development of generative skills like creativity.	• Cryptic error messages in text-based languages can be a source of frustration without guidance. • Assessments often focus on task completion rather than deep conceptual understanding, and different tools can yield inconsistent results for the same skills.

4 Media Production and literacy

Key findings

- Multimedia tools have shown positive effects on literacy outcomes, but their success hinges on avoiding cognitive overload from unrelated interactive features. Well-designed multimedia content supports comprehension and vocabulary development.
- Digital writing tools have the potential to build good typing skills and provide scaffolds like grammar support, which enables students to focus on content generation, improving writing quality, especially for those with learning disabilities. However, a balanced approach that develops both students' handwriting and keyboarding is essential for students' writing development, particularly in the early years of schooling.
- Computer-assisted instruction with adaptive feedback mechanisms can improve foundational literacy skills, such as decoding and writing, especially for younger students.
- Podcasting can enhance collaborative learning and language skills by involving students in creating and consuming digital audio content, though technical access and time constraints may limit broader implementation.
- Digital storytelling can improve students' reading and writing abilities, particularly when multimedia elements are carefully integrated with the content. It seems particularly effective for students from low socio-economic backgrounds or with limited access to enriching educational opportunities outside of school.
- Reading from paper supports deeper comprehension and reflective engagement, particularly for complex or informational texts, while digital reading often leads to skimming and less sustained engagement.
- Social media facilitates instant communication, enabling students to collaborate on projects and seek help outside traditional classroom hours. However, it also presents challenges such as distractions from non-academic content, privacy concerns and the risk of negative interactions.

Media production and literacy tools have the potential to enhance students' language development, literacy skills and overall academic performance. These are also tools that have significant potential to enhance reading, writing and language development, particularly for students who may lack stimulation in their home environments. Tools such as multimedia platforms, podcasting software and computer-assisted instruction (CAI) have demonstrated positive effects on literacy outcomes; however, factors such as learner background, engagement with multimedia elements and the presence of feedback mechanisms can moderate these effects.

This chapter presents findings from the studies examining the impact of digital media tools on literacy development and academic performance. Studies underscore the importance of integrating multimedia elements thoughtfully, recognising the role of adaptive feedback and addressing challenges such as cognitive load and accessibility to ensure successful learning processes. Table 4.1 presents some key terms discussed in this chapter.

Table 4.1. Key terms in media production and literacy

Key terms	Definition	Examples of Tools
Automaticity in writing	The development of fluency in handwriting and keyboarding, allowing students to focus on content rather than transcription.	TypingClub, NitroType, Handwriting Without Tears – Tools that focus on improving typing speed and handwriting fluency to enhance compositional performance.
Computer-assisted instruction (CAI)	Technology-based programs designed to support skill acquisition in foundational literacy areas.	Headsprout, Lexia Core5 Reading – Programs that offer structured, game-like episodes focusing on foundational skills like phonics, fluency, and reading comprehension.
Digital media in writing	Tools like blogs and wikis that promote motivation by allowing students to write for real-world audiences.	Kidblog, Edublogs, Wikispaces – Platforms that allow students to publish their writing online, giving them a sense of real-world audience and boosting engagement and accountability.
Digital storytelling	The use of multimedia elements (e.g. images, sound, video) to enhance students' language development and literacy skills.	Storybird, Book Creator, Adobe Spark – Tools that allow students to create multimedia stories with text, images, and audio to enhance comprehension and writing skills.
Interactive features	Features such as hotspots or games within digital tools that aim to increase engagement but may lead to cognitive overload.	TumbleBooks – An interactive reading programme with built-in games, puzzles, and hotspots, which can sometimes distract from the core reading experience.
Multimedia tools	Digital tools that provide interactive, engaging content to enhance literacy outcomes.	Epic!, Raz-Kids, PebbleGo – Digital platforms offering interactive storybooks with multimedia elements that improve vocabulary and story comprehension.
Podcasting	The creation and consumption of digital audio content to support language development and collaboration skills.	Anchor, Audacity, GarageBand – Tools that allow students to create and share podcasts, improving language skills, vocabulary, and collaboration.
Social media in education	The use of social networking platforms to support learning by fostering collaboration, communication, and access to diverse educational content, while also building digital literacy and critical thinking skills.	YouTube, Instagram, TikTok – Platforms where students can access educational videos, create content, and engage with peers and teachers to enhance learning experiences.
Writing tools	Technology-based interventions that support writing proficiency, particularly for students with learning disabilities.	Grammarly, Google Docs with voice typing, CoAssistive writing tools that offer grammar correction, word prediction, and speech-to-text functionalities.

Digital media on literacy development

Integrating digital media in education has shown promising effects on literacy development, particularly in comprehension, vocabulary acquisition and writing proficiency. Meta-analyses by Silverman et al. (2024[23]) and Takacs, Swart and Bus (2015[24]) provide insights into how multimedia tools influence literacy outcomes among learners. Both meta-analyses emphasise that digital media interventions can significantly enhance literacy development when designed to align with learning objectives. Multimedia features that support these objectives can improve comprehension and vocabulary acquisition, especially for disadvantaged learners. However, due to their distracting nature, interactive elements not directly related to the educational content may be counterproductive. Adaptive digital tools with feedback mechanisms are especially effective in improving writing proficiency. The effectiveness of these interventions is also influenced by learner characteristics such as age and socio-economic background, the pedagogical approaches used and the duration of the interventions.

Impact of educational technology interventions on literacy outcomes

Silverman et al. (2024[23]) conducted a meta-analysis of educational technology interventions and their impact on various literacy outcomes. These interventions resulted in the largest effect size ($g = 0.81$) for the writing proficiency outcome, followed by moderate improvements in decoding (g = 0.33), language comprehension (g = 0.30) and reading comprehension (g = 0.23). However, when standardised measures were used, the effects were smaller for all outcomes, suggesting that the impact of digital media may be overstated when researcher-developed assessments are used for reading comprehension.

Their findings highlight the effectiveness of digital tools, particularly when they include adaptive features and feedback mechanisms. These features allowed learners to receive tailored guidance, leading to better performance in writing tasks. In contrast, digital tools lacking feedback mechanisms or adaptive learning strategies showed lower effectiveness in improving reading comprehension. Without personalised adjustments, students can struggle to apply new knowledge effectively.

There were several significant moderating effects:

- **Educational level**. Studies with younger students showed that they benefited more from digital interventions, especially in decoding and writing tasks. These students showed more significant improvements compared to older students (g = 0.81 for writing proficiency). Older students and those with higher prior knowledge exhibited less pronounced gains, particularly in reading comprehension and language comprehension, where the effects were smaller (g < 0.3).
- **Pedagogical orientation**. Interventions with behaviourist approaches generally yielded more substantial effects in decoding-focused interventions, particularly in tightly structured skill development. On the other hand, interventions with cognitivist and constructivist approaches showed more promise in language comprehension and reading comprehension interventions.
- **Duration of interventions**. Interventions with longer durations showed a significant effect on decoding skills, while medium durations had positive effects on both language comprehension and coding abilities.

An essential aspect of literacy development is the development of fluency in handwriting and keyboarding, known as automaticity in writing. This fluency allows students to focus on content generation rather than the mechanical process of transcription. Tools like TypingClub, NitroType and Handwriting Without Tears are designed to improve typing speed and handwriting fluency, thereby enhancing compositional performance. By focusing on improving these foundational skills, students can allocate more cognitive resources to higher-order writing tasks.

Multimedia storybooks

Takacs, Swart and Bus (2015[24]) investigated the impact of multimedia-enhanced storybooks on young children's literacy development. Their study showed that these digital tools can effectively support literacy skills, but the success of these interventions is moderated by specific factors such as multimedia features, interactive elements, outcome measures and learner characteristics.

The study identified that multimedia features like animated pictures, sound effects and background music aligned with the story improved story comprehension (effect size g = 0.17) and vocabulary acquisition (g = 0.20). These features enhanced understanding by providing visual and auditory cues that matched the narrative, thereby aiding in the development of core literacy skills. Conversely, interactive features such as games and hotspots that were not directly related to the story were found to be detrimental to learning outcomes. These elements were distracting and reduced story comprehension (g = -0.27) by causing cognitive overload and drawing attention away from the narrative.

Positive effects were observed in story comprehension and expressive vocabulary acquisition, indicating that well-designed multimedia elements can aid in literacy development. However, the presence of irrelevant interactive elements led to reduced learning outcomes, as students may struggle to balance engaging with these features and following the story.

Learner characteristics played a significant role in moderating the effects of digital interventions. Studies included in Takacs, Swart and Bus (2015[24]) that focused on disadvantaged learners, including those from low socio-economic backgrounds or other less stimulating environments, showed greater benefits of multimedia features. Takacs et al. note that multimedia elements, such as animations and sound effects, were particularly helpful for these learners, providing additional support for comprehension and engagement.

Computer-assisted instruction and podcasting in literacy development

The systematic reviews by Rigney, Hixson and Drevon (2020[25]) and Acosta and Garza (2011[26]) explore the learning processes facilitated by computer-assisted instruction and podcasting, with a focus on their integration into educational practices for literacy development. These studies examine how programmes like Headsprout and podcasting contribute to student engagement and skill development, particularly in reading and language acquisition.

Headsprout, a computer-assisted instructional (CAI) program, is designed to support early reading skills, including phonemic awareness, phonics, fluency, vocabulary and comprehension, based on the five key areas identified by the National Reading Panel (Rigney, Hixson and Drevon, 2020[25]). The programme is divided into two main components: Early Reading, which targets students in kindergarten through second grade (7–8-year-olds); and Reading Comprehension, which is aimed at students in third (8–9-year-olds) through fifth grade (10–11-year-olds). These components are delivered through interactive, game-like episodes that engage students in structured learning activities designed to build foundational reading skills. The review of Headsprout highlights how it fosters successful learning by allowing students to work at their own pace, receiving immediate feedback and gradually mastering reading skills (Rigney, Hixson and Drevon, 2020[25]). These interactive and adaptive features are instrumental in building student confidence and fluency, which is essential for further academic success. However, while the review highlights improvements in phonics and fluency, it also notes limited evidence regarding the impact on phonemic awareness, a crucial aspect of early reading.

Acosta and Garza (2011[26]) conducted a systematic review of podcasting as a tool for language development, particularly for English Language Learners (ELLs) in PreK-12 classrooms. Podcasting involves students in both creating and consuming digital audio content, providing an engaging medium for practising language skills such as vocabulary, listening and reading comprehension. The review shows that podcasting facilitates successful learning processes by fostering collaboration among students, who work together to produce podcasts, thus enhancing critical thinking and communication skills. Podcasting also promotes a sense of autonomy, as students control the content and pace of their learning, which has been shown to increase their engagement and motivation. These features make podcasting a valuable tool for language development, particularly in supporting ELL students. However, limited access to technology, the time-intensive nature of podcast production and the need for both teachers and students to acquire technical skills pose significant barriers to podcasting's widespread adoption.

Reading instruction

This section addresses reading comprehension across different mediums. Many earlier reviews, however, do not focus exclusively on studies conducted within school settings, complicating efforts to isolate findings directly relevant to educational contexts. Clinton (2019[27]) identified a general screen inferiority affect, suggesting that paper-based reading tends to enhance comprehension and metacognitive engagement more effectively than screen-based reading. Notably, Clinton's (2019[27]) results were more pronounced for adults, raising questions about their applicability to school-aged readers. To address this gap, we highlight two recent studies by Hakemulder and Mangen (2024[30]) and Støle, Mangen and Foldnes (2024[31]), which, although not confined to school contexts, offer valuable insights into educational settings. Collectively, these studies suggest that while digital reading provides accessibility and convenience, it often fosters skimming habits that impede deep engagement, particularly with complex, reflective texts.

Literary reading on paper and screens: Associations with meaningful reading experiences

Hakemulder and Mangen (2024[28]) investigate how screen-based reading affects readers' engagement with literary texts, focusing on how habitual exposure to digital reading might shape one's capacity for meaningful, immersive reading. The study references prior meta-analyses (e.g. Clinton, 2019; Delgado et al., 2018), which report a consistent 'screen inferiority effect' in comprehension, particularly for informational texts. However, these effects appear less prominent for narrative texts, possibly due to the different cognitive demands of informational versus narrative reading. This distinction aligns with the 'Shallowing Hypothesis', which suggests that frequent screen reading encourages a quick, superficial engagement with the text, undermining the cognitive persistence needed for reflective engagement with more complex materials.

In this study, Hakemulder and Mangen (2024[28]) conducted experiments involving 66 participants, aged 14 to 67 years, recruited from friends and family of students at Utrecht University in the Netherlands. Participants read Doris Lessing's short story 'Flight' on either a digital screen or on paper. The study measured two dimensions of engagement: eudaimonic responses (reflective, meaning-seeking engagement) and hedonic responses (focused on pleasure and enjoyment). It also surveyed participants about their general reading habits, particularly their tendency to read short-form texts on digital devices.

The results revealed a notable association between habitual digital reading and reduced eudaimonic engagement. Specifically, participants who regularly read shorter texts on screens reported lower levels of meaningful engagement, such as feeling personally moved or gaining insights from the story, compared to those who read on paper. Readers on paper generally reported higher levels of immersion and personal reflection. Even after accounting for individual characteristics, the findings suggest that screen reading habits may diminish a reader's capacity for deep, meaningful interaction with literary material, supporting the Shallowing Hypothesis.

Even if this study is not directly from the school context, Hakemulder and Mangen (2024[28]) highlight serious educational implications stemming from these findings, particularly concerning the importance of fostering 'deep reading' skills in students. Defined as the ability to engage thoughtfully with complex texts, deep reading involves fully absorbing content, connecting it to personal experience, adopting perspectives and appreciating nuances. This skill, foundational to literary comprehension, is threatened by the increased shift toward digital, often short-form reading.

The authors argue that while digital tools offer accessibility and convenience, they may not adequately cultivate the cognitive patience and stamina required for sustained, reflective reading. They advocate for a balanced educational approach that integrates digital literacy and traditional reading skills, emphasising paper-based reading experiences, particularly for complex literary texts. This approach is recommended to ensure that students are equipped to process written material across formats, enhancing both comprehension and critical thinking. By prioritising paper-based reading for long, complex materials, educational programmes can better foster the reflection, analytical skills and cognitive endurance that are essential for navigating a complex information landscape (Hakemulder and Mangen, 2024[28]).

Overall, the study by Hakemulder and Mangen (2024[28]) suggests that regular screen reading, especially of short texts, may cultivate a reading style less conducive to cognitive persistence and reflective engagement, both essential for literary understanding. This finding underscores the need for schools to promote balanced reading habits that encourage deep, immersive engagement and critical thinking, ultimately strengthening students' capacity for meaningful reading across different mediums.

Reading performance on paper vs. digital: Insights from PIRLS 2021

Støle, Mangen and Foldnes (2024[29]) analysed findings from the Progress in International Reading Literacy Study (PIRLS) 2021 in Norway, focusing on how the reading medium – paper versus digital – affects reading performance among fifth-grade students. This study compared comprehension scores between students who took the test on paper and those who took it digitally while keeping the test content consistent across both formats. As noted above, prior meta-analyses have generally shown a 'screen inferiority effect', with comprehension scores tending to be lower when reading on screens (Clinton, 2019[27]; Delgado et al., 2018[30]). However, most research has concentrated on adults, leaving open questions about how digital reading might impact younger readers.

The PIRLS 2021 findings revealed a significant mode effect: Students scored higher on the paper-based test than on the digital version, with an average score of 0.80 on paper compared to 0.74 on screens (for Norwegian students). Students were more likely to omit answers on the paper-based test, particularly for multiple-choice questions. Contrary to earlier research suggesting a stronger effect for informational texts, the Norwegian results showed the mode effect was about the same for informational and literary texts, indicating that reading on screens may pose comparable challenges across different text types.

Støle, Mangen and Foldnes (2024[29]) discuss essential implications of these findings for teachers and educational practice. Despite students' high familiarity with digital devices, the results indicate that digital reading may not foster the same depth of comprehension as reading on paper. This suggests that teachers should carefully consider when and how digital reading is used, particularly for tasks that require deep comprehension. Teachers might prioritise paper-based reading for longer, more complex texts that demand sustained focus and careful processing to support students' reading development, especially among younger students who are building foundational skills.

The authors further highlight that digital reading often encourages skimming and scanning habits, which may lead to more superficial engagement with text. Teachers, therefore, have a role in helping students develop strategies that support focused reading on screens, such as highlighting or summarising key ideas to help them process digital texts without sacrificing comprehension. By fostering balanced reading experiences across both mediums, teachers can help students build the cognitive flexibility needed to engage deeply with content in both digital and print formats, ultimately supporting their academic growth in an increasingly digital world (Støle, Mangen and Foldnes, 2024[29]).

Writing instruction

This section examines how technology-based and traditional writing instruction impact students' writing skills, particularly for those with learning disabilities. It underscores the importance of combining digital and analogue approaches to enhance writing fluency, helping students focus more on content than mechanics.

Effects of technology-based writing instruction

The use of technology-based writing instruction can have positive impacts on students' writing performance, with a particular benefit for students with learning disabilities. Little et al. (2018[31]) investigated the effects of technology-based interventions on writing skills, including grammar, spelling and ideation. They found that technology-based writing instruction had a small but significant positive effect on writing performance, with a small effect size (g = 0.28). This suggests that technology-enhanced writing tools, while not dramatically transformative for all students, can meaningfully improve overall writing skills in K-12 classrooms.

A particularly strong effect was observed for the studies with students with learning disabilities, with a high effect size (g = 1.10). This finding indicates that students with learning disabilities may benefit substantially more from technology-based writing instruction than their typically developing peers. The study suggests that technology-based writing instruction may provide much-needed scaffolding and support for students with learning challenges, allowing them to develop skills in spelling, grammar and ideation more effectively.

Analogue vs. digital in writing: The role of automaticity

The study by Malpique et al. (2024[32]), conducted in Portugal, aimed to investigate the impact of automaticity in writing, focusing on both paper-based and keyboard-based text composition in Grade 2 students. The researchers sought to understand how transcription fluency – handwriting and keyboarding skills – affect students' writing performance, specifically their compositional fluency (number of words written and correctly spelled) and quality (clarity and coherence of the text).

The study involved a series of writing tasks where students were asked to compose text using handwriting and keyboarding. The researchers measured the speed and accuracy of students' handwriting and keyboarding and controlled for several factors such as spelling, word-reading, reading comprehension and students' attitudes toward writing. The goal was to isolate the effects of transcription fluency on the students' overall writing performance.

Their findings revealed that transcription fluency was a significant predictor of writing performance in both modalities, but it had a stronger effect on the keyboard-based tasks. This suggests that students who developed automaticity in keyboarding were able to produce higher-quality written compositions with greater fluency. The study emphasised the importance of explicit instruction and practice in both handwriting and keyboarding during early schooling to foster automaticity, which in turn allows students to focus more on the content of their writing.

The study underscores that both transcription skills – handwriting and keyboarding – are essential for students' writing development, particularly in the early years of schooling. While the results indicate that keyboarding automaticity had a stronger effect on compositional fluency and quality, handwriting remains important for foundational literacy development. The study explicitly advocates for instruction and practice in both handwriting and keyboarding, arguing that mastering both modalities enables students to focus more on the content of their writing rather than the mechanics of transcription. Malpique et al. (2024[32]) suggest that a balanced approach to teaching both analogue and digital writing skills is critical. Such an approach ensures that students can perform well in both paper-based and keyboard-based tasks.

Impact of digital storytelling on academic achievement across different subjects

Digital storytelling as a method combines traditional narrative structures with modern multimedia elements, including images, sound, video and graphics (Akgün and Akgün, 2020[33]). This method has been shown to enhance academic achievement across various subjects and educational levels, particularly in science. Akgün and Akgün (2020[33]) highlight its impact across a wide range of subjects, particularly benefiting for samples with middle school and university students in science and language learning. In contrast, Sahin and Coban (2020[34]) emphasise its effectiveness in mathematical courses for younger learners, underscoring its value in early education.

Akgün and Akgün (2020[33]) further explains that digital storytelling as an interactive process allows students to explore subject matter more deeply and engage in active content creation. Their study examined a broad range of subjects – such as science, mathematics, Turkish, English and social studies

– across various educational levels, revealing that digital storytelling has a strong positive impact on academic achievement (g = 1.081), though the effects vary by subject.

In science, digital storytelling had the highest impact (g = 1.562), as the integration of multimedia elements may help students visualise and comprehend complex scientific concepts more effectively. In mathematics, the effect was comparatively smaller (g = 0.254), possibly due to the abstract nature of the subject; however, digital storytelling was still beneficial in explaining real-world applications of mathematical concepts. For language learning, specifically Turkish (g = 0.995) and English (g = 0.846), digital storytelling significantly enhanced literacy skills, particularly in reading comprehension and writing, by allowing students to engage with language in a dynamic and interactive way. Additionally, in social studies (g = 0.686), digital storytelling enriched students' understanding of historical events and cultural narratives, making the material more relatable and engaging.

In terms of educational levels, the meta-analysis found that, among the studies analysed, those with university and middle school students reported the highest effects of digital storytelling, while studies with elementary school students showed smaller but still positive effects (Akgün and Akgün, 2020[33]). This may suggest that older students are better able to engage with the multimedia elements of digital storytelling, likely due to their more advanced cognitive and language skills.

Sahin and Coban (2020[34]) focused on the use of digital storytelling in mathematical and statistical courses for younger learners. Their study found an overall high effect of this on academic achievement (g = 0.75). Engaging multimedia elements, such as images and animations, may help break down complex mathematical concepts and support foundational learning. The interactive and multisensory nature of digital storytelling may capture the attention of young students, enhancing their understanding of key concepts while fostering active participation and engagement during lessons.

The role of signalling in multimedia learning

Signalling, a technique involving the use of visual cues – such as arrows, highlights, or zoom effects – is a cognitive tool designed to guide learners' attention to critical elements within multimedia content. By directing attention to essential information and reducing cognitive load, signalling enhances students' ability to focus on important details, particularly in complex learning environments.

A study by Alpizar, Adesope and Wong (2020[35]) highlights the integration of signalling in multimedia learning environments as a means of improving students' attention, retention and the transfer of knowledge across various subjects. They reported a moderate positive effect of signalling on learning outcomes (d = 0.38), indicating that studies where students received signalling, they demonstrated better retention and application of information compared to those where such cues were not provided. This demonstrates the significant potential of signalling to enhance multimedia learning experiences.

One of the notable findings from Alpizar, Adesope and Wong (2020[35]) is that signalling is particularly beneficial for learners with low prior knowledge, who often struggle with processing new or complex material. Signalling helps these learners focus on key information, alleviating cognitive load and enhancing understanding. For students with low prior knowledge, the effect size of signalling was moderate (d = 0.47). For example, in a mathematics lesson focused on solving algebraic equations, teachers can use signalling techniques, like highlighting variables, to aid students in identifying critical components of the material.

Alpizar, Adesope and Wong (2020[35]) also differentiated between dynamic signals (e.g. moving arrows, zoom effects) and static signals (e.g. bold or underlined text), finding that dynamic signals yielded a larger effect size (d = 0.50). These dynamic cues actively engage learners, guiding their attention and helping sustain focus throughout lessons. For instance, in a science lesson on the water cycle, arrows pointing to different stages can enhance students' understanding of the sequence of events.

The effectiveness of signalling is also contingent on the pacing of the lesson. The study highlights that signalling is most effective in learner-paced environments, where students control the speed of the material (d = 0.51). In contrast, system-paced environments (d = 0.22) for example, in a history lesson utilising a digital timeline zooming into significant battles, allows learners to process information at their own pace, improving retention and comprehension.

Lastly, Alpizar, Adesope and Wong (2020[35]) illustrate that signalling is beneficial across various subjects, emphasising its versatility in different educational contexts. In biology, for instance, signalling can aid students in understanding complex processes like cell division, while in language arts, visual cues can direct attention to key themes or symbols in literary texts.

Social media and communication

Astatke, Weng and Chen (2023[36]) and John and Yunus (2021[37]) explore the role of social media in education, focusing on how platforms like WhatsApp, YouTube, Facebook and Instagram enhance collaborative learning and communication. Astatke, Weng and Chen (2023[36]) examine the impact of social networking sites (SNS) on secondary school students' academic achievement, while John and Yunus (2021[37]) analyse how these platforms support the development of speaking skills in English as a second language (ESL) learner. Despite these differing focuses, the findings reveal notable similarities regarding the benefits and challenges associated with social media in education.

Social media has the potential to foster collaborative learning by allowing students to engage in peer-to-peer communication, share resources and provide feedback. Both studies indicate that platforms like Facebook and WhatsApp effectively promote group discussions and joint academic projects, facilitating interactions that are essential for improving speaking fluency and engaging in academic discourse across subjects (Astatke, Weng and Chen, 2023[36]; John and Yunus, 2021[37]). By providing a less formal setting for interaction, social media has the potential to reduce anxiety and encourage participation, which is critical for language development and academic success.

Another key advantage is the real-time communication enabled by platforms like WhatsApp, where students can practice speaking skills or discuss academic topics outside the classroom. This flexibility allows for more frequent practice, as students can send voice messages or participate in discussions asynchronously, effectively breaking down time constraints (John and Yunus, 2021[37]). In terms of project-based learning, platforms such as YouTube offer students access to a diverse range of educational materials and opportunities to create their own content. Students can record and share videos, thereby enhancing their public speaking and presentation abilities while also accessing tutorials that deepen their understanding of complex subjects (Astatke, Weng and Chen, 2023[36]; John and Yunus, 2021[37]).

However, both reviews identify several challenges associated with social media in education. Distraction is a major concern, as students may be tempted to engage with non-academic content, such as entertainment, instead of focusing on their academic tasks. This tendency can significantly reduce the time and attention dedicated to learning (Astatke, Weng and Chen, 2023[36]; John and Yunus, 2021[37]). Additionally, the anonymity of social media platforms can lead to cyberbullying, with inappropriate comments and negative interactions discouraging students from participating in online speaking activities or academic discussions, which can ultimately impact their overall performance (John and Yunus, 2021[37]).

Moreover, the digital divide poses a significant barrier to effective engagement in social media-based learning. Not all students have equal access to the necessary technology or stable internet connections, which can hinder their participation in collaborative learning activities, especially in project-based tasks that require video sharing on platforms like YouTube (John and Yunus, 2021[37]). Furthermore, the vast amount of information available on social media can overwhelm students, making it challenging to discern credible sources from unreliable ones. Privacy concerns also emerge as a critical issue, as the potential for personal data exposure and misuse on social media platforms can discourage students from fully participating in online educational activities (Astatke, Weng and Chen, 2023[36]; John and Yunus, 2021[37]).

Both studies emphasise the importance of considering the age of students in the integration of social media into educational practices. Astatke, Weng and Chen (Astatke, Weng and Chen, 2023[36]) specifically focus on secondary school students, highlighting their unique needs and challenges. Meanwhile, (John and Yunus, 2021[37]) discuss how the integration of social media can vary depending on the age group of English as a second language learners, which affects the strategies that educators might employ. The role of teachers is also highlighted as crucial in providing guidance and support, ensuring that students can navigate these platforms safely and productively.

Summary

Through systematic reviews and primary studies, the chapter explored how digital storytelling, multimedia tools, podcasting and writing technologies impact literacy outcomes such as reading comprehension, writing proficiency and language development (see Table 4.2). Findings highlight that digital storytelling can effectively improve reading and writing skills, especially when multimedia is thoughtfully integrated. Multimedia tools contribute positively to literacy when designed to minimise cognitive overload. Podcasting supports collaborative learning and language skills, though technical and access challenges remain. Computer-assisted instruction and balanced use of analogue and digital writing tools foster foundational literacy skills. Notably, the findings suggest that reading from paper tends to support deeper comprehension and reflective engagement than reading on screens, particularly for complex texts.

Table 4.2. Summary of media production and literacy tools

Category	Successful processes	Challenges
Sub-tool selection and outcomes	• Reading on paper generally supports deeper comprehension and more reflective engagement with complex texts. • Well-designed multimedia with relevant visual cues ("signalling") improves comprehension and guides student attention. • Learning is more effective in learner-paced environments where students can control the speed of the material. • Media creation tools (e.g. podcasting) can enhance collaborative learning and language skills.	• Digital reading often encourages skimming habits, which can lead to lower comprehension (the ‘screen inferiority effect’). • Irrelevant or distracting interactive features can cause cognitive overload and detract from the core content. • Social media integration presents issues of distraction and student privacy. • Media production projects can be limited by time and technology constraints.
Educational level applications	• Multimedia storybooks and Computer-Assisted Instruction (CAI) are highly effective for teaching foundational literacy skills to younger students. • Digital storytelling is highly effective with middle school and university students.	• The appropriateness of certain media, particularly social media, varies significantly by age group and requires careful management.
Subject-specific applications	• Digital storytelling shows positive effects on academic achievement, particularly in science and language learning. • Computer-Assisted Instruction (CAI) is an effective tool for developing foundational literacy skills (e.g. phonics, fluency).	• The impact of digital storytelling varies by subject; for example, the effect has been found to be smaller in mathematics compared to other areas.
Teacher support and role	• Teachers are crucial for selecting appropriate tools, balancing digital and analogue methods and helping students develop strategies for deep reading on screens.	• A lack of teacher training in necessary technical skills can hinder effective implementation.
Equity and diversity considerations	• Digital media tools can be particularly beneficial for students from disadvantaged or low socio-economic backgrounds.	• Positive effects may be less pronounced for students who already possess strong skills. • Distracting interactive features can be more detrimental for disadvantaged learners.
Assessment and feedback	• Digital tools with adaptive features and immediate feedback are particularly effective for improving foundational writing and reading skills.	• Tools that lack adaptive features or feedback mechanisms show lower effectiveness, as students may struggle without personalised guidance.
Development of automaticity	• Developing fluency (automaticity) in both handwriting and keyboarding frees up cognitive resources, allowing students to focus on higher-order tasks like content generation.	• Without explicit instruction, struggles with the physical act of writing (in either medium) can hinder the fluency and quality of a student's composition.

5 Gaming

Key findings

- Game-based learning can enhance motivation by providing structured goals, autonomy and immediate feedback, helping students stay engaged and take ownership of their learning.
- Serious games can contribute to deeper understanding and improved cognitive skills across subjects like mathematics, science and social studies, supporting their role as effective educational tools.
- Exergames, combining physical movement with cognitive tasks, can offer benefits for both fitness and cognitive functions, including attention and memory, particularly in subjects requiring problem-solving.
- Language learning is supported by narrative-driven games and RPGs, which promote authentic communication, vocabulary acquisition and collaboration.
- Studies have found that specific open-ended games can foster creativity, self-directed learning and teamwork, while role-playing games can enhance critical thinking by immersing students in complex, decision-driven scenarios. Similarly, simulation and strategy games can help students engage with abstract concepts in mathematics and science by modelling real-world systems and providing immediate feedback.
- However, the transfer of skills from a game to real-world academic contexts is a major cross-cutting challenge with limited supporting evidence for many games.
- Transitioning games from entertainment to educational contexts presents challenges, and aligning games with educational objectives requires careful planning and implementation. Teachers may not always be sufficiently prepared for this type of integration.
- Games may require certain hardware or physical space, which may not always be available in every setting.

Learning through play has long been recognised as an essential part of education, with roots tracing back to philosophers like Plato. Plato emphasised that play is not simply entertainment but a critical element in children's learning and development (Frost, 2010[38]). Through playful activities, children engage in exploring their environment, enhancing their cognitive and social and emotional skills.

Building on these foundational principles, game-based learning (GBL) integrates the benefits of play with structured educational content, using games as a tool to foster creativity, problem-solving and deeper engagement with learning objectives.

This chapter synthesises findings from key meta-analyses and systematic reviews on gaming in education. To clarify the discussion of game-based learning,

Table 5.1 defines the main categories of educational games addressed in recent research and provides examples for each type.

Table 5.1. Key terms in gaming

Game type category	Definition	Game examples
Adventure games	Games that focus on exploration and problem-solving in narrative environments.	Adventure math games (Mao et al., 2022[39])
Augmented reality games (ARGBL)	Games that use augmented reality technology to blend real-world environments with digital elements for educational purposes.	Pokémon Go (Ruiz-Ariza et al., 2018[40])
Commercial-off-the-shelf (COTS) games	Commercial games developed for entertainment, but with potential educational applications.	Brain Age 2, My Sims, Sims 2 (Tokac, Novak and Thompson, 2019[41])
Drill-and-practice games	Games that focus on repetitive practice of specific skills, often through drills.	Drill-and-Practice math games (Byun and Joung, 2018[42])
Educational games	Games are designed with educational content and goals in mind and are often aligned with curricula.	GraphoGame (McTigue et al., 2020[43])
Exergames	Physical activity-based games that combine exercise with cognitive or educational tasks.	Dance Dance Revolution, Cyber Cycling (López-Serrano et al., 2021[44])
Game construction	Games where students design and construct games, engaging in creative problem-solving.	Scratch for Mathematics (Mao et al., 2022[39])
Role-playing games (RPGs)	Games where players assume the roles of characters in a fictional setting, making decisions that influence the narrative.	Dungeons & Dragons-based games (Mao et al., 2022[39])
Sandbox games	Open-ended games that allow players to freely explore and manipulate the game world without strict goals or constraints.	Minecraft (Alawajee and Delafield-Butt, 2021[45])
Serious games	Games specifically designed for educational purposes, such as improving specific skills in a structured way.	DimensionM (Tokac, Novak and Thompson, 2019[41])
Simulation games	Games that model real-world systems or phenomena, allowing students to manipulate variables and observe outcomes.	Physics or Chemistry Simulations (Mao et al., 2022[39]); My Sims (Panoutsopoulos and Demetrios, 2012[46])
Socially assistive robots (SARs)	Games or activities mediated by robots to assist in educational and social learning contexts.	KindSAR, Forensic Science AR (Papadopoulos et al., 2020[47])
Strategy games	Games that require players to use tactics and planning to achieve objectives.	Civilization series (Mao et al., 2022[39])

Impact of game-based learning on motivation and engagement

Bai, Hew and Huang (2020[48]) conducted a qualitative synthesis that reported on three recurring areas of what pupils like about game-based teaching. Firstly, pupils experience a greater degree of self-determination when games are used. This relates to the theory of the importance of setting learning goals and can support perseverance in learning tasks. Further, pupils experience recognition through quick feedback on their progress. Recognition plays a key role in motivational theory (e.g. Deci and Ryan, 1985[9]). It can contribute to a sense of pride or an experience of mastery that helps pupils become more focused and persistent. Finally, given feedback is often built into games, they can provide pupils with feedback into how they perform. This allows the pupils to learn from their mistakes and to improve their performance.

Learning motivation is closely related to positive experiences, and several systematic reviews studied the use of games in relation to the joy of learning, interest, motivation and engagement (see, e.g. Lopez et al., 2023[40], and Alawajee and Delafield-Butt, 2021[43]). These studies underscore the importance of enjoyment and interest in sustaining students' commitment to learning activities.

A key finding from Lopez et al. (2023[49]) is that serious games significantly increase engagement and motivation by making learning enjoyable and interactive. The use of game mechanics, such as rewards and progress tracking, helps sustain student interest and participation, particularly in subjects like mathematics. Students are more motivated when they can see their progress and understand how their actions directly impact the outcomes within the game.

Hainey et al. (2016[50]) review multiple studies showing that digital games, particularly serious games, enhance student motivation by creating interactive and challenging learning environments. Games improve affective and motivational outcomes by offering students environments where they are actively engaged in the learning process. Hainey et al. (2016[50]) highlight that students are more likely to be motivated when they are given opportunities to make decisions and influence the outcome of the game. This is especially true in role-playing games (RPGs), where students take on specific roles and must navigate complex scenarios, making decisions that impact the game's progression. This sense of ownership over their learning process fosters a deeper level of engagement and persistence.

López-Serrano et al. (2021[44]) specifically focus on the role of exergames, which combine physical activity with cognitive tasks to increase engagement in academic settings. Exergames, such as *Dance Dance Revolution* and *Cyber Cycling*, require students to perform physical movements while completing cognitive tasks. This combination of physical activity and mental engagement has been shown to boost motivation in students, particularly when used during physical education or as part of academic breaks. The dynamic nature of exergames keeps students more focused and invested in their learning by linking physical exertion with cognitive improvement.

Game-based learning in different subjects

This section examines the role of game-based learning (GBL) across subjects, illustrating how digital games support engagement, motivation and skill development in educational settings. Studies by Lopez et al. (2023[49]), Fadda et al. (2022[51]), Hainey et al. (2016[50]) and Thompson and Von Gillern (2020[52]) provide insights into GBL applications in mathematics, science, social studies and language learning.

Applying game-based learning in mathematics

In mathematics, digital games – particularly strategy and simulation games – are commonly used to help students engage with abstract problem-solving processes. These games offer interactive environments where students are required to plan, evaluate different strategies and make decisions to achieve long-term goals. For example, simulation games that model real-world processes, such as resource management or financial systems, help students to apply mathematical concepts like geometry, arithmetic and logic in practical contexts. By allowing students to experiment with variables and receive real-time feedback, these games promote critical thinking and problem-solving in a way that traditional exercises may not.

Lopez et al. (2023[49]) highlight how serious games are particularly effective in mathematics. They provide students with real-time problem-solving tasks, allowing them to engage actively with complex mathematical concepts. For instance, games often include levels that adapt to the student’s progress, offering personalised learning experiences that help students learn at their own pace. In subjects like social sciences and communication, serious games promote critical thinking and social skills by engaging students in collaborative and interactive tasks, such as role-playing scenarios where they must communicate and solve problems together.

Fadda et al. (2022[51]) conducted a meta-analysis on the motivational effects of digital games in mathematics education. Their analysis reported a small to moderate effect size ($d = 0.27$). Some moderators explained the variation across intervention effects:

- **Intervention length**. Shorter interventions, typically spread over several weeks, were more effective at sustaining motivation. Longer interventions, however, led to diminishing returns, suggesting that students lose interest over time.
- **Motivational components**. The treatment effect was stronger when motivation was measured by expectancy ($d = 0.31$) rather than by value ($d = 0.21$). Educational digital games enhance motivation more by fostering students' confidence and self-belief (expectancy) rather than highlighting the subject's importance (value), indicating that building self-confidence results in greater motivational gains.

Applying game-based learning in science and social studies

In science, simulation games are employed to help students understand cause-and-effect relationships in complex systems (Hainey et al., 2016[50]). For example, games that simulate ecosystems allow students to explore environmental changes by manipulating factors such as pollution or resource consumption. These games provide students with a hands-on experience of scientific inquiry, enabling them to observe and reflect on how different variables affect overall outcomes. The ability to simulate real-world systems supports knowledge acquisition in scientific principles by making abstract processes tangible and easier to understand.

In social studies, role-playing games (RPGs) have been highlighted for their effectiveness in promoting critical thinking and empathy. These games place students in complex narrative scenarios where they must assume roles – such as diplomats, journalists, or historical figures – and make decisions that influence the game’s storyline. This process requires students to consider multiple perspectives, engage in ethical decision-making, and navigate socio-political dilemmas. By immersing students in real-world problems through interactive storytelling, RPGs help them develop a deeper understanding of historical events and social dynamics.

Effective genres to promote language development

In language learning, RPGs and other narrative-driven games are used to enhance collaborative learning and language development (Hainey et al., 2016[50]). These games provide a communicative environment where students interact with characters, develop dialogues and navigate through storylines using language in authentic ways. Digital RPGs has potential to encourage students to apply their linguistic skills in meaningful contexts, promoting language proficiency, creative thinking and problem-solving. These games engage students in linguistic and cognitive development by requiring students to participate in narrative creation and decision-making.

Video game-based instruction is a promising approach for enhancing vocabulary acquisition, especially among English language learners. By leveraging the engaging and motivating nature of gaming, students are exposed to new vocabulary in context, which aids in comprehension and retention. Thompson and Von Gillern (2020[52]) measured the impact of video game-based interventions on educational outcomes, specifically in vocabulary acquisition. The overall effect size for digital game-based instruction was moderate-to-large ($d = 0.699$). The study shows that digital games can effectively help English learners develop their vocabulary for English language instruction. There were also some significant moderators:

- **Grade level**. Effects varied across grade levels covered, with the studies with college samples showing a larger effect than those with younger grade levels, which showed moderate effects and greater variability. This could be due to higher motivation among college students, as English proficiency offers immediate academic and career benefits. Further, college students are typically more cognitively developed than younger students, which may enable them to engage more effectively with and benefit from the complexities of digital game instruction.

- **Hardware type**. Type of gaming platforms (consoles, PCs, mobile devices) used across studies showed moderate-to-large effect sizes for English vocabulary learning. Although studies with console-based games showed a larger effect size, there were only two studies on consoles, limiting conclusions.
- **Game type**. Commercial-off-the-shelf (COTS) games and serious games were examined. Although studies with COTS games outperformed the ones with serious games, the limited number of COTS studies makes it difficult to draw strong conclusions.

Specific games and genres

Minecraft in education: Learning and social engagement

The systematic review by Alawajee and Delafield-Butt (2021[45]) explores the potential benefits and challenges of using Minecraft – an example 'sandbox game' of an expansive open world to explore – as an educational tool. The focus of this study is on both academic learning and the development of social skills through the game, with an emphasis on how Minecraft fosters creativity, problem-solving and social collaboration in a structured educational context. The study discusses Minecraft's effectiveness in improving student engagement, motivation and learning outcomes in various academic subjects.

Minecraft is described as a sandbox game where students can freely explore, create and interact with a virtual environment. The open-world nature of the game encourages exploration and experimentation, making it particularly well-suited for subjects that require creative thinking and problem-solving, such as science and history. Through its multiplayer feature, Minecraft also promotes collaborative learning, allowing students to work together to complete tasks, build structures and solve problems within the game world.

One of the main successful learning processes identified in the study is Minecraft's ability to promote self-directed learning. Because the game gives players autonomy to choose how they want to engage with the content, it encourages students to take ownership of their learning process. For example, in subjects like geography or ecology, students can use Minecraft's creative tools to construct models of ecosystems, cities, or landscapes, which helps to deepen their understanding of these subjects in an interactive way. The game's immersive environment also supports critical thinking and problem-solving, as students must make decisions, test hypotheses and adjust their strategies based on the feedback provided by the game.

The review also highlights how Minecraft can be used to develop social skills. As a multiplayer game, Minecraft encourages communication, collaboration and leadership among students. When playing in groups, students must negotiate roles, share resources and work together to achieve common goals, such as building a city or solving in-game challenges. This fosters teamwork and empathy as students learn to listen to each other, resolve conflicts and consider different perspectives. For example, the game has been used to help students with autism spectrum disorder (ASD) develop better social communication skills by creating safe, structured environments where they can interact with their peers without the pressures of face-to-face communication.

However, several challenges associated with Minecraft's use in education are also identified in the review. One of the main concerns is age-appropriateness. While Minecraft is suitable for a wide range of age groups, younger children may struggle with the game's complexity and open-ended nature, leading to frustration or disengagement. Additionally, the study points out concerns about technology access and safety, particularly in multiplayer environments where students may interact with unknown players. Teachers and educators need to ensure that proper guidance and safety measures are in place to prevent inappropriate interactions.

Another significant challenge is the generalisation of learning. Although Minecraft is effective in promoting creativity and collaboration within the game, there is limited evidence on whether the skills developed in the game transfer to real-world learning scenarios. For example, while students may excel at building structures or solving problems in Minecraft, it is unclear whether these skills improve their academic performance in traditional subjects like mathematics or language arts.

The effect of GraphoGame on early literacy development

McTigue et al. (2020[43]) examine the effectiveness of GraphoGame, a digital learning tool for early reading acquisition, particularly for students at risk of reading difficulties like dyslexia. The analysis focused on word-reading proficiency, including letter-sound correspondence, phonological processing and decoding. Despite its use in various countries, the overall impact of GraphoGame on word-reading outcomes was negligible (g = -0.02), showing no significant difference between GraphoGame and other reading interventions or no intervention controls. However, some factors contributed to a better outcome:

- **Adult interaction**. In studies where teachers or caregivers provided significant guidance, the effect size increased, indicating a moderate positive impact of GraphoGame on word-reading proficiency. This suggests that GraphoGame is most effective in structured environments with active adult involvement, where learning can be scaffolded by adults.
- **Language transparency**. The study also found that the game was more effective in languages with transparent orthographies, like Finnish and Spanish, where letter-sound relationships are consistent, showing more positive results in improving reading skills. In contrast, in languages with opaque orthographies, like English, where these relationships are less straightforward, the game was less effective, with minimal gains in word-reading outcomes.
- **Intervention duration**. The duration of the intervention also played a role in determining the game's effectiveness. Longer-term interventions, spanning several months, tended to produce better results, particularly when paired with high levels of adult support. In contrast, shorter interventions (lasting only a few weeks) did not yield significant improvements in early literacy, likely because students had insufficient time to fully engage with the game’s content.

Role-playing games for narrative learning and collaborative learning

Role-playing games (RPGs) and other types of digital games offer a dynamic and engaging approach to education by immersing students in narrative-driven scenarios where they must assume roles, solve problems and make decisions that affect the outcome of the game. Hainey et al. (2016[50]) provide a systematic review of how digital games – particularly serious games – and role-playing games are used in primary education to promote social skills, decision-making and critical thinking. These digital games are designed to engage students interactively and help them develop higher-order thinking skills through immersive experiences. The digital games explored by Hainey et al. (2016[50]) include serious games, which are specifically designed for educational purposes, and commercial-off-the-shelf (COTS) games, which are adapted for use in classrooms. The review also discusses other digital game genres used in education, such as strategy games, simulation games and puzzle games. These genres are commonly employed to teach subjects like mathematics, science and social studies, helping students engage with challenging topics in a more interactive and visually appealing way. For instance, simulation games are often used to model real-world systems, such as ecosystems or economic processes, allowing students to manipulate variables and observe the effects of their decisions in a controlled environment. This interactive learning fosters a deeper understanding of complex concepts and helps students develop problem-solving skills.

RPGs, in particular, are highly effective at promoting collaborative learning. In these games, students must work together to navigate challenges, make decisions and solve problems, all of which promote communication and teamwork. Hainey et al. (2016[50]) highlight the success of RPGs in social studies, history and language arts, where students are required to think critically about historical events, social dynamics, or literary narratives. By placing students in decision-making roles, these games help develop critical thinking skills as students evaluate multiple perspectives and consider the consequences of their actions.

The learning process in these digital games is characterised by active participation and narrative engagement. Students are not passive learners; instead, they take on an active role in shaping the story and influencing the outcomes through their decisions. This engagement helps them apply their knowledge in real-world contexts and strengthens their problem-solving abilities. However, Hainey et al. (2016[50]) also note that younger students may sometimes struggle with the complexity of decision-making in RPGs or may become overwhelmed by the narrative elements, leading to disengagement. Teachers must carefully scaffold these experiences to ensure that students remain engaged and can successfully navigate the learning process.

Developing critical thinking through role-playing and game construction

As alluded to above, digital games have the potential to foster critical thinking skills. Mao et al. (2022[39]) examined the impact of game-based learning (GBL) on students' critical thinking abilities. Their study revealed a significant positive effect of GBL on critical thinking, with a large overall effect size (g = 0.863). This demonstrates that GBL interventions generally promote critical thinking skills and dispositions, although the effect varies based on several factors.

The studies measured critical thinking in terms of two main constructs: *critical thinking disposition* and *critical thinking skill*. Critical thinking disposition reflects an individual's inclination to think critically, while critical thinking skills denote the actual competencies used to assess and evaluate information effectively. GBL had a stronger impact on critical thinking disposition (g = 1.774), compared to critical thinking skills (g = 0.661). This suggests that while GBL enhances students’ inclination to engage in critical thinking, the actual improvement in their ability to apply critical thinking skills is more moderate.

There were some significant factors that had an impact on the effectiveness of GBL:

- **Game type**. The types of games used played a crucial role in determining the effectiveness of GBL interventions. Role-playing games (RPGs) had the highest impact (g = 1.828), indicating their strong potential to develop critical thinking. Games that involve game construction, such as platforms like Scratch, also showed a positive effect (g = 0.769), though less significant than RPGs. Simulation games had a moderate impact (g = 0.522), while adventure games exhibited a relatively small effect (g = 0.153).
- **Cultural context**. The analysis also considered cultural context as a moderator. GBL interventions were more effective in studies from collectivist cultures (g = 1.282) compared to individualistic cultures (g = 0.432). Individuals in collectivist cultures tend to prioritise the group's goals over their own personal ambitions. This may be due to the greater emphasis on group goals and self-critique in collectivist cultures, which aligns well with the collaborative nature of many games that foster critical thinking. In contrast, individuals in individualistic cultures prioritise their personal goals, allowing for greater independence and self-expression.
- **Game design**. Game construction platforms like Scratch showed a moderate effect on critical thinking by fostering creativity and logic.

Exergames: Integrating physical activity and cognitive learning

Exergames are games that combine physical activity with cognitive challenges. These games have demonstrated significant potential in supporting learning processes in school-aged children and adolescents and provide a unique approach to education by integrating movement with tasks that engage cognitive functions.

López-Serrano et al. (2021[44]) conducted a systematic review that explored the impact of exergames on both physical and cognitive development, with a specific focus on how these tools enhance cognitive performance, motivation and classroom behaviour. They found that exergames were particularly effective during structured physical education lessons or short, active breaks in academic classes. The combination of physical activity and cognitive tasks resulted in improvements in executive functions (EFs), such as response inhibition, visual attention and mental processing speed. These benefits were especially notable in subjects requiring strong executive functions, such as mathematics, where students experienced enhanced working memory and mental agility.

The use of exergames in schools is most effective when employed during structured physical education lessons or as active breaks between academic subjects. These games provide immediate feedback, essential for cognitive development. For example, students playing Dance Dance Revolution must coordinate physical movements with on-screen prompts, which enhances their mental processing and response inhibition. Similarly, Cyber Cycling combines physical exertion with cognitive tasks, fostering improvements in both physical fitness and cognitive performance. These benefits are particularly evident in subjects like mathematics, where executive functions such as problem-solving and working memory are essential.

One key finding from López-Serrano et al. (2021[44]) is that persistent use of exergames leads to long-term cognitive and behavioural benefits. Regular participation in exergames improved academic performance, particularly in mathematics, and positively influenced self-concept, classroom behaviour and social relationships. Students who consistently engaged with exergames demonstrated improved behaviour in the classroom and enhanced relationships with peers, suggesting that exergames contribute to holistic development by supporting cognitive growth and social engagement.

In terms of successful learning processes, López-Serrano et al. (2021[44]) emphasised the integration of physical activity with cognitive tasks, which provides dual benefits for students. The physical engagement keeps students active and motivated, while the cognitive challenges embedded in the games improve executive functions. This combination of physical and cognitive engagement is particularly effective in subjects requiring problem-solving and sustained attention, such as mathematics.

However, López-Serrano et al. (2021[44]) also identified several challenges associated with implementing exergames in educational settings, all of which demand relevant investment:

- **Lacking infrastructure**. One major barrier is the availability of resources. Many schools lack the necessary infrastructure, such as gaming consoles, adequate space and equipment, to fully integrate exergames into their curricula.
- **Need for teacher training**. Additionally, teachers often require extra training to effectively use exergames to maximise physical and cognitive benefits for students.
- **Inclusivity**. Another challenge is inclusivity, as some students with physical disabilities may struggle to engage with exergames, creating unequal learning experiences.

Summary

Gaming in education emerges as a multifaceted tool that can significantly enhance learning experiences across various subjects. Game-based learning (GBL) leverages the engaging nature of games to improve motivation, engagement and the development of critical skills such as problem-solving, critical thinking and collaboration. Serious games have been particularly effective in subjects like mathematics, science and social studies, providing interactive environments that deepen understanding and foster cognitive skill development. Meanwhile, exergames successfully integrate physical activity with cognitive tasks, benefiting both physical fitness and cognitive functions like attention and memory, and role-playing games promote creativity, teamwork and critical thinking by immersion in open-ended, decision-driven scenarios.

Despite the clear benefits, integrating games into educational contexts presents challenges. Aligning games with educational objectives requires careful planning to ensure they meet curricular goals and effectively support learning outcomes. Additionally, educators must address potential issues such as accessibility, varying levels of student familiarity with gaming and the need for professional development to effectively implement GBL strategies.

Table 5.2. Summary of gaming tools

Category	Successful processes	Challenges
Sub-tool selection and outcomes	• Use specific genres to target skills: Serious games for cognitive understanding, RPGs for critical thinking and sandbox games for creativity. • Offer a dynamic and engaging alternative to traditional instruction that enhances intrinsic motivation through autonomy and clear goals. • Use exergames to combine physical activity with cognitive tasks, offering dual benefits for fitness and attention.	• The educational effectiveness varies greatly by genre, and aligning commercial games with specific learning objectives is difficult. • The transfer of skills from the game to real-world academic contexts is a major challenge with limited supporting evidence. • Motivation can decrease during longer interventions as the initial novelty wears off.
Educational level applications	• Adapt games for all levels, from primary education to college students.	• Younger students may struggle with the complex decision-making required in some advanced games. • The effectiveness of some games is minimal without significant guidance from an adult.
Subject-specific applications	• Apply effectively across various subjects, including mathematics, science, social studies and language learning.	• The impact of digital games can be inconsistent; for example, the effect has been shown to be smaller in mathematics compared to other areas.
Teacher support and role	• Teachers are crucial for scaffolding the gaming experience and connecting gameplay to the curriculum to ensure learning occurs.	• Teachers often lack the necessary training to integrate game-based learning effectively. • Transitioning a game from entertainment to a structured educational tool requires significant pedagogical planning.
Equity and diversity considerations	• Provide safe, structured environments for students with special needs (e.g. ASD) to practice social and communication skills. • Game-based learning may be more effective at fostering critical thinking in collectivist cultures.	• Equitable access to the necessary technology, infrastructure and resources remains a key barrier. • Implementation of certain games (e.g. exergames) requires hardware and physical space that many schools lack. • Students' diverse levels of prior gaming familiarity must be addressed to ensure equitable engagement.
Assessment and feedback	• Enhance engagement and support self-regulated learning through clear goals and immediate, built-in feedback cycles.	• In-game feedback may focus on performance (e.g. points, scores) rather than articulating progress toward specific learning goals.

6 Extended reality and simulations

Key findings

- Extended reality (XR) technologies can enhance understanding in STEM subjects by making complex, abstract concepts more accessible through immersive experiences. The effectiveness of XR tools varies with the age of students and there may be particular benefits for older students in terms of focus and retention with complex concepts.
- XR also provides personalised, self-paced learning experiences and has potential to promote collaborative learning opportunities, enhancing student communication and problem-solving skills, and to increase motivation and creativity by encouraging experimentation.
- Gamified virtual reality (VR) environments can improve language learning by reducing anxiety, boosting motivation and supporting vocabulary practice and pronunciation.
- Augmented reality (AR) and VR technologies can support students with special needs by improving focus, comprehension and motivation, aiding in the development of social, physical and life skills, increasing self-determination and engagement.
- Challenges like high costs, technical limitations, health concerns and the need for specialised teacher training affect the effective integration of XR technologies into educational settings.
- Teachers' guidance and scaffolding are crucial to maximising XR's effectiveness and maintaining student motivation.
- Without proper integration into broader teaching practices, reliance solely on XR may lead to fragmented learning experiences.

Extended reality (XR) technologies – including augmented reality (AR), virtual reality (VR) and mixed reality (MR) – have the potential to transform education by creating immersive learning experiences that make complex, abstract concepts more accessible. These tools create interactive, sensory-rich environments that can be especially helpful in classrooms where students have varying levels of prior knowledge. In addition to XR, simulation-based technologies like Dynamic Geometry Software (DGS) and Computer Algebra Systems (CAS) provide interactive learning opportunities. The different types of XR technologies and simulation technologies are summarised in Table 6.1.

To effectively integrate such tools into teaching practices, teachers must understand the factors influencing successful implementation and address associated challenges. Careful planning, adequate teacher support and alignment with educational objectives are essential.

Table 6.1. Key terms in extended reality and simulations

Technology		Definition	Tool examples
Extended reality (XR) technologies	Virtual reality (VR)	Immersive environments simulate a virtual world, enabling interaction with 3-D objects in a wholly digital space and enhancing problem-solving and abstract thinking skills.	VR headsets (e.g. Oculus Rift, HTC Vive), motion controllers
	Mixed reality (MR)	Combines AR and VR, allowing interaction with both digital and physical objects in real-time, supporting the exploration of abstract concepts.	Hololens, Meta 2 headset, Magic Leap
	Augmented reality (AR)	Overlays digital objects onto the real world, allowing real-time manipulation of shapes to enhance spatial and geometric reasoning.	Smartphones, tablets, AR glasses, Makey Makey circuits, Projection systems, Scratch combined with AR
Simulation technologies	Computer Algebra Systems (CAS)	Software for symbolic manipulation of algebraic expressions, allowing exploration of algebraic concepts through dynamic calculations and real-time visual feedback.	Wolfram Mathematica, Maple, TI-Nspire CAS
	Dynamic Geometry Software (DGS)	Interactive tools for constructing and manipulating geometric figures in real time, exploring properties of shapes and relationships between geometric elements.	GeoGebra, Cabri Geometry, The Geometer's Sketchpad
	Intelligent Tutoring Systems (ITS)	Adaptive educational systems that provide personalised instruction and feedback, guiding learners through tasks with intelligent support based on individual performance.	Cognitive Tutor, Knewton, ALEKS
	Virtual Laboratories	Simulations for conducting experiments in a virtual environment facilitate the exploration of scientific concepts that might otherwise be inaccessible due to resource limitations or safety concerns.	Virtual Chemistry Lab, PhET Simulations, Crocodile Physics

Integrating extended reality technologies in education

XR technologies offer significant benefits in enhancing learning experiences. However, their integration into education faces challenges related to cost, teacher training, technical limitations, accessibility and health concerns. Addressing these challenges is crucial for the effective and equitable implementation of XR tools in educational settings.

Successful learning practices using extended reality

Extended reality (XR) tools – including augmented reality (AR) and mixed reality (MR) – are most effective when integrated with traditional and interactive instructional strategies. Combining AR and MR with established teaching methods enhances student engagement and comprehension by providing diverse learning experiences (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). For example, supplementing lectures with AR visualisations can clarify complex concepts. In contrast, relying solely on XR tools without integration into broader teaching practices may lead to fragmented learning experiences and may fail to meet educational objectives (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). The ability to interact with 3D models and simulations enables students to grasp intricate ideas that traditional methods may struggle to convey.

Learning processes are more successful when teachers provide scaffolding and guidance for navigating XR experiences (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). Educator involvement ensures that XR activities align with curriculum goals and keep students focused on learning objectives. However, limited teacher training and unfamiliarity with XR technology can hinder its effective integration, reducing its educational impact (Pellas, Kazanidis and Palaigeorgiou, 2020[53]; Yakubova et al., 2023[54]).

Immediate, interactive feedback in XR tasks encourages student engagement and deepens learning by allowing responsive adjustments (Yakubova et al., 2023). Real-time feedback helps students understand the consequences of their actions, promoting deeper comprehension. Conversely, delays in feedback or poorly designed interactions can cause disengagement and confusion (Pellas, Kazanidis and Palaigeorgiou, 2020[53]), potentially leading to frustration or misunderstandings.

MR and AR are particularly useful in subjects requiring the visualisation of abstract concepts, such as biology and physics (Yakubova et al., 2023[54]; Pellas, Kazanidis and Palaigeorgiou, 2020[53]). However, these tools may have a limited impact on subjects that do not rely heavily on visual or spatial components. In literature or history, where textual analysis and critical thinking are central, MR and AR may not significantly enhance learning outcomes (Pellas, Kazanidis and Palaigeorgiou, 2020[53]).

The effectiveness of XR tools varies with the age of students. Secondary education students benefit especially from XR technologies, as these tools help them engage with complex concepts through immersive, hands-on learning (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). Older students' maturity enables them to navigate immersive environments effectively, enhancing focus and retention. Conversely, younger students may struggle with XR environments, potentially experiencing cognitive overload or reduced focus (Yakubova et al., 2023[54]).

A major advantage of AR and VR in education is their ability to promote personalised learning experiences. These technologies allow students to explore and interact with scientific and mathematical phenomena at their own pace, enabling differentiated instruction that adapts to each student’s needs and abilities. For example, AR applications allow students to visualise molecules in 3D, deepening their understanding of chemical reactions beyond what is possible through traditional teaching (Sırakaya and Alsancak Sırakaya, 2022[55]). VR also supports differentiation by offering virtual field trips and complex experiments, helping students learn difficult concepts in personalised contexts (Zhang and Wang, 2021[56]).

MR environments have been shown to facilitate collaborative problem-solving and teamwork by allowing students to interact with both digital and physical objects in group activities. MR enables students to work together on complex concepts in science and mathematics, fostering deeper understanding through shared learning experiences (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). This collaborative approach, combined with the hands-on nature of MR, makes it a powerful tool for teaching these subjects. Studies indicate that students who use MR in collaborative tasks, such as designing virtual circuits or manipulating 3D models, benefit from both improved understanding and enhanced communication skills (Pellas, Kazanidis and Palaigeorgiou, 2020[53]).

Challenges using extended reality

While XR technologies offer many benefits, their integration in education faces significant challenges. Cost is a major barrier, as the high expenses associated with XR hardware, software, updates and maintenance often make adoption unfeasible, particularly for underfunded schools (Sırakaya and Alsancak Sırakaya, 2022[55]; Zhang and Wang, 2021[56]; Pellas, Kazanidis and Palaigeorgiou, 2020[53]). Equitable access is critical for effective learning, yet financial constraints can restrict access for many students. Accessibility is another concern, as students from lower socio-economic backgrounds or underfunded schools may not have the same exposure to XR tools, exacerbating educational inequalities (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). Adequate technological infrastructure is essential to support accessibility, but without it, equitable access remains a challenge.

Teacher training also poses significant challenges. Teachers must develop both technical skills and strategies to integrate XR into the curriculum, but training can be costly and time-consuming. Without proper support, teachers may feel unprepared or resistant, limiting the potential of XR technologies (Pellas, Kazanidis and Palaigeorgiou, 2020[53]; Yakubova et al., 2023[54]). Successful integration requires teachers to provide guidance and align XR activities with learning objectives to maximise their educational impact.

Finally, technical issues such as software glitches, hardware malfunctions and compatibility problems can disrupt learning and cause frustration among both students and teachers, reducing engagement and potentially leading to the abandonment of XR technologies (Sırakaya and Alsancak Sırakaya, 2022[55]).

Augmented reality and dynamic geometry software in mathematics

Benefits of augmented reality in mathematics

Pellas, Kazanidis and Palaigeorgiou (2020[53]) state that AR tools have been utilised in mathematics education to improve students' understanding of geometric and spatial reasoning. AR allows students to interact with 3D geometric shapes, enabling them to solve spatial problems that are challenging to address using traditional teaching methods. The real-time manipulation of these shapes helps make abstract mathematical concepts more concrete and easier for students to grasp. The interactive and immersive nature of AR engages students more deeply, as it allows them to interact directly with the mathematical concepts in a more meaningful way. The use of AR in the classroom also supports collaborative problem-solving, where students can work together to explore, for instance, geometric shapes and solve spatial reasoning problems.

Impact of dynamic geometry software on learning outcomes on mathematical skills

Dynamic Geometry Software (DGS) refers to computer-based interactive tools designed to facilitate the exploration and understanding of geometric concepts. DGS enables users to construct, manipulate and visualise geometric figures dynamically. Juandi et al. (2021a[57]) reported a large effect size (g = 1.07) on the impact of DGS on students' mathematical skills. Another meta-analysis by Juandi et al. (2021b[58]) that focused explicitly on GeoGebra also reported a large effect size (g = 0.96) on the impact of this tool on students' mathematical skills.

Two meta-analyses discuss several conditions for effective use of DGS (Juandi et al., 2021a[57]; Juandi et al., 2021b[58]):

- **Class size**. Higher effect sizes in classes with fewer than 30 students compared to larger class sizes consisting of 31 or more students.
- **Duration of exposure**. Using tools over shorter instructional periods of fewer than four weeks had higher effect sizes than longer exposure times. A possible reason is attributed to the Hawthorne effect, where students may improve their efforts due to the novelty of the new treatment, leading to diminished effects over more extended treatment periods.
- **Individual computer access**. There were higher effect sizes in studies with students with individual access to a computer than students who shared computers with two or more students.
- **Educational level**. Higher effect for studies with junior high school student samples compared to senior high school counterparts. However, there were no major differences between the effects, suggesting a stable effect of using GeoGebra.

Hillmayr et al. (2020[59]) also provide relevant findings that support many points discussed here but from a broader technological perspective in mathematics and science education. They found an overall medium effect of the use of digital tools on student learning (g = 0.65). Mathematics as a moderator also had a similar medium effect size (g = 0.55). With specific tools, dynamic mathematical tools had a large effect size (g = 1.02). Additionally, they observed that smaller class sizes had an even greater positive impact on learning outcomes.

Extended reality and simulation tools in science-based subjects

XR tools are increasingly used in science education to help students understand complex phenomena. These technologies offer immersive and interactive experiences that make abstract or inaccessible concepts tangible, enhancing student engagement and understanding.

Applications of mixed reality and augmented reality

MR and AR tools facilitate effective learning in subjects that require the visualisation of abstract concepts, such as biology, physics and chemistry (Yakubova et al., 2023[54]; Pellas, Kazanidis and Palaigeorgiou, 2020[53]). The ability to interact with 3D models and simulations helps students grasp complex ideas that are challenging to convey through traditional methods. The possibilities offered also varied between different subjects.

AR applications allow students to visualise cell structures, ecosystems and animal behaviour through interactive 3D models. These tools provide hands-on virtual experimentation opportunities that make complex biological concepts more accessible (Pellas, Kazanidis and Palaigeorgiou, 2020[53]). By interacting with detailed models, students can explore microscopic and macroscopic processes that are otherwise difficult to observe.

AR and VR technologies in physics education help students understand complex processes, such as planetary motion or electricity, by allowing them to manipulate variables and observe real-time effects. VR-based virtual experiments enable students to explore phenomena that are too dangerous, costly, or impractical to replicate in physical laboratories, such as nuclear reactions or space exploration missions. Additionally, VR offers virtual field trips to otherwise inaccessible locations like outer space or the ocean floor, providing students with firsthand experiences of complex phenomena (Zhang and Wang, 2021[56]). The immersive nature of these tools fosters deeper engagement and comprehension, which is particularly important for secondary education students grappling with increasingly complex scientific concepts (Yakubova et al., 2023[54]; Sırakaya and Alsancak Sırakaya, 2022[55]).

AR enables the visualisation of molecular structures in 3D, helping students understand chemical reactions and the spatial orientation of molecules – concepts that can be difficult to grasp through traditional methods (Sırakaya & Alsancak Sırakaya, 2022). Students gain insights into chemical bonds and interactions by manipulating virtual molecules, enhancing their understanding beyond textbook diagrams. Hillmayr et al. (2020[59]) further highlight that simulations such as virtual laboratories allow students to conduct experiments in a controlled virtual environment. These tools offer opportunities to explore scientific concepts that may be otherwise inaccessible due to resource limitations or safety concerns. By enabling students to manipulate variables and observe outcomes in real-time, simulations reinforce understanding of scientific concepts through active experimentation and problem-solving.

Using virtual reality in foreign language learning

Pinto and colleagues (2021[60]) explored how immersive VR environments can support second language acquisition, with a focus on vocabulary, pronunciation and communication skills. These environments allow learners to apply language skills in real-world contexts, enhancing engagement and motivation. The review revealed that VR's immersive nature provides rich language exposure, enabling learners to practice their skills in contexts that resemble native-speaking environments. The interactivity of these systems facilitates the development of key language skills as students actively engage with content, practising vocabulary and pronunciation within meaningful scenarios. Additionally, gamified VR experiences can increase motivation and reduce anxiety by offering immediate feedback and goal-oriented tasks.

According to Pinto et al. (2021[60]), VR tools, particularly head-mounted displays (HMDs) and desktop VR systems, were primarily used in foreign language learning, providing immersive scenarios where students could practice communication and vocabulary. These tools proved especially useful for helping students develop listening and speaking skills by immersing them in language-rich environments. Notably, Pinto et al. (2021[60]) found that younger learners responded well to these immersive, gamified environments.

However, despite its advantages, the study also highlighted challenges associated with using VR in language learning. High costs of VR equipment and technical limitations, such as system crashes or delays in feedback, were identified as significant barriers. Most of the studies included in Pinto et al. (2021[60]) were conducted in technologically advanced countries, such as the United States, Canada and various European nations, where access to funding and advanced technology facilitated implementation. Furthermore, some students reported issues with physical discomfort, such as dizziness or eye strain, which could limit the time they spend in VR environments. Teacher support and technical training were also emphasised as essential for effective implementation, ensuring that both educators and students can maximise the benefits of VR technology.

The impact of virtual reality on interdisciplinary learning

VR has the potential to transform interdisciplinary learning by providing immersive and interactive environments that enhance students' understanding of complex concepts across various subjects. Yu and Xu (2022[61]) conducted a meta-analysis to examine the effects of VR on learning outcomes, focusing on intellectual skills, motor skills, cognitive strategies and attitudes. Based on the findings, VR can significantly enhance students' cognitive abilities, procedural knowledge and engagement across subjects such as science, mathematics and language learning.

VR supports the development of spatial visualisation and problem-solving abilities. Interactive 3D environments can help students grasp complex mathematical and scientific concepts by making them more tangible and easier to manipulate. This interactivity leads to improved student engagement and academic achievement. VR's capacity to make abstract concepts more accessible contributes significantly to learning outcomes in subjects like mathematics and science. Further, VR's ability to simulate real-world scenarios and provide real-time feedback enables students to practice procedural tasks in disciplines like biology, physics and engineering.

The highest effect size was found for the studies with students at the university level, followed by middle school and a much lower effect for the ones in primary school. University students generally have more advanced cognitive skills, higher intrinsic motivation and greater technological familiarity, enabling them to benefit more effectively from the immersive and interactive nature of VR compared to younger students.

However, it is worth noting that managing cognitive load in VR-based learning environments is particularly challenging when dealing with complex topics. Albus, Vogt and Seufert (2021[62]) conducted a primary study exploring strategies to address this in VR-based science education for secondary students in Germany, focusing on seawater desalination. The study utilised attentional aids in instructional design to manage cognitive load and improve learning outcomes. This primary study highlights the importance of managing cognitive load in VR learning. Effective strategies include simplifying interfaces to reduce extraneous load, scaffolding complex topics to manage intrinsic load and using attentional cues to enhance germane load.

Applying augmented reality in special education

According to Yakubova et al. (2023[54]), augmented reality (AR) can be a valuable tool for enhancing academic and developmental outcomes in students with autism spectrum disorder (ASD) and intellectual and developmental disabilities (IDD). Baragash et al. (2020[63]) further note that AR can make learning more accessible and engaging for students with cognitive, sensory, or physical disabilities by catering to their unique needs. This technology has demonstrated the potential to improve focus, comprehension and motivation in special education settings.

Potential impact of augmented reality on students with special education needs

Baragash and colleagues (2020[63]) conducted a meta-analysis to examine the extent to which AR assists individuals with special needs, the effectiveness of AR in each domain of special education – social, living, physical and learning skills – and to identify the specific domain where AR is most impactful. They argue that AR tools can significantly enhance learning outcomes in special education, benefiting students with cognitive impairments, intellectual disabilities (ID), autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and other developmental challenges. The meta-analysis found that AR applications were highly effective in enhancing various skills, with a large overall effect size (0.951) and consistently high effect sizes across the various domains.

The meta-analysis found that, regarding learning skills, AR was most beneficial in promoting vocabulary acquisition and overall learning, especially in students with ASD and intellectual disabilities. By providing real-time feedback and interactive tools, these systems allowed students to engage with learning materials through immersive experiences, increasing motivation and retention of new concepts. AR-based systems often offer visual cues, enabling students to better understand and remember academic content, such as math, science and language, and more abstract concepts. However, its effectiveness diminishes if feedback is delayed or the content lacks alignment with learning goals or the students' specific needs.

The study also found that AR enhances physical skills by improving motor abilities and facilitating navigation in real-world settings, particularly for individuals with ID and ASD. AR tools support navigation tasks and physical interactions in location-based contexts, providing guidance for activities like relocating and navigating spaces. This helps reduce social isolation and improves relationships among individuals with disabilities. However, overly simplistic or disengaging environments without tangible links to real-world tasks can limit its benefits.

Finally, AR offers valuable support for developing daily living skills within immersive, controlled environments. AR tools enable students to practice and master tasks such as navigating their environments and performing routine activities independently, with scaffolded guidance. This significantly improves students' self-determination and quality of life. However, it may fail to translate effectively if real-life applicability is lacking or if students are required to perform tasks without sufficient guidance.

Applications of augmented reality in specific domains of special education needs

Yakubova et al. (2023[54]) conducted a systematic review exploring the potential of AR to enhance academic skills in areas such as literacy, functional skills and social development for students with ASD and IDD. AR interventions provide tailored, scaffolded learning experiences that address the specific needs of these students, enabling deeper engagement with educational content. The studies reviewed were conducted in various countries, predominantly in technologically advanced regions such as the United States and parts of Europe, reflecting the current availability of AR technologies in these areas.

One of the key applications of AR is in teaching literacy skills. Yakubova et al. (2023[54]) noted that AR interventions have been effectively applied to help students recognise letters, identify vowel sounds and improve reading comprehension. Interactive visual aids allow students to hear, see and interact with words and letters in ways that traditional teaching methods often do not provide, while students also receive immediate feedback – essential for learners who benefit from structured and repetitive tasks. Moreover, this multisensory approach increases engagement and helps students with ASD and IDD stay focused by catering to sensory preferences.

AR has been instrumental in supporting social development among students with ASD. Specific applications are designed to help these students practise recognising facial expressions and making eye contact in social situations (Yakubova et al., 2023[54]; Baragash et al., 2020[63]). By providing a safe and controlled environment, AR enables students to develop essential social skills critical for their overall development. Despite these benefits, adequate teacher support is vital – as outlined further below – and, additionally, reliance on technology might limit real-life social interactions if not balanced appropriately.

AR can support functional skills acquisition, allowing students to practice essential life skills in a controlled, risk-free environment. For students with ASD and IDD, learning functional skills such as money management and time-telling can be challenging. AR applications can simulate real-world scenarios, providing opportunities for students to engage in practical exercises without real-world consequences. This controlled setting helps build confidence and competence in performing essential tasks.

Finally, multisensory AR experiences also help maintain engagement by combining visual, auditory and tactile elements. For students with ASD and IDD, who often have unique sensory processing needs, AR can provide customised sensory inputs that enhance learning. By catering to individual sensory preferences, AR can make learning more accessible and enjoyable.

Challenges for successful implementation of augmented reality for students with special education needs

Sensory overload may occur for students with special education needs such as those with ASD who are sensitive to visual and auditory stimuli. The immersive nature of AR can sometimes overwhelm students, leading to distractions or disengagement. It is essential to carefully design AR content to ensure it does not become overly stimulating, thereby preserving its educational advantages.

Teacher involvement and structured guidance are crucial for the success of AR interventions in special education. Students may struggle to use AR effectively in social learning contexts without adequate teacher support. Teachers play a vital role in guiding students through AR experiences, helping them interpret feedback and encouraging them to apply learned skills in real-life situations. However, a lack of comprehensive teacher training limits the effective integration of AR into individualised education plans.

Access to AR technology may also be limited by high costs, especially in resource-constrained schools. This limitation means that not all students who could benefit from AR interventions will have the opportunity to experience them, potentially widening the educational gap between different socio-economic groups.

Summary

This chapter highlights positive learning outcomes from using XR and simulations in education. In mathematics, augmented reality and dynamic geometry software allow students to manipulate shapes in real time, improving spatial reasoning and comprehension of abstract concepts, while in science, virtual laboratories provide safe environments for experiments that would be difficult or dangerous in physical labs.

The effectiveness of such technologies is often greatest in smaller classes, when students have individual device access and when interventions are short and focused. Combining them with traditional teaching strengthens cognitive understanding, spatial reasoning and procedural knowledge, though results vary by subject, grade and classroom integration.

Challenges include equipment costs, teacher training needs and technical limitations. Younger learners may also struggle with the cognitive demands of immersive environments. Effective use therefore depends on careful integration, teacher support and alignment with curriculum goals.

Table 6.2. Summary of extended reality and simulations tools

Category	Sucessful processes	Challenges
Sub-tool selection and outcomes	• Use AR to enhance spatial reasoning, VR for full immersion (e.g. science labs, language practice) and simulations for interactive experimentation. • Provide unique learning opportunities (e.g. virtual field trips, unsafe experiments) that are otherwise unavailable. • Well-designed environments with instructional aids (e.g. visual cues) can enhance focus and retention. • Support self-paced, personalised and collaborative learning.	• High costs, technical limitations (e.g. glitches, malfunctions) and potential health concerns (e.g. dizziness, eye strain) are significant barriers. • The highly immersive nature of VR can cause cognitive or sensory overload if not designed carefully. • Effectiveness can diminish over longer instructional periods as the initial novelty wears off.
Educational level applications	• Especially beneficial for secondary and university students engaging with complex concepts. • Dynamic Geometry Software (DGS) shows strong positive effects in junior high school.	• Younger students may experience cognitive overload in highly immersive XR environments. • The positive effects of VR have been found to be much lower in primary school compared to other levels.
Subject-specific applications	• Highly effective for visualising abstract concepts in STEM subjects (e.g. molecular structures, planetary motion). • Powerful for immersive foreign language learning and providing targeted support in special education.	• There is limited impact in subjects that are primarily text-based, such as literature or history, and do not rely heavily on visual components.
Teacher support and role	• Most effective when teachers actively guide, scaffold and integrate XR experiences with traditional teaching methods.	• A lack of specialised teacher training is a major barrier that can lead to teachers feeling unprepared or overwhelmed. • Collaborative activities within XR require teacher guidance to be productive.
Equity and diversity considerations	• Powerful tools for students with special needs (e.g. ASD), improving focus, motivation and academic and life skills.	• The high financial cost of hardware and software is a primary barrier, creating significant equity issues for underfunded schools. • Implementation is more effective in smaller classes with individual computer access – conditions not available to all students. • The immersive experience can be overstimulating for students with sensory sensitivities.
Assessment and feedback	• Immediate, interactive feedback encourages engagement, reinforces learning and allows for responsive adjustments. • Real-time feedback is an essential mechanism for acquiring skills in foreign language pronunciation and for students in special education.	• The potential for personalisation is limited if the software is not adaptive to the learner's progress. • Delayed or poorly designed feedback can cause confusion and disengagement.

7 Artificial intelligence and learning analytics

Key findings

- Artificial intelligence (AI) technologies in formative assessment provide immediate, personalised feedback that has the potential to enhance student engagement and learning outcomes.
- AI tools can facilitate improved communication and group dynamics in collaborative settings, supporting dialogic learning and group problem-solving.
- Learning analytics can help identify at-risk students, providing timely interventions to support diverse learners and enhance equity and inclusiveness.
- AI-powered empathic conversational agents can offer emotional support and personalised feedback. This can foster dialogic learning and support students' emotional and cognitive needs.
- Ethical considerations such as data privacy, fairness and potential bias necessitate careful implementation and oversight by teachers to ensure ethical use of AI in education.
- Teacher involvement is essential in interpreting AI feedback, guiding ethical use and ensuring equitable learning outcomes.

This chapter explores the transformative potential of artificial intelligence (AI) and learning analytics (see Table 7.1) in enhancing educational practices in primary and secondary education. With the increasing integration of AI in educational settings, innovative tools are emerging to support formative assessment and learning analytics, providing real-time feedback and tailored instructional strategies. The chapter also considers the impact of AI on collaborative learning and the role of empathic conversational agents, as well as the use of learning analytics to promote inclusiveness and to support self-regulated learning.

Finally, the chapter addresses ethical concerns such as data privacy, fairness and the role of teachers in interpreting AI feedback. Through an analysis of these studies, this chapter highlights key themes such as real-time feedback, AI's effectiveness in formative assessment, collaborative learning, learning analytics, motivation, digital literacy, inclusiveness and ethical considerations in using AI in education.

Table 7.1. Key terms in artificial intelligence and learning analytics

Key component	Definition	Examples from studies
Artificial Intelligence (AI)	AI refers to the simulation of human intelligence by machines to analyse data, automate tasks and provide personalised learning experiences.	Natural Language Processing (NLP) tools, Empathic Conversational Agents, AI-based feedback systems (Ouyang, Dinh and Xu, 2023[64])
Formative assessment	An ongoing process that allows for real-time evaluation of student learning, with immediate feedback to guide improvement.	Kahoot, Socrative, Nearpod (See et al., 2022[65])
Learning analytics	Learning analytics involves the measurement, collection and analysis of data about learners to optimise educational outcomes.	Google Analytics for Education, Edmodo Insights, Brightspace Analytics (Ouyang, Dinh and Xu, 2023[64])

Artificial intelligence in formative assessment and learning analytics

The use of AI-driven tools in formative assessment and learning analytics has demonstrated notable potential in primary and secondary education. Both formative assessment and learning analytics involve the application of AI technologies to provide real-time feedback, improve student engagement and assist teachers in monitoring student progress and making data-driven instructional decisions. The studies conducted by See et al. (2022[65]) and Ouyang, Dinh and Xu (2023[64]) offer insights into how these AI-enhanced processes can positively influence learning outcomes, particularly in subjects like mathematics, reading and STEM, while also revealing some limitations and challenges.

See et al. (2022[65]) conducted a systematic review focusing on how digital technologies can enhance formative assessment in schools. One prominent example discussed is the use of learner response systems such as Kahoot, Socrative and Nearpod, which allow teachers to pose questions to students during lessons, with responses being aggregated in real time. These systems provide teachers with immediate feedback on student comprehension, enabling them to adjust their instructional approaches instantly to address gaps in knowledge. This has been especially useful in subjects like mathematics and reading. For instance, a math teacher may use Kahoot to quickly gauge student understanding of multiplication, while the data allows them to focus on students needing extra help.

Despite these successes, See et al. (2022[65]) found that these technologies are not universally effective across all subjects. Their review suggests that while learner response systems can be beneficial for subjects like math and reading, there is insufficient evidence to support their effectiveness in other subject areas. Additionally, the long-term effectiveness of these gamified systems is questionable. Over time, the novelty of platforms like Kahoot may wear off, leading to reduced student engagement and participation. The review also points to concerns about over-reliance on gamification. While gamified elements like points, leaderboards and competitive features can motivate students initially, they may not lead to deeper learning or improved academic outcomes in the long term. Additionally, the effectiveness of these tools can vary significantly based on the quality and context of implementation. For instance, the timing and content of feedback are crucial: feedback that is too generic or delayed may fail to address student needs effectively. Furthermore, the systems’ reliance on multiple-choice formats limits their ability to assess more complex learning processes, such as critical thinking or problem-solving skills.

On a broader scale, Ouyang, Dinh and Xu (2023[64]) conducted a systematic review to explore the applications and challenges of AI-driven educational assessment tools in STEM education within the secondary education context, focusing on their effectiveness in assessing academic performance, monitoring learning progress and evaluating instructional quality. One key advantage identified was that AI tools such as machine learning (ML) and natural language processing (NLP) algorithms can automatically assess students' cognitive engagement in real-time. These tools can analyse interactions with digital learning materials or problem-solving tasks, particularly in subjects like physics, engineering and mathematics. For example, an AI-based system can assess how students approach solving an equation in a physics class, identifying common misconceptions and offering immediate feedback for the teacher to address. This can help educators tailor their teaching to meet individual learning needs.

However, the review also highlighted significant challenges. A major issue is that AI systems are limited in their ability to capture emotional and social aspects of learning. While these tools are effective at providing cognitive feedback, they often fail to account for students' emotional well-being or how they collaborate with peers, which can be critical for overall learning success. AI-driven systems tend to focus primarily on cognitive and behavioural data, overlooking these essential factors. Moreover, Ouyang, Dinh and Xu (2023[64]) stress the importance of teacher involvement. Without sufficient interpretation and application of the data generated by AI systems, the effectiveness of these tools could be significantly diminished. Teachers play an essential role in ensuring that the insights provided by AI are used to make meaningful instructional adjustments.

To address these challenges, Ouyang, Dinh and Xu (2023[64]) suggest combining AI tools with traditional instructional methods to create a more holistic learning environment. They emphasise that AI should support rather than replace teacher judgment and interaction, ensuring that emotional and social factors are also considered when evaluating student performance.

Artificial intelligence in collaborative learning and feedback systems

AI in Collaborative Learning and Feedback Systems has emerged as a promising approach to enhancing group dynamics and individual contributions within educational settings. Both Ouyang and Zhang (2024[66]) and Xu (2024[67]) have conducted systematic reviews exploring how AI-driven tools can facilitate collaboration by providing real-time feedback and supporting engagement across various learning tasks. These reviews underscore the potential of AI technologies to transform the collaborative learning experience, while also identifying significant challenges that need to be addressed.

In the review by Ouyang and Zhang (2024[66]) AI tools are examined within the context of computer-supported collaborative learning (CSCL) environments. These tools are designed to monitor group interactions by analysing communication patterns and behaviours during collaborative activities. A key benefit identified in the study is the ability of AI systems to track the contributions of each participant in real time, allowing for more equitable participation and improved group dynamics. For example, during a group project, AI tools can assess the level of engagement from each member by analysing their verbal or written input, providing immediate feedback on participation and helping to adjust imbalances in group collaboration. This real-time feedback fosters an environment where students are more aware of their role within the group, ultimately leading to better social and cognitive engagement.

The successful learning processes facilitated by AI tools, as described by Ouyang, Dinh and Xu (2023[64]), involve enhancing both cognitive and social dynamics in group tasks. By providing real-time insights into participation levels, AI systems enable students to reflect on their contributions and make adjustments accordingly, which is particularly useful in group projects that require continuous collaboration and communication. However, the study also highlights significant challenges associated with the use of AI in collaborative learning. One of the primary issues is the difficulty AI tools face in capturing the emotional and social nuances that are critical for successful group dynamics. While AI can effectively track cognitive engagement, it often overlooks the emotional regulation and interpersonal communication that are essential for maintaining group cohesion. As a result, teacher intervention remains crucial for interpreting AI-generated feedback and ensuring that students are engaging effectively.

Similarly, Xu (2024[67]) explores the use of AI in supporting collaborative learning, with a particular focus on the role of ChatGPT in facilitating group discussions, writing tasks and problem-solving activities. ChatGPT is highlighted for its ability to provide personalised feedback during collaborative tasks, which helps students refine their ideas and improve the overall quality of their work. For example, in a group writing task, ChatGPT might suggest improvements to the group's draft, helping them enhance their arguments or organisation of content. The real-time, interactive nature of ChatGPT helps maintain the flow of collaboration, ensuring that group members stay engaged and motivated throughout the task.

Despite these advantages, Xu (2024[67]) identifies several challenges with using AI in collaborative settings. One of the key challenges is ensuring the accuracy of feedback provided by tools like ChatGPT. While the AI can offer helpful suggestions, the reliability of its feedback can vary depending on the complexity of the task. This variability may require teacher oversight to ensure that students do not rely solely on AI-generated feedback without critically evaluating its relevance or accuracy. Xu (2024[67]) also points out that disparities in students' digital literacy can impact how effectively they engage with AI tools. Students with lower levels of digital literacy may struggle to use tools like ChatGPT effectively, leading to disparities in participation and collaboration outcomes within group tasks.

Artificial intelligence for automated assessment and writing

The integration of AI into writing tasks has the potential to enhance objectivity, streamline grading processes and reduce teacher workload. According to the systematic review by Martínez-Comesaña and colleagues (2023[68]), AI tools for automated assessment in writing, particularly for students in primary and secondary education, utilise key technologies such as Natural Language Processing (NLP) and neural networks. These technologies offer significant improvements in the consistency and fairness of assessments, as well as the speed with which feedback is delivered to students.

NLP enables AI tools to efficiently grade written assignments by comparing student responses with pre-defined model answers. These tools analyse various aspects of a student’s writing, such as grammar, coherence and structure, providing immediate feedback. For example, an AI tool might assess an essay for its grammatical correctness and overall organisation, offering suggestions for improvement in real-time. This not only accelerates the grading process but also ensures that evaluations are applied uniformly to all students, reducing human biases in assessment (Martínez-Comesaña et al., 2023[68]).

Neural networks further enhance the assessment process by identifying patterns in student writing and predicting performance. These algorithms analyse trends in multiple assignments, such as recurring errors or areas of improvement, helping to generate consistent and data-driven evaluations. For instance, neural networks can track a student's progression in writing over time and flag persistent challenges, thereby helping teachers to address individual student needs more effectively (Martínez-Comesaña et al., 2023[68]).

The successful application of these technologies in writing assessment results in several important outcomes. First, automated grading ensures objective, consistent evaluation across a wide range of written tasks. This is especially beneficial in high-stakes assessments, where fairness is critical. Additionally, using AI in grading provides real-time formative feedback, encouraging students to improve their work before final submission. This iterative feedback loop fosters a more dynamic learning environment, promoting continuous improvement in writing skills (Martínez-Comesaña et al., 2023[68]). Another advantage here of AI-based assessment tools is the reduction of teacher workload. By automating routine grading tasks, teachers can focus on more complex, higher-value instructional responsibilities, such as providing personalised support to students or designing creative curriculum materials (Martínez-Comesaña et al., 2023[68]).

Despite these benefits, several challenges are associated with AI-driven writing assessments. A major concern is the potential for ethical issues, particularly regarding fairness and bias. If the AI systems are trained on biased datasets, they may inadvertently reinforce those biases in their grading, leading to unfair evaluations. Moreover, AI struggles with the assessment of creative or open-ended responses, which often require human judgment to properly evaluate aspects such as tone, style and originality. These types of responses can be too complex for AI tools to assess effectively (Martínez-Comesaña et al., 2023[68]). Another significant issue is data privacy. The use of AI for writing assessment requires large datasets, which often include sensitive student information. This raises concerns about how this data are stored, processed and used (Martínez-Comesaña et al., 2023[68]).

More broadly, as the primary study in Box 7.1 outlines, there are also important considerations around the use of analogue tools in digital assessments. This primary study, conducted in Australia, sheds light on how test formats – paper-based versus computer-based – affect students' ability to manage cognitive demands and ultimately perform tasks requiring high levels of mental effort.

Box 7.1. Analogue vs. digital in assessment: The role of cognitive load

In an important primary study, Pengelley et al. (2023) illustrate the challenges of managing cognitive load in digital assessments. The findings highlight how combining analogue tools, such as scratch paper, with digital assessments can help overcome these challenges, offering a balanced approach to optimising student performance in cognitively demanding tasks.

In the study, 263 secondary school students participated in a repeated measures experiment where they completed an Ohm’s Law quiz in both paper-based and computer-based formats. The quiz was designed to assess students' understanding of Ohm’s Law, a core concept in physics, and included both straightforward and complex questions. During the paper-based test, students were allowed to use scratch paper to perform calculations and organise their thinking. In contrast, scratch paper use was restricted in the computer-based test, forcing students to rely solely on their working memory for problem-solving.

The study measured cognitive load in two ways: through students' self-reported perceptions of difficulty and their mental effort during the quiz. The results demonstrated that students performed significantly better on the paper-based assessment, particularly when answering more difficult questions. This performance advantage was closely linked to the availability of scratch paper, which helped students externalise their thinking and reduce cognitive load, allowing them to focus on problem-solving. In contrast, the restricted use of scratch paper in the computer-based test led to a higher cognitive load, especially on complex questions, as students struggled to manage multiple pieces of information in their working memory.

The findings of Pengelley, Whipp and Rovis-Hermann (2023[69]) suggest that paper-based assessments provide a significant advantage when managing cognitive load in difficult tasks. By enabling students to offload cognitive work onto external tools like scratch paper, paper-based tests reduce the burden on working memory and enhance performance. Conversely, computer-based assessments, when lacking such external supports, can increase cognitive load, particularly in tasks that require complex calculations or the integration of multiple pieces of information.

The study concludes that the format of the test, whether paper-based or computer-based, plays a central role in determining cognitive load and performance, especially in problem-solving tasks. Educators should carefully consider the test format for subjects that involve high levels of cognitive demand, such as physics. Pengelley, Whipp and Rovis-Hermann (2023[69]) recommend incorporating analogue tools, such as scratch paper, into assessments to help students manage their cognitive load. Furthermore, in digital assessments, the introduction of digital scratchpads or similar tools could help replicate the benefits of paper-based methods, enabling students to externalise their thinking processes even in computer-based environments.

Artificial intelligence’s impact on motivation and digital literacy

The integration of AI technologies, particularly ChatGPT, into educational contexts has garnered attention for its potential to enhance both student motivation and digital literacy. The systematic review by Xu (2024[67]) examines how AI tools, especially in ChatGPT-assisted environments, impact learners’ intrinsic and extrinsic motivation while also addressing the significance of digital literacy in ensuring effective engagement with these technologies. The study specifically explores the interaction between digital skills, motivation and AI-supported learning, providing insights into how students' outcomes can be enhanced by AI-driven learning tools.

Xu (2024[67]) focuses on the role of AI in increasing student motivation through real-time interaction and personalised feedback, which enhances engagement. In ChatGPT-supported learning environments, AI tools provide immediate feedback and tailored learning tasks that foster intrinsic motivation (self-driven learning) and extrinsic motivation (motivation through external rewards and feedback). The study shows that students using AI tools like ChatGPT report higher motivation levels compared to traditional learning environments. This is especially evident in contexts like language learning, where students engage with AI-driven chatbots for writing, speaking and interactive learning tasks.

The technology is employed throughout the learning process, with ChatGPT facilitating continuous interaction, allowing students to receive immediate corrections and suggestions. This dynamic interaction not only enhances engagement but also promotes self-regulated learning. The study highlights that students are more likely to stay motivated when they see direct results from their efforts through AI feedback. Moreover, ChatGPT assists learners in becoming more autonomous, enabling them to take control of their learning paths, especially in language acquisition tasks, where personalised feedback plays a crucial role (Xu, 2024[67]).

Digital literacy emerges as a critical factor in determining the effectiveness of AI tools. Xu (2024[67]). identifies that students with higher levels of digital literacy are better equipped to engage with AI platforms like ChatGPT, maximising their learning potential. These students can navigate AI interfaces more effectively, manipulate digital tools and apply critical thinking skills in analysing the feedback they receive. On the other hand, students with low digital literacy may face challenges in fully engaging with AI tools, which can result in lower levels of motivation and reduced learning outcomes.

The study emphasises that successful learning processes with AI tools are characterised by immediate, personalised feedback that helps students adjust their learning strategies. This real-time feedback is particularly effective in maintaining student motivation, as it allows learners to see the impact of their efforts and make improvements instantly. In addition, ChatGPT supports self-directed learning, where students are encouraged to take initiative and reflect on their learning progress (Xu, 2024[67]).

However, several challenges are identified in the study. One significant challenge is the risk of digital fatigue and task monotony if AI tools like ChatGPT are not thoughtfully integrated into the learning process. Students may become disengaged from repetitive tasks, reducing the motivational impact of these tools. Additionally, while ChatGPT provides effective feedback, there are concerns about the lack of emotional nuance in AI-driven interactions. The study suggests that teachers need to provide oversight and guidance to ensure that AI tools are used effectively and ethically. This is especially important in addressing digital literacy gaps, where unequal access to technology or insufficient digital skills can lead to disparities in learning outcomes (Xu, 2024[67]).

Empathic pedagogical conversational agents in formative assessment

Following the challenges identified in the previous chapter regarding the difficulty of AI tools in capturing emotional or social engagement, empathic Pedagogical Conversational Agents (PCAs) offer a potential solution to these limitations. While traditional AI-driven tools, such as those explored by Ouyang, Dinh and

Xu (2023[64]), excel in providing real-time cognitive feedback, they often fall short in recognising the emotional dynamics crucial to the learning process.

Empathic PCAs, as highlighted in Ortega-Ochoa, Arguedas and Daradoumis (2024[70]), are powered by natural language processing (NLP) and machine learning algorithms that analyse verbal or written input from students. These agents are designed to detect emotional cues during interactions, adjusting their responses accordingly. In some cases, students interact with PCAs through written communication, such as typing answers or responses to questions, while in others, PCAs engage students through spoken dialogue.

Ortega-Ochoa, Arguedas and Daradoumis (2024[70]) specifically addressed the focus on how PCAs can integrate emotional intelligence with formative assessment, aiming to offer not only cognitive but also emotional support to students in real-time. The primary group examined in the study consisted of primary and secondary school students, as empathic PCAs are designed to be adaptable to students' developmental stages (Ortega-Ochoa, Arguedas and Daradoumis, 2024[70]).

For example, a student struggling with a challenging math problem might express frustration verbally or in written form. The PCA, detecting this emotional cue, can provide both step-by-step guidance on solving the problem and offer motivational support, such as encouraging the student to keep trying or suggesting a brief pause if the student appears overwhelmed.

PCAs are particularly valuable in dialogic learning, where sustained interaction between the agent and the student fosters deeper comprehension and reflection. In a science class, for instance, a PCA might engage students in a reflective conversation, prompting them to explain their reasoning behind a lab experiment. As the conversation progresses, the PCA adapts its responses based on the student's understanding, offering personalised feedback that helps students correct their approach in real-time. Ortega-Ochoa et al. (2024[70]) emphasise that this continuous dialogue helps students not only process academic content but also build their confidence and emotional resilience.

However, several challenges persist with the use of empathic PCAs. A key issue is the difficulty in sustaining meaningful dialogue over time, particularly as interactions become more complex. As students' progress into more sophisticated learning tasks, the PCA's ability to maintain engagement and provide nuanced feedback diminishes. While the PCA can detect basic emotional responses like frustration, recognising and responding to more subtle or layered emotional states remains a technological challenge (Ortega-Ochoa, Arguedas and Daradoumis, 2024[70]).

Another challenge is ensuring that feedback is timely and accurate. While PCAs aim to offer immediate responses, the accuracy of the feedback can vary, especially in tasks that require precise academic interventions, such as advanced mathematics or physics problems. If the feedback is incorrect or delayed, it can frustrate students rather than support them, underscoring the importance of combining PCA feedback with teacher oversight to ensure its relevance and usefulness.

Moreover, ethical concerns arise with the deployment of PCAs, particularly around data privacy and security. Since PCAs rely heavily on processing personal and emotional data to deliver personalised feedback, there are concerns about how this data are managed, stored and used. Additionally, the use of these agents outside scheduled learning times raises questions about the boundaries of AI interaction in educational settings (Ortega-Ochoa, Arguedas and Daradoumis, 2024[70]).

Learning analytics in virtual laboratories for self-regulated learning

Learning analytics (LA) has the potential to enhance self-regulated learning (SRL) in STEM education by providing real-time feedback, supporting iterative experimentation and tracking student behaviour in virtual lab environments. Through these features, LA can empower students to take control of their learning, refine their approaches based on data-driven insights and collaborate more effectively in group settings. The systematic review by Elmoazen et al. (2023[71]) highlights how AI-based LA tools, when integrated into virtual laboratories, can track student behaviour, offer immediate feedback and promote self-regulation by helping students reflect on their performance and adjust strategies accordingly. AI-based tools in Elmoazen et al. (2023[71]) refer to the use of AI techniques such as process mining, sequence mining and clustering to analyse student interaction patterns, categorise behaviours and provide tailored support within virtual laboratories.

In virtual labs, LA tools have the potential to track student behaviour by collecting log data, such as the time spent on each task, interactions with virtual lab tools and individual or group collaboration. For instance, these systems might monitor how long a student engages with a specific step in a chemistry experiment, offering detailed insights into student performance and engagement. This data allows teachers and students to better understand learning patterns and make necessary adjustments during the learning process (Elmoazen et al., 2023[71]).

Another key application of LA tools in virtual labs is their ability to provide real-time feedback. For example, if a student makes an error during a physics simulation, the system can immediately notify the student and provide corrective suggestions. This allows students to adjust their strategies as they engage in the experiment, promoting a more responsive and reflective learning process (Elmoazen et al., 2023[71]).

LA tools also support iterative experimentation by allowing students to perform multiple trials of the same experiment, analyse results and refine their approaches based on feedback. This iterative process encourages a deeper understanding of scientific concepts, as students can repeatedly engage with the material and explore various solutions without the limitations of physical lab environments (Elmoazen et al., 2023[71]). A further advantage is the promotion of self-regulated learning. LA tools support students in setting learning goals, monitoring their progress and refining their strategies based on the feedback provided. This is especially beneficial in STEM education, where developing problem-solving skills and independent learning abilities is crucial (Elmoazen et al., 2023[71]).

Despite these benefits, Elmoazen and colleagues (2023[71]) outlined several challenges exist with the use of LA in virtual labs. One significant challenge is the complexity of interpreting the feedback generated by these tools. Students may find it difficult to understand the data provided without clear guidance, which can lead to confusion and limit the effectiveness of the feedback. Another challenge is the fragmentation of virtual lab platforms, with each platform using different tools and methods, making it hard to standardise feedback and learning interventions. Additionally, LA tools often fail to capture emotional and motivational data, which are essential for maintaining student engagement, particularly in challenging scientific tasks.

Learning analytics in support of inclusiveness

AI-based learning analytics have shown potential to improve inclusiveness in education by addressing the needs of students with disabilities and marginalised groups. The systematic review by Khalil, Slade and Prinsloo (2023[72]) highlights how learning analytics can be used in pre-higher education and higher education settings to track student interactions, provide real-time interventions and improve retention rates for disadvantaged students. The review emphasises that the integration of learning analytics has been particularly useful for offering accommodations, such as captions for hearing-impaired students or personalised learning paths for those with learning difficulties. By monitoring student behaviour, such as log-ins, task completion and time spent on activities, these systems can help ensure that all students receive the support they need to succeed.

One significant success factor identified is the ability of learning analytics to provide personalised interventions. Real-time support allows students to stay on track and receive immediate assistance when they encounter difficulties. For example, a student with dyslexia might receive text-to-speech options for reading assignments, helping them to manage their learning more effectively. Furthermore, predictive analytics is another key element, allowing early identification of students at risk of falling behind, thus enabling timely interventions (Khalil, Slade and Prinsloo, 2023[72]). These processes contribute to creating a more inclusive learning environment by reducing disparities and promoting equity.

However, the study also identifies several challenges. One of the most significant is the inconsistent use of learning analytics across different institutions, which can lead to gaps in the support provided to disadvantaged students. Additionally, while learning analytics systems can collect vast amounts of data, educators may struggle to interpret this data effectively and apply meaningful interventions. Furthermore, the ethical implications surrounding data privacy and usage without proper consent pose challenges that must be addressed to ensure that students' rights are protected (Khalil, Slade and Prinsloo, 2023[72]).

Summary

This chapter examined the transformative role of AI-driven assessment and learning analytics in primary and secondary education. These technologies can provide immediate, personalised feedback, support data-driven instruction and promote inclusiveness for diverse learners. They also offer cognitive and emotional support through tools like conversational agents, real-time feedback systems and automated assessment technologies, particularly within collaborative and self-regulated contexts.

Despite these advances, challenges remain. AI still struggles to capture social and emotional dimensions, and issues of privacy, bias and digital literacy persist. Teacher involvement is therefore essential, not only to ensure accuracy and equity, but also to safeguard the ethical use of technology and maintain the social and emotional aspects of education. Balancing digital and analogue tools is likewise important to manage cognitive load and support students in complex tasks.

Table 7.2. Summary of artificial intelligence and learning analytics tools

Category	Successful processes	Challenges
Sub-tool selection and outcomes	• Enhances formative assessment by providing students with immediate, personalised feedback that can improve engagement. • Automates grading for certain task types, which can reduce teacher workload and increase objectivity by applying evaluation criteria uniformly.	• Struggles to evaluate creativity, nuance and complex open-ended responses that require human judgment. • The factual accuracy and relevance of generative AI feedback can be inconsistent and may require verification by the teacher.
Educational level applications	• Tools like learner response systems and conversational agents are designed to be adaptable for use across both primary and secondary education.	• The novelty of gamified AI assessment systems (e.g. Kahoot) may wear off over time, leading to reduced student engagement.
Subject-specific applications	• Particularly useful in STEM, mathematics and reading for providing immediate feedback on specific, structured skills. • Automated Writing Evaluation (AWE) can be applied across many subjects to provide feedback on grammar and structure.	• The effectiveness is limited in assessing subjects that require high levels of creativity or nuanced interpretation, such as the arts and humanities.
Teacher support and role	• Augments teaching by handling routine tasks, freeing educators to focus on more complex instructional responsibilities and direct student support. • Combining digital assessments with analogue tools (e.g. scratch paper) is an effective strategy for managing cognitive load.	• AI should be used to support, not replace, professional teacher judgment and interaction. • Teacher involvement is essential for interpreting AI-generated data, guiding students on its ethical use and making meaningful instructional adjustments.
Equity and diversity considerations	• Can support equitable evaluation by reducing human biases in grading if designed and used transparently. • Provides personalised accommodations (e.g. text-to-speech, captions) and learning paths to support students with disabilities.	• Data privacy, student consent and the risk of algorithmic bias reinforcing societal inequities are significant ethical hurdles. • If AI models are trained on biased data, they risk amplifying societal inequalities in their evaluations. • Significant disparities in students' digital literacy can create an 'AI divide', leading to unequal learning outcomes.
Assessment and feedback	• Learning analytics can identify at-risk students, allowing for proactive and timely interventions. • Real-time feedback enhances engagement, motivation and supports self-regulated learning.	• Complex data dashboards can be difficult for teachers and students to interpret and act upon without clear guidance. • AI-driven feedback often lacks crucial social and emotional nuance, focusing primarily on cognitive data.

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