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Visual Learning Analytics for Educational Interventions in Primary and Secondary Schools: A Scoping Review

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Abstract

Visual Learning Analytics (VLA) uses analytics to monitor and assess educational data by combining visual and automated analysis to provide educational explanations. Such tools could aid teachers in primary and secondary schools in making pedagogical decisions, however, the evidence of their effectiveness and benefits is still limited. With this scoping review, we provide a comprehensive overview of related research on proposed VLA methods, as well as identifying any gaps in the literature that could assist in describing new and helpful directions to the field. This review searched all relevant articles in five accessible databases — Scopus, Web of Science, ERIC, ACM, and IEEE Xplore — using 40 keywords. These studies were mapped, categorized, and summarized based on their objectives, the collected data, the intervention approaches employed, and the results obtained. The results determined what affordances the VLA tools allowed, what kind of visualizations were used to inform teachers and students, and, more importantly, positive evidence of educational interventions. We conclude that there are moderate-to-clear learning improvements within the limit of the studies' interventions to support the use of VLA tools. More systematic research is needed to determine whether any learning gains are translated into long-term improvements.

Notes for Practice

- VLA tools integrate visual and automated analysis to enhance educational decision-making in primary and secondary schools, yet evidence of its effectiveness remains limited.
- This scoping review, based on Arksey and O'Malley's framework, explores VLA methods and their interventions in primary and secondary schools and highlights gaps in literature to guide future research and practice.
- Results indicate moderate-to-clear learning improvements with VLA tools in classrooms, but call for more systematic research to assess long-term impacts.

Keywords: Visual learning analytics, learning analytics dashboard, educational interventions, primary school, secondary school, scoping review, systematic review

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1. Introduction

There has been a noticeable expansion in the use of digital technologies in primary and secondary education spurred by the COVID-19 pandemic. Already before the pandemic, the process of enhancing conventional methods of teaching and learning by incorporating or supplementing them with digital alternatives was ongoing. However, the evidence to support digital technology as a facilitator for teaching and learning is still modest (Delgado et al., 2015; McGrath & Åkerfeldt, 2019). Indeed, classroom implementation of any digital technologies remains a challenge, requiring teachers to understand their own professional growth and to endure rapidly evolving digital technologies (Kimmons et al., 2020). Nonetheless, the use of digital technology in education makes it possible to gather a wide range of data about students. Educational data include text answers, quizzes, numbers, timestamps, user data, and the behavioural-use data of digital learning materials or platforms used in the classrooms. The data produced can be scrutinized using learning analytics (LA), providing insights into the educational advancement of individual students or groups, but it can be considerable, and its visualization or analysis can be difficult to make sense of for teachers (Vieira et al., 2018). Therefore, LA methods have been developed to aid sensemaking of educational data (Larrabee Sønderlund et al., 2019). LA is defined as "the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Siemens & Baker, 2012, p. 1).

LA can support teachers in making informed instructional choices by presenting the information on Visual Learning Analytics (VLA) tools or Learning Analytics Dashboards (LADs). Nonetheless, the tangible benefits that VLA tools offer to teachers and students in the classroom setting are still relatively under-documented (Viberg & Grönlund, 2021). Despite this, their usage is deemed logically justifiable due to their capabilities or affordances that can enhance effective teaching and learning methods (Yeung et al., 2021). For instance, a video made accessible to students in their native language, with subtitles in another language, allows for a greater level of control by the user. Reviewing content aids in repetition and reinforcement, while the presence of both text and audio supports multi-sensory learning. Analyzing user data from these interactions can be presented visually for teachers, guiding their instructional strategies. However, this technical and mental integration is complex. The TPACK framework — which outlines the interaction between knowledge of technology, pedagogy, and content — suggests that successful technological integration in education requires a teacher to be proficient in all three areas (Koehler & Mishra, 2009). Consequently, the effective incorporation of digital technology necessitates the cultivation of several competencies and skills (Vuorikari et al., 2022). With a broader use of VLA tools in primary and secondary classrooms (Masiello et al., 2024), it is therefore urgent to comprehend how to optimize the affordances of LA in educational settings in an ethical and inclusive manner so that teachers can effectively integrate a VLA tool into the classroom and use its affordances to make data-informed pedagogical decisions to aid learning. The realization of knowledge gaps through this review of the field can provide a research direction. More importantly, this review can provide teachers with insights about how to capitalize on LA and its visualizations to improve teaching and learning processes and outcomes. Therefore, this paper addresses the state-of-the-art knowledge about LA and its visualization research, that is, visualization techniques that are part of LADs or VLA tools and are used to afford information that directly contributes to teaching and learning activities.

1.1. LA and Its Affordances

VLA tools are defined by Schwendimann et al. (2017) as "a single display that aggregates different indicators about learner(s), learning process(es) and/or learning context(s) into one or multiple visualizations" (p. 8). They are developed with the intention to increase motivation, self-direction, learning effectiveness, performance of students, and teacher engagement (Verbert et al., 2013). With the broader use of these technologies, it becomes necessary for teachers to gain data literacy, that is, the ability to use data for decision-making, including the ability to identify, collect, analyze, and act on the knowledge generated from data (Kippers et al., 2018). As with LA, an important aspect of VLA is its use or affordance. The term affordance refers to "the perceived and actual property of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (Norman, 2002, p. 9). In our case, affordance is the relationship between the properties of a VLA tool (e.g., a visualization showing progress over time) and the capabilities of the teacher or student (i.e., their skills and competences) that determines just how visualizations could possibly be used or interacted with. A recent review states that the most common affordances for university students interacting with VLA tools are comparisons, awareness, and monitoring affordances that describe practice (Paulsen & Lindsay, 2024). Other less explored affordances are recommendation, feedback, reflection, and goal setting, which are pedagogical concepts related to learning activities in the classroom (Paulsen & Lindsay, 2024). A study that looked at university educators (teachers, tutors, and facilitators) found similarly that affordances of LA are to understand practice, that is, student performance and prediction of performance (Farrell et al., 2017). Other affordances are also to understand and possibly modify learning design, student engagement and motivation, and social interaction between students (Farrell et al., 2017). As Farrell et al. (2017) suggest, educators seek data that suits their specific position within their institution, aligns with their domain subject and teaching approach, and fulfills their unique requirements related to these aspects. Thus, we interpret LA affordances as being shaped by teacher–student interaction: their activities and needs regarding visualizations, specific content, and the learning environment itself. To explore the integration of VLA tools that directly contribute to teaching and learning activities, we used the TPACK framework to elicit technical and pedagogical affordances of VLA tools. This enabled us to analyze what LA affordances are expressed in different educational contexts, how teachers and students choose to use the VLA tools when teaching and learning, how teaching and learning interventions led by the affordances of LA are accomplished, and their possible impact on teaching and learning.

1.2. VLA Tools in Education

VLA tools are slowly becoming an integral part of teaching and learning at all levels, especially in higher education (Sahin & Ifenthaler, 2021). With proper data literacy skills, teachers can execute analytical tasks, identify interesting features in data, and better understand student needs. For instance, Govaerts et al. (2012) developed the student activity meter to visualize student time spent and resource use to support awareness for teachers and students about how students spend their time. Mohseni et al. (2022) proposed the Similarity-Based Grouping Tool (SBGTool v2.0) to aid teachers in grouping students based on similar learning outcomes and activities, finding the link between student involvement and success, and using the number of correct answers and student answers to maximize the collaborative learning potential in the classroom. Despite the positive results, data literacy seems to be a prerequisite for making these VLA tools effective. These are just a few examples from the large body of LA research focusing on students and teachers in higher education. The lower grades are significantly less researched (Apiola et al., 2022). Nevertheless, longitudinal research in primary and secondary education have demonstrated that earlier knowledge is necessary for building later knowledge, and interventions at earlier ages can contribute to lasting results (Watts et al., 2014). In addition, while research on the use of VLA tools in the classroom has increased rapidly during the last decade (Valle et al., 2021), there is still a lack of research on how an intervention with data visualization has had an impact on pedagogical practice and learning in primary and secondary education (Viberg & Grönlund, 2021).

This study aims, therefore, to synthesize the evidence of teaching and learning interventions in relation to the use of VLA tools in primary and secondary education. We address this knowledge gap with a systematic scoping review on the topic, that is, VLA visualization techniques used to provide, or afford, information that directly contributes to teaching and learning activities. For instance, the visual information might show how students are progressing, their learning trajectory (LT), how their learning outcomes compare to one another, and how they are similar to or different from one another. Such visual information can then be used by the teacher (technological knowledge), for example, to help one student focus on the task at hand (pedagogical knowledge), to help another student get more advanced exercises (content knowledge) before losing motivation, to group several students together so that they can support each other (pedagogical knowledge), and to guide one student toward fulfillment of the learning objectives (pedagogical and content knowledges) in order to get a final mark.

The rest of the article is organized as follows: section 2 describes the research methodology, section 3 presents the findings, section 4 discusses the findings, section 5 provides a general discussion, and section 6 concludes the paper.

2. Review Methodology

Scoping reviews (Arksey & O'Malley, 2005) are systematic literature reviews that summarize research in a variety of fields, including healthcare and education, and with a variety of methods. The scoping review allows for the discovery of gaps in the evidence base where little or no previous research has been done, as well as determining the necessity for a possible systematic review (Arksey & O'Malley, 2005). The authors argue that a scoping review is a reliable strategy for discovering primary and secondary literature sources. Moreover, the same authors have claimed that a scoping review gives meaning to the "what" and "why" explanations of inquiry, rather than the "who, where, and how," and provides a complete overview of the research under question. This scoping review followed the Arksey and O'Malley's five-stage framework: 1) identifying the research questions using the SPICE model (SBU, 2016), 2) identifying relevant studies, 3) study selection, 4) charting the data and collating, and 5) summarizing and reporting the results. The next subsections describe in detail each of these steps.

2.1. Identifying the Research Questions

The authors are two researchers in information visualization (one junior and one senior), one researcher in educational technologies, and one researcher in educational science with experience in LA. The following exploratory research questions were developed to assure that a wide range of literature relevant to the topic of interest and using a variety of methods was gathered:

RQ1. What are the documented uses of VLA tools in primary and secondary education?
RQ2. What types of visualization are used?
RQ3. How are the teaching and learning interventions carried out using the VLA tools?

2.2. Identifying Relevant Studies

A broad number of keywords and search terms were used to obtain comprehensive coverage of the existing literature on the subjects of visualization, educational performance, LTs, and student behaviour modelling in primary and secondary schools. The search terms were expanded through discussion between the co-authors. Additionally, a university librarian helped in narrowing key search terms and finding databases most likely to deliver the desired results.

The SPICE model was also utilized to formulate the parts of the research questions investigated in this review: ***S****etting* (context of the study); ***P****erspective* (the user with their different values and attitudes); ***I****ntervention* (the phenomenon being studied); ***C****omparison* (which includes the process); and ***E****valuation* (which includes evaluating the results and outcomes).

Table 1 lists all the inclusion and exclusion criteria. A study was included in this scoping review only if it fulfilled all the inclusion criteria. Five electronic databases were searched: Scopus, Web of Science (WoS), Educational Resource Information Center (ERIC), Association for Computing Machinery (ACM), and Institute of Electrical and Electronics Engineers (IEEE Xplore). These five databases covered education, technology, and the research published in cross-disciplinary journals and conferences. Google Scholar was also used to search for additional records, taking all document types into account. The search process in all databases was carried out between March and June 2023, and the time frame for publications was between January 2000 and March 2023. Also, we only considered papers published in English. In the search method, the following field tags were used: "Abstract (AB)" and "Title (TI)."

Table 1. Inclusion and Exclusion Eligibility Criteria

Criteria	Specified Criteria
Inclusion	IC1: Papers that describe at least one visualization
	IC2: Papers about learning/teaching interventions (not visualizations just for research results or statistical analysis)
	IC3: Papers published in English
	IC4: Papers published between January 2000 and March 2023
	IC5: Research carried out in primary and secondary schools
	IC6: Papers that used qualitative and quantitative methods of data collection and analysis
	IC7: Research articles such as short (≥4) and full papers, proceedings papers, reviews, surveys, editorial material, early access articles, book chapters, and book reviews
	IC8: Papers about teachers and students (children aged 6–19 years old)
Exclusion	EC1: Non-English language papers
	EC2: Papers focusing on other fields than primary and secondary education
	EC3: Students older than 19 (higher education/tertiary education)
	EC4: Papers published before 2000
	EC5: Papers with fewer than 4 pages such as posters, conference abstracts, editorials, and commentaries
	EC6: Papers not focusing on teaching and learning visualizations (e.g., scientific visualizations)

Table 2. Search Results Before Removing the Duplicates

Database	Field Tags	Search results
Web of Science	Abstract	2,012
Web of Science	Title	82
Scopus	Abstract & Title	3,705
ERIC	Abstract	585
ERIC	Title	17
ACM	Abstract	168
ACM	Title	10
IEEE Xplore	Abstract	376
IEEE Xplore	Title	331
Total		7,286

NOTE: Google scholar is excluded.

The detailed search query for the five databases on *Abstract* and *Title* results is presented in Appendix A. Tables A.1 and A.2 show the number of Abstract and Title results in ERIC, respectively. EndNote X9/20 Mac from Clarivate was also used to keep track of bibliographies and references.

Figure 1 presents a high-level summary of the processes involved in performing this scoping review, as well as how the processes relate to one another. After integrating the results of the search, the number of articles found throughout the five databases was 7,286 (Table 2). Furthermore, the manual search on Google Scholar of the key terms in the study titles returned 54 additional publications, and those were integrated into the same EndNote file, for a total of 7,340.

2.3. Study Selection

Since a considerable number of articles were duplicates, 2,933 articles were deleted from the total of 7,340. Furthermore, a total of 842 publications were eliminated from the EndNote file based on a set of exclusion words. These words encompassed terms like *nurse*, *medical*, *clinical*, *business*, *engineering*, *Twitter*, *YouTube*, *Facebook*, *undergraduate*, *university*, *freshman*, *higher education*, *college*, *virtual reality*, *augmented reality*, *classification*, and *accuracy*. In addition, 3,319 publications were excluded from the list for meeting one or more of the exclusion criteria described in Table 1. The Preferred Reporting of Items for Systematic Reviews and Meta-Analyzes (PRISMA) statement was used to guide the article selection procedure (Moher et al., 2009). The PRISMA flow diagram for article selection is shown in Figure 2. The excluded articles predominantly dealt with examining student data in higher education, as well as scientific articles that employed visualization merely to present study results. Finally, the authors obtained full-text versions of 246 publications and excluded 201 of those. A reliability assessment of the remaining 45 articles was also performed, as presented below.

Forty-five papers were reviewed by all co-authors for eligibility, who were asked to provide a score (No:0 [is not met], Unsure:0.5, Yes:1 [is met]) for each of the inclusion criteria (IC1–8) for each article; each article could get a maximum score of 32, four for each IC. Studies scoring "unsure" were further reread and possibly re-scored by the reviewers in collaborative discussions. After this, articles with fewer than 32 points were eliminated because they failed to meet all the inclusion criteria. Lastly, 20 papers were found to be of relevance for the research topic. All articles excluded at the final stage failed to satisfy IC2 (*papers about learning/teaching interventions [not visualizations just for research results or statistical analysis]*) while three articles also failed to meet IC8 (*papers about teachers and students [children aged 6–19 years old]*).

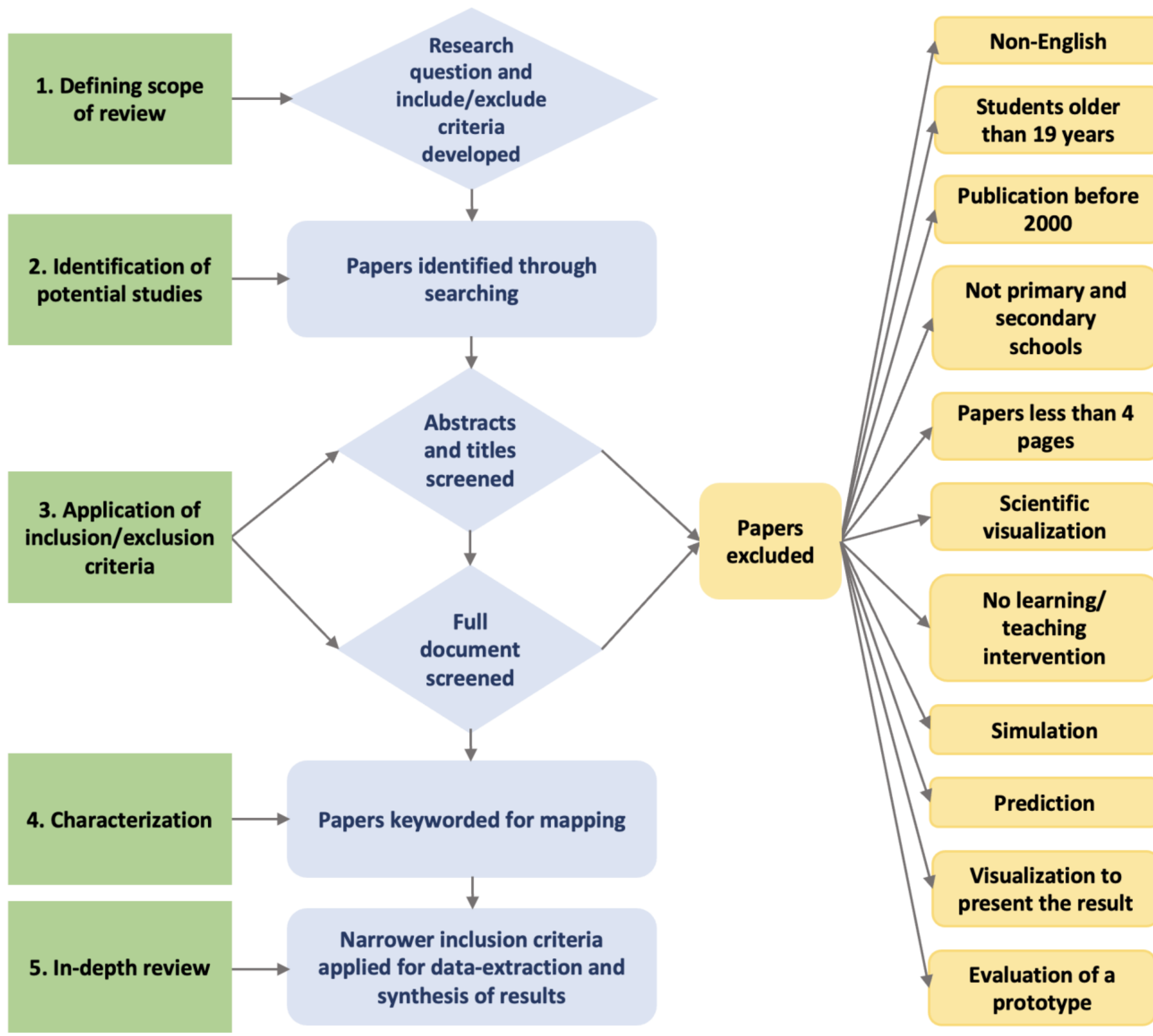

Figure 1. Review process and operationalization of methods.

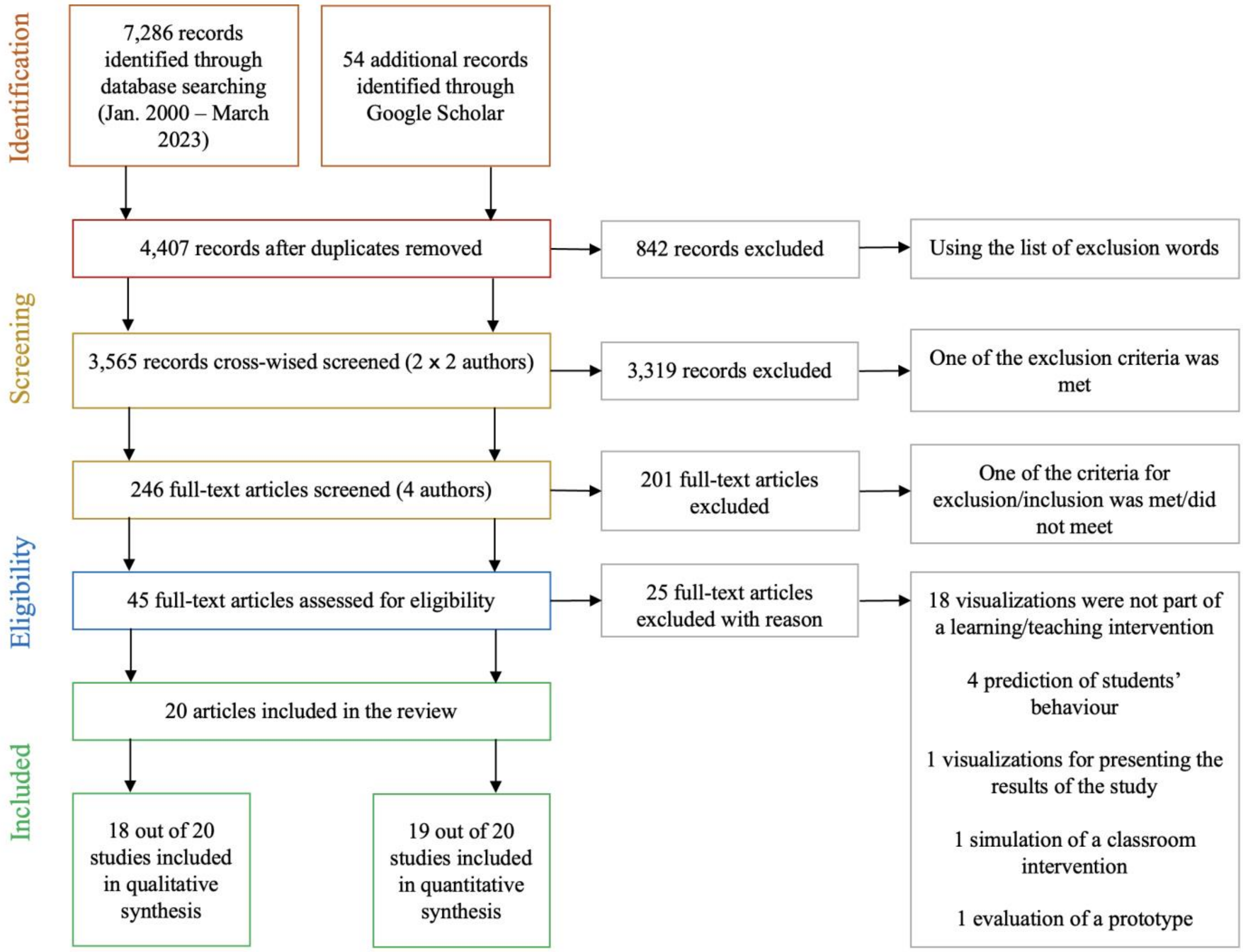

Figure 2. PRISMA flow diagram for article selection.

2.4. Data Charting and Collating

For each article, the authors extracted the following information: the author(s), year, study location, intervention, study design, population, study method(s), study aim(s), as well as a brief comment on the outcomes of the study. Data charting, collating of the studies and the study numbers are presented in Table B.1 in Appendix B.

2.5. Summarizing and Reporting Findings

The fifth and final stage of Arksey and O'Malley's scoping review framework, which summarizes and reports the findings, is described in section 3.

3. Findings

Twenty studies from 11 different countries were included in this scoping review (Figure 3). Literature from Africa and South America that fit our criteria were noticeably absent (Figures 3 and 4). A large portion of the included studies were published in 2021–2022, see Figure 5.

The VLA tools presented in the included articles are shown in Table B.2 in Appendix B with a short description of their purpose.

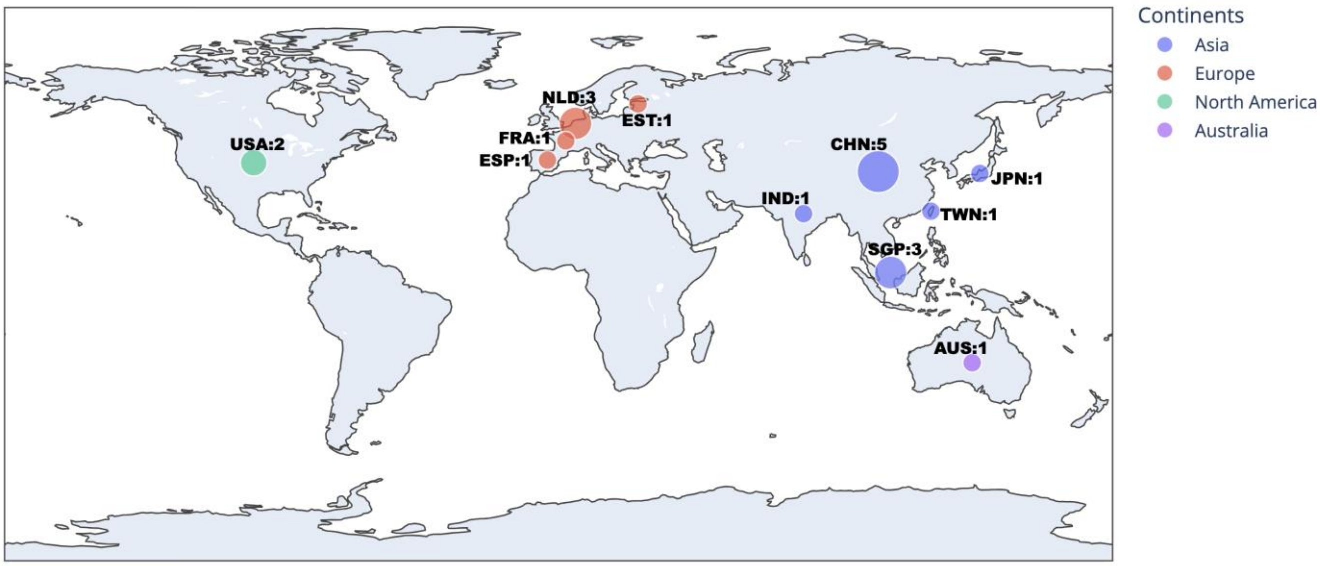

Figure 3. Division of the included articles by country.

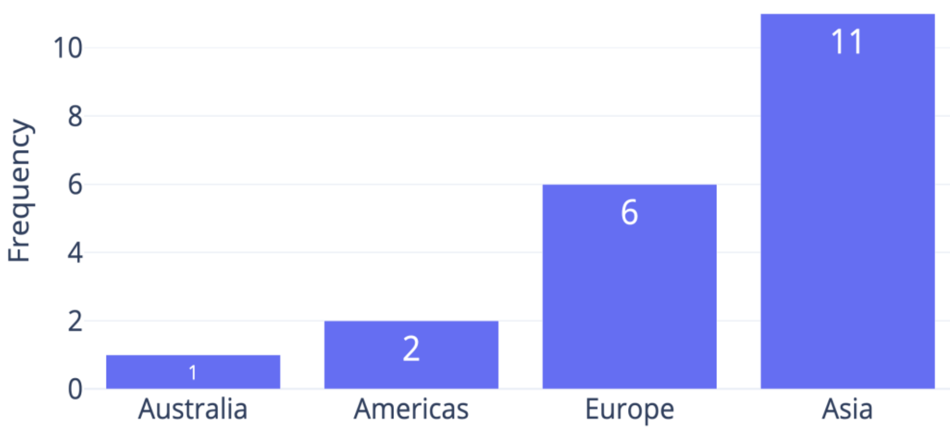

Figure 4. Number of publications by continent.

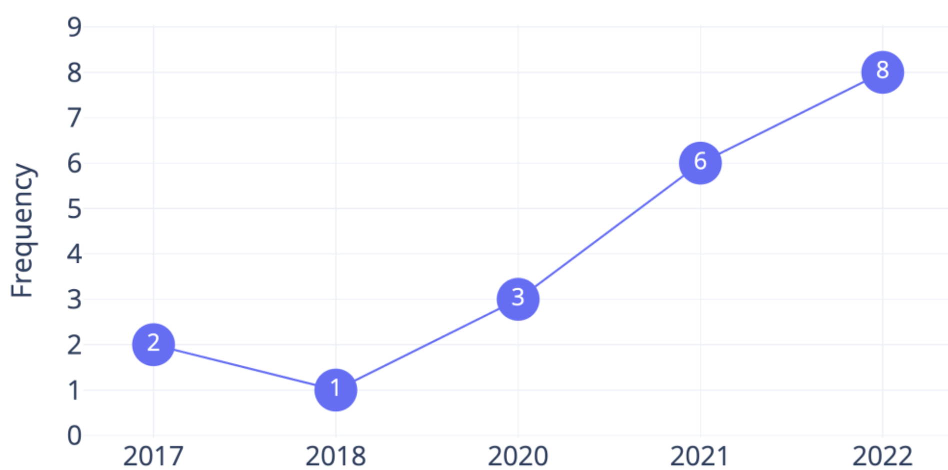

Figure 5. Number of publications by year.

3.1. Answering RQ1. What are the documented uses of VLA tools in primary and secondary education?

To explore the uses of VLA tools in primary and secondary education, we extracted the affordances of the tools pertaining to the technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) of the TPACK framework. Our analysis is summarized in Table 3. These studies underlined the diversity and breadth of applications of VLA tools in primary and secondary education, emphasizing their pivotal role in enhancing and personalizing the educational experience for both teachers and students.

Table 3. The Affordances that VLA Tools Allow Divided According to the TPACK Framework

Affordance	Description	Feature and (Study Number)
Technological Knowledge (TK):		
Adaptive Systems	Technologies that modify content or resources based on student performance or needs.	Adaptive learning in Snappet (study 3) and web-based personalized tutoring system (study 16)
Visualization Dashboards	Tools that visually present data or information, typically to monitor and analyze student progress.	Monitoring functionality (studies 1, 5); LA tool within WiREAD (study 2) and WIoTED (study 4); Personalized visualizations (study 6); Alerts in Inq-ITS (study 7), in ClassDojo (study 13), and in CWS-VINA (study 14); and student support (studies 17, 18, 20)
Integration with Existing Systems	Incorporation or embedding of new technological tools or features into pre-existing educational platforms or environments.	Moodle (study 1); IoT technologies (study 4); Online learning platform (study 5); Dydate (study 13)
Pedagogical Knowledge (PK):		
Feedback Mechanisms	Systems or methods that provide feedback, whether formative or summative, to students or teachers about learning progress or performance.	(Studies 1, 2, 4–7, 9, 10, 13–16, 18–20)
Monitoring and Intervention	The process of tracking student progress and making timely interventions to support or guide learning.	(Studies 1, 3, 5–7, 9–13, 16, 18–20)
Enhancement of Pedagogical Approaches	Research or tools focused on improving or refining teaching methods or strategies.	Connecting analysis to instructional actions (studies 1, 3–5, 7, 9–12); Examining how students used resources from learning environments (studies 2, 6, 8, 14–17, 19); Teaching and learning intervention targeting both teachers and students (studies 13, 18, 20)
Collaborative Learning	Tools or methods that promote learning through teamwork or collective efforts, often in a technology-enhanced environment.	Collaborative reading (study 2); Collaborative learning (studies 4, 18); Peer tutoring (study 5); Collaborative educational game (study 11); Group awareness (studies 14, 15); Collaboration and group awareness (Socially shared regulated learning) (study 20)
Student Engagement	Tools or research aimed at understanding, promoting, or monitoring student engagement in the learning process.	(Studies 1, 4, 16)
Content Knowledge (CK):		
Subject-Specific Focus	Research or tools that emphasize a specific academic subject or discipline, such as mathematics, reading, or science.	Science lessons (studies 1, 16); Critical reading (study 2); Math and spelling (study 3); French grammar and spelling (study 5); Arithmetic (study 6); Science inquiry (study 7); Mathematics (studies 8, 13); Human circulatory system (study 9); STEM (study 10); English vocabulary (studies 11, 19); Collaborative English writing (14); Electricity (study 17); Leveraging video-based content (study 18)
Skill Development	Focus on enhancing specific skills, such as critical reading, vocabulary acquisition, or time management.	Critical reading skills (study 2); Teachers' use of VLA tool (studies 3, 5); Self-regulated learning (studies 2, 6, 16, 17, 19); Note taking (study 8); Inquired based learning (study 10); Learning progression (study 12); Effective learning strategies (study 13); Collaborative problem-solving (study 15); Time management (study 17); Collaborative work (study 20)

3.2. Answering RQ2. What types of visualization are used?

Various visualization techniques were used in the included articles as part of VLA tools. Table 4 summarizes the visualization techniques used in relation to the target users, the discipline in which the tool is used, and the VLA tool.

Table 4. Summary and Comparison of the Visualization Techniques Used in the VLA Tools

Visualizations techniques																Target Users	Discipline	(Study number) & VLA tool
✓					✓											Teacher	Science	(1) Moodle-based
✓	✓		✓	✓							✓					Student	English	(2) WiREAD
							✓	✓								Teacher	Mathematics	(3) Snappet
	✓		✓									✓				Teacher	English (spelling)	(4) WIoTED
✓			✓		✓					✓						Teacher	French (grammar & spelling)	(5) PROGDASH
✓	✓		✓					✓								Student	Mathematics	(6) PVs
✓	✓			✓												Teacher	Science	(7) Inq-Blotter
							✓		✓							Student	Mathematics	(8) NoTAS
✓	✓	✓		✓												Teacher	Science	(9) IPR
✓	✓	✓								✓						Teacher	STEM	(10) ADA
✓						✓										Teacher	English	(11) Learning dashboards
✓		✓	✓													Teacher	Mathematics	(12) BASS & Wright Map
✓		✓				✓									✓	Student & teacher	Mathematics	(13) ClassDojo & Dydate
		✓		✓					✓							Student	Language	(14) CWS–VINA
✓					✓									✓		Student	Mathematics	(15) iTalk–iSee
✓	✓															Student	English, Mathematics & Science	(16) Web-based personalized tutoring system
✓	✓															Student	Mechanics, electrical engineering	(17) Visualization and Reflection Tool
	✓	✓											✓			Student & teacher	Mathematics & General studies	(18) VBVL
✓						✓										Student	English	(19) Vocab+
✓				✓	✓		✓									Student & teacher	Vocational training	(20) K–12 LAD

: Bar chart; : Network diagram; : DM techniques; : ML techniques
: Textual feedback; : Table; : Text highlight; : Discussion forum
: Scatter plot; : Pie chart; : Histogram; : Five-pointed star
: Line chart; : Heatmap; : Radar chart; : Treemap

3.3. Answering RQ3. How are the teaching and learning interventions carried out using the VLA tools?

The interventions, designed by the authors and carried out with the VLA tools, resulted in several learning effects. These are presented in Table 5, together with the scientific methods used to collect the data.

Study 1 evaluated the suggested LA tool on 53 students from two fifth-grade classes over the course of one semester, with 26 students in the experimental group and 27 students in the control group. Researchers observed science lessons and conducted teacher interviews afterward. Although this study met the criteria for our scoping review, one weakness is that the learning intervention was not explicitly described in the study outcomes.

Study 2 investigated how students made sense of the WiREAD's VLA tool components and visualizations by comparing the influence of WiREAD's collaborative critical reading and VLA tool affordances on student learning outcomes (three WiREAD classes, N=116, Grade 9, 15-year-olds) to a control group (three classes, N=92, Grade 9, 15-year-olds) at the start and end of a 16-week term (two semesters) in a Singapore high school. The study also included the participation of three English language teachers.

In study 3, teachers (N=38) were invited to elaborate on how they reflected on and made sense of the information on the dashboard in stimulated recall interviews. The participating teachers worked with students ranging from Grade 2 (8-year-olds) to Grade 6 (12-year-olds). During a 50-minute mathematics lecture, students did math on a tablet using the Snappet software, and each teacher was observed. The software gathered data on student performance and displayed it to teachers on dashboards. Teachers used the dashboards to get real-time information about their students' skills, progress, performance, and errors. The dashboard provided the possibility to improve educational effectiveness through influencing teachers' daily teaching practices.

Study 4 employed WIoTED to track and analyze 395 tasks accomplished by 18 students aged 13 to 15 (12 boys and six girls) during their first year of secondary school in Spain. When a student was engaged in classroom learning activities, the system recorded information on the type of student interaction, time, progress, and so on. The study also included the participation of three teachers.

In study 5, researchers interviewed 17 teachers, with the interviews lasting between 30 and 50 minutes. They also administered a questionnaire. The questionnaire and interviews focused on 1) teachers' overall perceptions of PROGDASH and 2) how they used the instrument in practice. Thirteen of the 17 teachers viewed the dashboard three or more times to monitor student activities on the learning platform, according to log data. Also, seven of the 13 teachers who examined PROGDASH on a regular basis said they did so to prepare a debriefing in their diaries. The teachers also utilized it to make changes to their lesson plans, assign work, and organize classroom activities (e.g., peer tutoring).

In study 6, three classes were randomly assigned to the experimental condition (n=60), and two to the control condition (n=32). After exclusion, 71 students remained in the study. On three consecutive days, students were taught and practised three arithmetic subskills in three 55-minute lessons. The students in the experimental condition began their lesson by using the learning path application, which provided them with three PVs to help them regulate their emotions. First, the students clicked on the dolphin icon (chosen in this study by the researchers) of a certain math subskill in the overview screen. At the beginning of each lesson, the students could then establish learning goals in the goal-setting screen. Thereafter, the students could observe their progress on the overview and goal setting screens at the start of the next lesson, communicated by the dolphin's position. Third, the students returned to the goal-setting screen after clicking on the dolphin, which now displayed more detailed information about the student's progress. Finally, the students were taken to the learning path screen when they clicked on the progress bar to see the learning routes for the subskill they had chosen.

Table 5. Outcomes of VLA Interventions with Respective Method of Analysis

Outcomes of intervention	Scientific methods	Study number
• Task and process feedback was frequently used following dashboard consultation and supported the teachers in their pedagogical decision-making. • Improvement in terms of score for the group using the VLA tool.	Quantitative and qualitative data taken from observations, teacher interviews, pre- and post-testing with control group.	(1)
• Fostered greater self-awareness and self-regulatory learning dispositions. • Increased learning motivation and engagement. • Promoted connective literacy among students. • Improved students' EL reading skills. • Enhanced understanding of broader 21C literacies.	Quantitative and qualitative data taken from pre- and post-tests with control group, self-reported questionnaires, qualitative feedback forms, and focus groups.	(2)
• Influenced teachers' pedagogical actions. • Frequent actions included progress and task feedback. • A quarter of dashboard discussions resulted in no specific teacher response. Dashboards were used to verify teacher assessments of student and class progress.	Quantitative and qualitative data taken from observations and teacher interviews, stimulated recall interviews, analysis of dashboard impact	(3)
• Detected various student behaviour patterns. • Demonstrated improvement of learning outcomes and motivation in developing foreign language skills. • Provided a better understanding of engagement progress in schools.	Quantitative data taken from experiments and observations, analysis of student interactions and tasks	(4)
• Supported teachers in using a curriculum-integrated online learning platform. • Enhanced understanding of dashboard integration in teachers' practices. • Increased student self-regulation, learning motivation. • Influenced student study behaviours.	Quantitative and qualitative data taken from interviews, questionnaire, and log data analysis of student activities, analysis of teacher use.	(5)
• Better regulation of students' practice behaviour. • Reduced complex MbMLC. • Reduced students' monitoring of accuracy overestimation. • Increased students' practice behaviour management and learning transfer.	Quantitative and qualitative data taken from quasi-experimental pre- and post-test with random assigned control group. Analysis of students' practice behaviour.	(6)
• Improved science inquiry skills for students. • Enhanced student engagement and collaborative learning behaviour. • Assisted science teachers with monitoring progress through real-time alerts and visualizations.	Quantitative and qualitative data gathered from classroom observations, analysis of improvement in inquiry practice, and teacher interviews.	(7)
• Helped maintain student focus during lessons. • Improved note-taking behaviour. • Facilitated higher engagement with content and awareness of effective learning strategies.	Quantitative and qualitative data gathered from experiments of use vs. non-use, surveys, and questionnaires.	(8)
• Offered comprehensive information and support to teachers about student participation and contribution. • Allowed student knowledge building and identification of high-quality ideas during online discussions.	Quantitative and qualitative data taken from online posting and social network analysis, and observations.	(9)

Outcomes of intervention	Scientific methods	Study number
• Improved students' IBL skills. • Improved student reflection on learning. • Allowed monitoring and adaptive support. • Allowed insights into students' IBL processes.	Quantitative and qualitative data taken from questionnaires, interviews, observations, focus groups, and log data gathering.	(10)
• Improved English vocabulary learning. • Fostered collaboration among students and engagement levels. • Offered tailored learning experiences. • Provided insights into student progress. • Allowed for informed teacher intervention and understanding.	Quantitative and qualitative data taken from pre- and post-tests with control group, motivation questionnaires, interviews, and observations.	(11)
• Outlined progression of reasoning skills in students. • Teachers gained a clearer understanding of development trajectories of students' skills.	Quantitative and qualitative data taken from pre- and post-tests and observations.	(12)
• Significant improvement in learning behaviours. • Facilitated student understanding of mathematical concept, problem-solving skills, and motivation. • Helped teachers explain complex concept in an easier manner.	Quantitative and qualitative data taken from pre- and post-tests with control group, questionnaires, and observations.	(13)
• Improved student writing performance compared to those who did not use the tool, especially for those with lower prerequisites. • Increased collaborative skills. • Influenced student attitudes toward the technology. • Facilitated teachers' group assignment. • Allowed monitoring for additional support.	Quantitative and qualitative data taken from pre- and post-tests, questionnaires, and interviews.	(14)
• Improved collaborative problem-solving skills. Fostered increased participation, engagement, and effective peer talk techniques. • Allowed teachers' insights into quality of group discussion.	Quantitative and qualitative data taken from focus groups, surveys, and interviews.	(15)
• Improved student learning performance. • Positive correlation between student engagement with the tool and their learning outcomes. • Led to personalized learning experience and enhanced motivation. • Allowed teacher monitoring, customization of learning material, and informed pedagogical decision-making.	Quantitative and qualitative data taken from randomized control trial pre- and post-tests and observations.	(16)
• Improved students' time-management skills and task completion times. • Allowed teachers to identify struggling students.	Quantitative and qualitative data taken from pre-, intervention, and post-tests with control group, and reflections.	(17)
• Enhanced student learning performance and self-regulated learning behaviours. • Increased engagement, participation, and comprehension of complex topics. • Enhanced remote teaching. • Identified students in need of additional support.	Quantitative and qualitative data taken from pre- and post-tests with control group, interviews, and questionnaires.	(18)
• Improved vocabulary learning performance. • Linked self-regulated learning behaviours to better vocabulary learning outcomes. • Teachers could identify students in need of additional support.	Quantitative data taken from pre-, mid-, and post-vocabulary tests, and data analysis of logs and tests.	(19)
• Improved students' collaborative problem-solving skills. • Increased awareness of individual and collective contribution to team tasks. • Allowed teachers monitoring and assessment. • Enabled teachers to identify students in need of additional support.	Quantitative and qualitative data taken from surveys, interviews, observations, and data analysis.	(20)

Study 7 determined if students made progress in inquiry practices, with the assistance of a teacher utilizing Inq-Blotter. Two eighth-grade teachers, 91 students who completed a number of activities and received help by the teacher, and 35 students in a control group who did not receive any help took part in the research. The objective was to determine whether students showed improvement in an inquiry practice after receiving help from the teacher, and whether this improvement was sustained across multiple activities.

Study 8 conducted a survey among two classes of first-year high school students studying mathematics, comprising 89 students in total, including 34 males and 55 females. The number of valid responses amounted to 86. Both students and teachers were equipped with their own tablet devices (either Surface Go or iPad 7) and tablet pens. The first class utilized the learning visualization function of NoTAS (referred to as "visualization"), while the second class did not use this function (referred to as "non-visualization"). The design of the classes aimed to eliminate any novelty or order effects. Additionally, prior to the survey, two practice sessions were held in both classes to help the students become familiar with NoTAS.

Study 9 evaluated the IPR by involving a group of 20 eighth-grade students. This assessment was conducted over a two-week period under the instruction of an experienced teacher. The students used Knowledge Forum (Scardamalia, 2004), an online discussion platform that facilitates knowledge building. The study gathered a total of 101 online postings (notes) written by students. These entries encompassed their thoughts, conversations, and arguments concerning a genuine problem directly linked to the science subject matter of the "human circulatory system."

The three iterations done in study 10 in the ADA solution encompassed a survey study, eight case studies examining the implementation of IBL in real classrooms, four teacher workshops, and an analysis of the utilization of the Go-Lab authoring platform. Furthermore, the research actively involved a total of 95 STEM (science, technology, engineering, and mathematics) teachers. The first iteration with 21 teachers was purely exploratory to gain a better understanding of their learning environments. A second iteration with 9 teachers and 28 Go-Lab experts aimed to 1) uncover additional teacher needs that arose during the actual use of the technologies in classrooms, 2) prioritize the list of needs, and 3) evaluate the suitability of initial ADA solutions for addressing those needs. In the third iteration with 34 Go-Lab experts and 22 teachers, the initial ADA solutions were refined. The actual adoption of ADA solutions among the 15,894 teachers who created ILSs over a four-year period was analyzed.

A pilot study was carried out in study 11. A total of 31 sixth-grade primary school students, consisting of 70% boys and 30% girls, participated in the study. They were randomly assigned to either the experimental group or the control group. The teacher began the session by introducing the game to the students in both experimental and control groups, allocating fifteen minutes for each group. Subsequently, the students in both groups spent forty-five minutes responding to a pre-test and a pre-motivation questionnaire, assessing their prior knowledge and motivation regarding English vocabulary. Following this, the students in the experimental group used the smart collaborative educational game, integrated with LA, for learning English, while the control group used the non-smart version of the educational game, lacking LA.

To estimate the item parameters presented in study 12, researchers utilized data obtained from both the pre-test and the post-test. A sample of 1,002 middle school students were involved in calibrating the learning progression. Then, a sixth-grade teacher conducted four replications of the learning progression, with a total of four classes and involving 93 students.

Study 13 conducted teaching practice research in mathematics at a primary school in Guangzhou, China. The study involved a total of 71 students from Grade 4, with Class 1 and Class 2 being the focus of the investigation. Class 1 Grade 4 was designated as the experimental group, while Class 2 Grade 4 served as the control group. The number of teachers participating in the study was not specified. To facilitate the research, four fourth-grade mathematics lessons were selected as the experimental vehicle, with additional data visualization tools incorporated based on the teaching context.

Quasi-experimental study 14 recruited 50 eighth-grade students from a junior high school in Taipei City to participate in an instructional experiment on collaborative writing. The students were grouped heterogeneously into collaborative writing groups based on their prior writing abilities as assessed in their school examination. Each group comprised 4–6 students. The experimental group, consisting of 26 students (11 males and 15 females), utilized CWS-VINA for collaborative writing, while the control group, comprising 24 students (8 males and 16 females), used a CWS-NVINA. The experimental process consisted of three stages: the preparation stage, the activity stage, and the feedback stage.

Participants for Hu’s study 15 were recruited from a low-ranking primary school located in a third-tier city in China. The school consisted of six large classes of fourth-grade students, each with approximately 60 students. To test the effectiveness of the iTalk-iSee–supported course, one class (N=59) was randomly selected. The participants, aged 9 and 10 years, comprised 59% males and 41% females.

In study 16, a randomized controlled trial was conducted at a physical tuition centre in Singapore during a school holiday to compare the impact of studying personalized content (intervention group) versus non-adaptive material (control group) on academic outcomes. The study recruited a total of 43 participants, consisting of fifth-grade primary school students from the tuition centre. To assess their existing skills, all participants were required to take a pre-test focused on three science topics. Based on the exam score, the students were ranked and randomly assigned to two study groups: the intervention group (21 students) and the control group (22 students). Both groups attended five supervised study sessions, each lasting two hours, over a two-week period. During these sessions, the intervention group studied from digital personalized worksheets, while the control group used printed generic worksheets.

Study 17 involved the participation of 40 male students enrolled in secondary vocational education in the Netherlands. These participants were first-year students from three different classes across two schools. They conducted an experimental study using a pre-test (domain knowledge test), intervention (two sessions in a digital learning environment), and post-test (domain knowledge test) design, with two different conditions. All students participated in two online learning environments, each consisting of two online labs, with eight assignments in each lab, and multimedia material providing instruction on electricity and electric power transmission.

Study 18 took place in a public primary school in Hong Kong, involving two sixth-grade classes. One class utilized the platform for their General Studies (GS) subject, while the other utilized it for mathematics. The researchers collaborated with the GS teacher and the mathematics teacher for a three-month classroom intervention, integrating the platform that supported VBVL. During lessons, both teachers utilized the record function of their video conferencing software (Zoom) to capture the sessions. Both teachers and students were encouraged to participate in the discussion forum, and the platform automatically assessed the exercises, delivering immediate feedback to the students and pre- and post-tests to assess subject knowledge.

Study 19 included 44 fourth-grade EFL (English as a foreign language) students, 20 boys and 24 girls, aged 10 and 11. The students were from a primary school located in mainland China. The data collection process involved gathering log data from the mobile app and administering pre-, mid-, and post-vocabulary tests. The study spanned approximately seven months, consisting of two phases: the pre-stage and the implementation stage. During the pre-stage, three one-hour orientations were conducted to introduce students to the Vocab+ app. In the implementation stage, students were encouraged to use the Vocab+ app outside of class time.

In study 20, a total of 21 high school students were divided into eight teams, with three to four members in each team with a designated team leader. These teams engaged in a 20-week blended learning environment with the goal of enhancing their collaboration, problem-solving, and lifelong learning skills. Throughout this period, the teacher provided coaching and guidance. The assessments were structured around three main deliverables, consisting of 26 tasks in total.

4. Discussion

Our scoping review summarizes the documented use of VLA tools in primary and secondary education, exploring affordances based on the TPACK framework. It details the visualizations employed, interventions made by authors for student and teacher outcomes, and highlights a broad application of VLA tools for monitoring, guiding pedagogical actions, and skill development across subjects. The 20 included articles emphasize the prevalent use of simple visualizations (e.g., bar charts, scatter plots, and line charts) for reporting educational data. Overall, these studies suggest positive and moderate effects of VLA tool usage by teachers and students, enhancing learning processes, outcomes, skills, and self-regulatory practices. Teachers, too, are impacted, showing development in educational processes and teaching practices.

Several systematic reviews enhance our understanding of effective VLA tool usage in higher education (Larrabee Sønderlund et al., 2019; Sahin & Ifenthaler, 2021). However, there is a scarcity of reviews on the same topic in lower education levels. Recent reviews on primary and secondary education (Apiola et al., 2022; Hirsto et al., 2022) highlight the diverse research in this domain, emphasizing the need for a stronger theoretical base and foundation for innovation. Our scoping review identified 20 studies in primary and secondary settings exploring VLA tool affordances for various knowledge domains, indicating a narrowing knowledge gap in learning/teaching interventions. This is crucial for comprehending the impact of technology on educational practices in these settings (Aguerrebere et al., 2022).

4.1. Documented Uses of VLA tools in Primary and Secondary Education (RQ1)

In terms of the technological affordances, our review shows that LA is used to provide analyses of educational data and is transformed into dashboards with mostly basic visualizations to monitor student progress and learning activities (studies 1, 2, and 4–6). Visualizations also generate alerts for teachers to initiate pedagogical actions (studies 7, 13, and 14). Dashboards not only offer visual information for students to support self-regulation (studies 17, 18, and 20) but two studies showcase adaptive systems adjusting content based on student performance or needs (studies 6 and 16). These technologies — often stand-alone or integrated into learning management systems like Moodle, Project-Voltaire, or Dydate — possess common technological affordances such as monitoring student progress, which is crucial for teachers to understand their students (Hantoobi et al., 2021; Valle et al., 2021). Monitoring also plays a role in prediction algorithms, utilizing Data Mining (DM) and Machine Learning (ML) techniques to interpret and predict student learning progress (Tomkins et al., 2016). However, the effectiveness of VLA tools relies on understanding how knowledge translates into interventions (RQ3 objective) according to Larrabee Sønderlund et al. (2019). The mere presence or technical affordance of a VLA tool is not sufficient to bring changes to educational processes; a deeper understanding of VLA tool affordances is necessary.

In terms of pedagogical affordances, our review shows that VLA tools are less likely to be used by teachers/students if they do not provide monitoring mechanisms such as formative feedback, as research has already demonstrated (Chen & Chen, 2009). This review demonstrates a clear link between pedagogical affordances and improved learning outcomes through teachers' informed use of data. Studies 1 and 13 reveal that regular use of the tool enhances teacher ability to evaluate data, leading to more varied feedback and improved student test scores. Similar positive results are observed in studies 2, 8, and 9, where students using WiREAD, IPR, and NoTAS can monitor their reading progress and idea trajectories, adjust their note taking, and achieve better results. Data-informed pedagogical practices, supported by study 17's findings on improved student time management, ensure adaptive teaching methods tailored to student needs. Study 20 further emphasizes the role of visualization and reflection in encouraging student adjustments and improvement through meaningful visual feedback.

VLA tools, as highlighted in several studies (2, 4, 5, 11, 14, 15, 18, and 20), support collaborative learning among students. These tools seamlessly integrate online learning with traditional in-class teaching, offering students the advantages of flexibility in pace and direct interaction with teachers. Our review underscores the efficacy of social network analysis, ML, DM, and MMLA techniques for analyzing collaboration, aligning with previous research (Alwahaby et al., 2022). Pedagogically, aggregating online interactions through a dashboard in the classroom can drive discussions and prompt teachers to take timely actions based on notifications and alerts. VLA tools play a crucial role in fostering proactive learning and collaboration, aligning with contemporary educational theories and the 21st century skills students need (Hirsto et al., 2022). Furthermore, these tools contribute to engaging students in the learning process, allowing teachers to implement effective pedagogical actions.

Data-informed practices lead to improved student outcomes through targeted instruction by teachers or enhanced self-awareness among students. Our review indicates efficient resource allocation, allowing teachers to focus on areas where students genuinely need help. Despite being in its infancy in primary and secondary education, research suggests that teachers should undergo competence development to effectively utilize VLA tools for pedagogical adjustments (Viberg & Grönlund, 2021). Data literacy remains a challenge, but a well-documented use of VLA tools, offering formative monitoring and feedback, can significantly impact teacher and student practices, ultimately benefiting student results.

In terms of content affordances, the review shows that VLA tools are used in specific school subjects, with Mathematics, Language, and Science being the most prominent. One reason for this is that these subject areas are prone to use problems with definitive answers (right or wrong) and therefore it is easier to collect data on student performance. This is also in line with much of the published research (Reich, 2022). Accordingly, these tools are also used primarily to develop mathematical, reading and writing, vocabulary, self-regulatory, and collaborative skills. All students will need a basic understanding of numeracy and literacy, besides self-regulatory and collaborative skills, since future careers contributing to a sustainable society will require an increasing level of proficiency in these areas, which can be achieved when VLA tools are integrated into pedagogical strategies. The affordances of VLA tools take place at the intersection of all three knowledge areas, TPACK, which is important for teaching and learning with these tools.

4.2. Type of Visualizations Used (RQ2)

Our scoping review shows that common visualization techniques — such as bar charts, textual feedback, and scatter plots — are considered by many of the included studies to monitor student progress, outcomes, failure, self-awareness, Self-Regulated Learning (SRL), motivation, and more. In addition, study 9 uses network diagrams to monitor student outcomes, while also using ML techniques to identify and visualize student idea trajectories. Studies 7, 8, and 14 also monitor student outcomes but utilize network diagrams and heatmaps. Research has shown that these visualization techniques are typically employed in the field of LA (Matcha et al., 2019; Sahin & Ifenthaler, 2021).

In 12 of the studies (3, 4, 6–11, 13, 14, 16, and 19), the authors also use more advanced techniques, such as DM and ML, to visualize data. Research has shown that these advanced techniques are often employed within higher education, i.e., to analyze multidimensional SRL behaviours (Martins et al., 2019) or allow teachers to identify students with similar activity patterns (Mohseni et al., 2021b). One major issue in utilizing more advanced techniques in primary and secondary education is that the datasets are usually private and small, favouring the employment of more traditional analytics methods such as statistics, data visualization, clustering, and regression (Du et al., 2021). These advanced techniques may need more research efforts in the future.

4.3. Teaching and Learning Interventions Carried Out Using VLA Tools (RQ3)

The studies encompass a wide range of interventions, conducted online and in classrooms using VLA tools, with a varying number of subjects, ranging from as few as 18 students (study 4) and 17 teachers (study 5) to larger cohorts like 208 students (study 2). Study 12 began with 1,002 students, narrowing down to 93 based on the study design. Grade levels examined range from fourth (study 13) to unspecified grades in secondary vocational education (study 17). Intervention durations also vary widely, from a 50-minute teacher lecture (study 3) to seven months with students (study 19). Most studies employ both qualitative and quantitative analyses, with study 19 being an exception, using exclusively quantitative measures such as pre- and post-tests and log data analysis. Twelve studies, including studies 12–14, incorporate control groups, comparing statistical significance through methods like independent sample t-tests.

The articles included in this scoping review have demonstrated that when LA visualizations are integrated into teachers' educational activities, positive educational results from the interventions can be drawn.

Visualization dashboards and adaptive systems (TK) for students for monitoring, feedback (PK), and skill development (CK). The VLA tool enabled students in the experimental group to follow a personalized learning path, assess progress, and regulate practice behaviour, reducing overestimation of monitoring accuracy (study 6). Personalized visualization improved practice behaviour management, learning transfer, and corrected bias in monitoring accuracy. While a VLA tool alone may not guarantee behavioural changes (Larrabee Sønderlund et al., 2019), study 6 demonstrated its efficacy in translating knowledge into practical results based on grounded SRL theories. Similarly, study 16 found that a personalized tutoring system enhanced learning outcomes in a short intervention, outperforming conventional instruction. This aligns with previous findings supporting the effectiveness of personalized learning systems (Kim et al., 2014) and challenges the growing adoption of LA-driven strategies without sufficient evidence of their impact (Larrabee Sønderlund et al., 2019).

Visualization dashboards (TK) for students for feedback, monitoring, engagement (PK), and skill development (CK). In study 2, the VLA tool facilitated positive learning outcomes for the experimental group, including enhanced self-awareness, self-regulated learning, and increased motivation. This aligns with study 17's findings, where students improved self-awareness, SRL, and time management. Study 19 also demonstrated improved vocabulary learning through self-regulation. Valle et al.'s (2021) review connects SRL theories to LAD, contributing to cognitive outcomes. The studies suggest students effectively translate progress knowledge into practical results. While study 17 raises uncertainty, we propose a human-centric co-design approach, as advocated by Sperling et al. (2023), to ensure VLA tools positively impact student learning outcomes by considering social aspects and stakeholder values.

Our review shows that the various visualization techniques to investigate SRL in some cases show an increase in motivation and engagement to learn and perform. The pedagogy of SRL is common practice, especially in higher education, and research has already demonstrated that these results are possible in primary and secondary education too (Sahin & Ifenthaler, 2021).

Visualization dashboards (TK) support teachers in monitoring, providing feedback, and enhancing pedagogical approaches (PK), fostering skill development in specific subjects (CK). In study 1, teachers, using the VLA tool, aided students in improving learning processes and developing 21st-century skills. Similarly, in studies 3, 7, 10, and 11, teachers accessed real-time data on students' skills, progression, performance, and mistakes. Reflecting on VLA tools, teachers adjusted teaching methods to enhance educational effectiveness and student engagement, impacting instructional practices. Recent research, such as Matcha et al. (2019), emphasizes that presenting visualization elements meaningfully raises awareness of learning processes for both learners and educators. Study 10 highlights the influence of VLA tools on teacher orchestration, awareness, assessment, and reflection in a technology-enhanced environment. While authors briefly touch upon using LA for examining and improving learning designs, Hantoobi et al.'s (2021) review underscores the formative stage of LA and decision-making in education, especially in lower education levels where LA research is neglected, and further development is needed.

Study 5 found that teachers monitoring students' online activities could plan pedagogical debriefing in their diaries when using it regularly. Similarly, study 4 reported that teachers could track student progress, interactions, and other details during classroom activities, enabling informed decision-making and pedagogical actions for feedback and student involvement. Both studies yielded positive results but were inconclusive regarding learning performance benefits. Pedagogical actions and feedback, crucial in teacher skill sets for formative assessment, were highlighted in Chen and Chen's (2009) study, showing improved learning performance with digital formative feedback. Additionally, study 9 indicated that empowered teachers monitoring students' idea trajectories provided feedback in online discussions, enhancing engagement, reflection, and sensemaking.

Study 12 demonstrates the VLA tool's effectiveness in monitoring student progress, measuring conceptual change, enhancing learning, and providing assessment. The study showcases efficient monitoring through item and empirical maps, aligning item locations with student performance. Study 8 found that the feedback system enhances learning strategies and motivation, but notes limitations in the tool, such as small sample size and student complaints about functionality. Matcha et al. (2019) suggest VLA tools may be less effective without awareness of student tactics, and dashboards should enhance understanding for optimal efficacy.

Study 13, among others, reveals that through improved skills, teachers foster student responsibility, resulting in positive behaviour and the avoidance of negative conduct. Teachers closely monitor and guide student learning, intervening as needed. In the experimental group, students effectively select learning materials and methods, fostering a productive learning cycle. Recent research (Sedrakyan et al., 2020) highlights collaborative dashboards tailored for diverse objectives, integrating design principles and technologies. These dashboards aim to enhance retention, engagement, and social interactions, providing personalized course and resource recommendations for both individual and group learning purposes.

In study 18, teachers efficiently extracted video segments, initiated forum discussions for extended classroom engagement, monitored discussions, and administered auto-graded quizzes. Students received feedback and improved learning outcomes in a flipped-classroom format where multimedia materials were provided before class. The literature supports the benefits of active engagement in the flipped method, whether in-person or online (Hew et al., 2020; Kay et al., 2019). The study suggests successful integration of various tools in post-flipped classrooms, enhancing video-based learning platforms.

Our review shows findings on improved student outcomes by monitoring student progress on the platforms and providing them with feedback, both from the teachers and the VLA tools. Previous research has claimed that most studies do not go beyond the monitoring phase (Schildkamp et al., 2014), while in our scoping review we show that there is evidence, at times modest, that teachers do move beyond this phase. However, these results constitute relevance for data literacy. To make effective pedagogic use of VLA tools, recent research establishes the significance of both basic and advanced data literacy for LA targeting individuals' skill sets and organizations' opportunities to integrate data literacy for LA into courses (Mandinach & Abrams, 2022). Data literacy for LA can enhance the use of evidence in education, but the challenge remains about how to ensure that teachers not only know how to read, analyze, and interpret data visualizations, but more importantly, how to translate them into practical educational intervention (Mandinach & Abrams, 2022).

Visualization dashboards (TK) aid collaborative learning, pedagogical enhancement (PK), and skill development (CK) for teachers and students. The VLA tool in study 11 enables teachers to observe student interactions within the game, facilitating targeted interventions. Educational games, as highlighted in established literature (Amoia et al., 2012), create real-life scenarios for effective language skill acquisition. In study 20, students monitor teamwork through socially shared regulated learning (SSRL), yielding positive outcomes like enhanced self-awareness and motivation. SSRL, viewed as evenly distributed social regulation (Panadero & Järvelä, 2015), shapes through group interactions. Teachers track student progress using LAD, aligning with Valle et al.'s (2021) findings that connecting SSRL to LAD development boosts cognitive results.

Study 14 developed a VLA tool to facilitate collaborative writing among students in the experimental group, enhancing group awareness, accessibility of collaborative writing, and reducing unequal participation, thereby improving learning performance. The study also investigated variations in collaborative writing outcomes and technology acceptance among students with diverse levels of writing skills and Computer-Mediated Communication (CMC) competence. As discussed in Chen, Ouyang, and Jiao (2022), online collaborative writing is a valuable approach for engaging students in group or paired writing activities, ultimately aiming to enhance their writing skills. Awareness is emphasized as a crucial phase preceding reflection, sensemaking, and behavioural changes in the learning process (Verbert et al., 2013).

In study 15, students were able to gain insights into their group's performance by positioning their group relative to the entire class. Additionally, through utilizing the VLA tool, they have understood their individual performance by conducting comparisons within the group. This aligns with the principles of collaboration analytics, which stress the application of established educational theories to translate readily observable data at the individual level into more advanced group constructs. The goal is to produce actionable insights for groups, as proposed by Martinez-Maldonado et al. (2021).

Several studies in this review highlight the feasibility of designing VLA tools to monitor student progress and understand their behaviour with the goal of enhancing teaching and learning interventions. Matcha et al. (2019) and Viberg et al. (2018) emphasize the need for research on strategies to implement and assess the effectiveness of VLA tools. The scarcity of such research contributes to the challenges teachers face in updating their curriculum with technology, a task made more difficult by the lack of pedagogical understanding. Aligning with Koehler and Mishra's (2009) findings, this review suggests that teachers' professional development should encompass digital/technical and pedagogical skills in addition to content knowledge in their discipline.

5. General Discussion

Our research questions were broad and specific at the same time, which was a limitation of our research. However, we wanted to assess the extent of all the available evidence, and, at the same time, we were specific in our focus on the use of visualization techniques, that is, the possible effects on teaching and learning practice when the techniques are used. This is an important factor for the teachers and school principals we work with in our own research, and probably also for other practitioners. The current evidence demonstrates that only a limited number of studies show positive improvements in learning outcomes in connection to personalized instruction built on LA (Viberg et al., 2018).

This review highlights positive outcomes and trends in interventions using data visualization to impact pedagogical practice and learning in primary and secondary education. However, the 20 studies in the review, while affirming these outcomes and trends, have limitations such as small sample sizes and brief interventions, restricting the generalization of findings. Despite these constraints, they reveal an opportunity for future studies to generate more compelling evidence. Recent reviews in the LA field (Sahin & Ifenthaler, 2021; Valle et al., 2021) emphasize the need for more convincing results, particularly in the context of primary and secondary education. Recognizing the evidence gap in LA research and its pedagogical impact at these educational levels, the studies advocate for increased focus on early school grades. The included studies showcase a diverse range of technological tools, pedagogical strategies, and content areas in primary and secondary education, with the TPACK framework providing insights into how educators and researchers integrate technology, pedagogy, and content for enhanced educational outcomes.

This paper is the first scoping review to shine a light on visualization techniques that are part of VLA tools and are used to provide information that directly affords and contributes to positive teaching and learning activities in primary and secondary education, leading to moderate-to-clear learning improvements within the limit of the intervention. Unfortunately, it is difficult to determine if there are any learning gains translated into long-term improvements.

We approach the findings of this scoping review with caution, recognizing the immense diversity in digital systems and school environments observed in our own ongoing LA research in primary schools. This diversity spans culture, customs, strategies, and attitudes toward technology and data. This variability aligns with current research, emphasizing the politically sensitive role of schools in society (Aguerrebere et al., 2022). Moreover, data in primary and secondary education is fragmented across proprietary platforms, each maintaining its own information despite students using a common identification for multiple services. The various methodologies of the 20 studies also exhibit a tendency toward disparate findings, underscoring the need for a clearer roadmap in technology infrastructure, interoperability, and standardized methodologies for transparent research in LA. Our review reveals insufficient studies for a comprehensive systematic review with randomized control studies, pointing to a need for more research in these settings to provide stronger evidence on the impact of educational interventions using VLA tools.

While there is an overall agreement that LA is "happening," there is also a concern "that it is happening in a way that research will be unable to characterize" (Aguerrebere et al., 2022, p. 228). For example, LA is centrally controlled in some countries, while it is implemented in heterogeneous systems in others, making it difficult to get a comprehensive characterization (Aguerrebere et al., 2022). Nonetheless, if VLA tools were to be used more effectively by teachers with data literacy competencies, they could even be the source of curriculum transformation. What we find is an encouraging use of VLA tools, moving from the promise of what these tools can do to what they afford to improve teaching and learning in primary and secondary education.

6. Conclusion

Using VLA tools helps to provide insights and inform pedagogical actions by analyzing large amounts of heterogeneous educational data. This study presented a scoping review of the existing VLA tools with the aim of providing useful evidence about existing visualization systems and what they afford in teaching and learning interventions in primary and secondary schools. What we have learned is that current visualization tools afford monitoring, feedback mechanisms, SRL behaviour, group and individual work, and skill development in specific subjects, resulting, in several studies, in improved learning performance during the intervention phases. We have also learned that practice in the classroom can promote the understanding of how to implement VLA tools for teaching and learning. To date, there is limited evidence of obvious added value of VLA to teachers' pedagogical actions to support students with different needs. We have highlighted some of the positive evidence. We will personally focus our future research on contributing to more stringent evidence of the effectiveness of VLA tools through cluster-controlled studies, hoping to produce educational value for both teachers and students. To reach this goal, we will co-create VLA tools and co-design educational activities with school principals, teachers, students, and EdTech companies to target child-specific stages of development by presenting different levels of visual information for different pedagogical uses.

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The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author Contributions

Conceptualization, Z. M., I. M., R. M. M., and S. M.; methodology, Z. M. and I. M.; validation, I. M., R. M. M., and S. M.; formal analysis, Z. M.; investigation, Z. M.; resources, Z. M. and I. M.; data curation, Z. M.; original draft writing, Z. M.; review and editing, Z. M., I. M., R. M. M., and S. M.; visualization, Z. M.; supervision, I. M.; project administration, I. M. All authors have read and agreed to the published version of the manuscript.

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Appendix A: Search Strategy

The search query for ERIC, WoS, Scopus and ACM on *Abstract* and *Title* is presented below.

((“primary school” OR “primary education” OR “junior school*” OR “junior education” OR “elementary school*” OR “elementary education” OR “grade school*” OR “grade education” OR “secondary school*” OR “secondary education” OR “high school*”) OR (teacher OR student))*

AND

(“visual learning analytics” OR “learning analytics dashboard” OR “design study” OR visuali*ation OR “education* dashboard*” OR “learning analy*” OR “educational analytics” OR “education* data*”))*

AND

((“student performance” OR “student learning” OR “educational perform*” OR “learning achieve*” OR “student* progression” OR “learning perform*”) OR (“learning trajector*” OR “learning progression” OR “learning path*” OR trajector* OR “student behavio*r modelling” OR “learning pattern*” OR “learning sequence*” OR “learning behavio*r*” OR “learning strateg*” OR “learning outcome*” OR “Learning result*” OR “learning curve*” OR “learning activit*”))*

The following was the search query for IEEE Xplore on *Abstract*. To address the restriction on the number of wildcards, we reduced the number of asterisks to seven before doing the search. Additionally, we removed *Teacher* and *Student* from the search query to reduce the number of irrelevant documents.

(“Abstract”: “primary school” OR “primary education” OR “secondary school” OR “secondary education” OR “elementary school” OR “elementary education” OR “high school”)

AND

(“Abstract”: “visual learning analytics” OR “learning analytics dashboard” OR “learning analytics” OR visualization OR “visual analytics” OR “education dashboard” OR “educational analytics”)

AND

((“Abstract”: “student” OR “learning” OR “educational”) OR (“Abstract”: “learning trajectories” OR “learning progression” OR “learning outcome” OR “student behaviour modelling” OR “learning sequence” OR “learning behaviour” OR “learning strategy”)).

Table A.1. ERIC: Search Results on Abstract of the Publications Written in English from January 2000 to March 2023

Set	Search	Results
S1	abstract (teacher OR student)	378,658
S2	abstract (“primary school*” OR “primary education” OR “junior school*” OR “junior education” OR “elementary school*” OR “elementary education” OR “grade school*” OR “grade education” OR “secondary school*” OR “secondary education” OR “high school*”)	99,570
S3	abstract (“visual learning analytics” OR “learning analytics dashboard*” OR “design study” OR visuali*ation OR “education* dashboard*” OR “learning analy*” OR “educational analytics” OR “education* data*”)	3,939
S4	abstract (“student performance” OR “student* learning” OR “educational perform*” OR “learning achieve*” OR “student* progression” OR “learning perform*”)	23,242
S5	abstract (“learning trajector*” OR “learning progression” OR “learning path*” OR trajector* OR “student behavio*r modelling” OR “learning pattern*” OR “learning sequence*” OR “learning behavio*r*” OR “learning strateg*” OR “learning outcome*” OR “Learning result*” OR “learning curve*” OR “learning activit*”)	26,287
S6	S1 OR S2	390,783
S7	S4 OR S5	45,243
S8	S3 AND S6	2,848
S9	S7 AND S8	585

Table A.2. ERIC: Search Results on Title of the Publications Written in English from January 2020 to March 2023

Set	Search	Results
S1	title (teacher OR student)	152,927
S2	title (“primary school*” OR “primary education” OR “junior school*” OR “junior education” OR “elementary school*” OR “elementary education” OR “grade school*” OR “grade education” OR “secondary school*” OR “secondary education” OR “high school*”)	22,637
S3	title (“visual learning analytics” OR “learning analytics dashboard*” OR “design study” OR visuali*ation OR “education* dashboard*” OR “learning analy*” OR “educational analytics” OR “education* data*”)	1,116
S4	title (“student performance” OR “student* learning” OR “educational perform*” OR “learning achieve*” OR “student* progression” OR “learning perform*”)	3,880
S5	title (“learning trajector*” OR “learning progression” OR “learning path*” OR trajector* OR “student behavio*r modelling” OR “learning pattern*” OR “learning sequence*” OR “learning behavio*r*” OR “learning strateg*” OR “learning outcome*” OR “Learning result*” OR “learning curve*” OR “learning activit*”)	4,868
S6	S1 OR S2	164,691
S7	S4 OR S5	8,393
S8	S3 AND S6	290
S9	S7 AND S8	17

Appendix A: Included Studies

Table B.1. Summary of the Included Studies

(Study number) **Author details**	**Year, Location**	**Intervention**	**Study design/ population**	**Study method(s)/ Study aim(s)**	**Outcomes**
(1) Rosmansyah, Y., Kartikasari, N. and Wuryandari, A. I.	2017, Indonesia	Implementation of a simple-to-use LA tool by making changes to the Moodle online application. Science teachers and students from two control and experimental groups used the tool during a whole semester.	Quantitative and qualitative data taken from observations, teacher interviews, pre- and post-testing. Using the proposed Moodle-based LA-tool during one semester in a primary school, involving 53 students from two 5th-grade-classes.	Observations during science lessons, followed by teacher interviews. Statistical analysis used for data evaluation, pre- and post-testing. A straightforward LA tool to aid teachers in monitoring their students’ learning processes and enabling early detection of student failure.	A simple-to-use LA tool for Moodle. Task and process feedback were the pedagogical actions most often used following a dashboard consultation. Although the study meets the criteria; the learning intervention is not reflected in the result explicitly.
(2) Tan, J.P-L., Koh, E., Jonathan, C. and Yang, S.	2017, Singapore	3 classes used WiREAD for 16 weeks. WiREAD measured learning and activities components. The results of the study are based on the qualitative data of surveys and interviews after the use.	Quantitative and qualitative data taken from pre- and post-tests, self-reported questionnaires, and qualitative feedback forms and focus groups conducted at the start and end of the 16-week innovation term that involves 3 WiREAD classes, containing 116 students, and 3 control classes, containing 92 students (Grade 9, 15-years-old).	The research had a design-based quasi-experimental design. This included surveys evaluating student experience of the VLA tool, as well as qualitative assessments collected through student focus groups and open-text evaluation forms. The VLA tool was rated on three criteria by students: 1) perceived ease of use, 2) perceived usefulness, and 3) perceived usefulness for learning and growth. Investigating “How do students make sense of the benefits and drawbacks associated with WiREAD’s LA dashboard components and visualizations?”	The WiREAD VLA tool had several benefits. It fostered greater self-awareness and self-regulatory learning dispositions, increased learning motivation and engagement, and promoted connective literacy among students. Those helped improve the students’ EL reading skills, as well as their understanding of broader 21st-century literacies.
(3) Molenaar, I. and Knoop-van Campen, C. A. N.	2018, Netherlands	Students ranging in age from Grade 2 to Grade 6 practice mathematics on a tablet using Snappet software during a 50-minute mathematics	Quantitative and qualitative data taken from observations for 38 math lessons and teachers’ interviews. This research included 38 teachers	Using Snappet, to investigate how teachers go through the various stages of the LA process model during mathematic lectures, both in	Teachers’ pedagogical actions were influenced by the dashboard. Following dashboard consultations, frequent actions included

(Study number) **Author details**	**Year, Location**	**Intervention**	**Study design/ population**	**Study method(s)/ Study aim(s)**	**Outcomes**
		lesson, while teacher dashboards provide real-time data reflecting students' progress and success.	from eight different primary schools (30 females and 8 males).	terms of consultation and practice, i.e., how the software influences teachers' pedagogical efforts and how teachers assess students' performance.	progress and task feedback. A quarter of dashboard discussions resulted in no specific teacher response. Dashboards also appear to be employed to verify teachers' assessments of student and class progress.
(4) Camacho, V. L., Guía, Olivares, Flores and Orozco-Barbosa	2020, Spain	395 tasks carried out by 18 students in real-time over a school year using WIoTED were monitored and analyzed.	Quantitative data taken from experiments and observations. This study included 18 students ages 13 to 15 years old (12 boys and 6 girls) in their first year of secondary school in Spain, as well as 3 teachers.	The WIoTED system's data collection, analysis, classification, and application of multimodal LA are described to evaluate the WIoTED system throughout the course of an academic year, get relevant data, and provide effective methods/tools to boost student participation in class. ML techniques and MMLA procedures were utilized to build models that can 'explain' when student involvement is present, so that this information may be utilized later. They have separated four stages of data capture and automatic analysis development, with the resulting technological system and structures, to implement the proposed technique in a practical educational setting.	WIoTED were applied to detect various students' behavior patterns, demonstrating their improvement and motivation (developing foreign language skills) and to obtain a better understanding of engagement progress in primary and secondary schools.
(5) Ez-Zaouia, M., Tabard, A., and Lavoué, E.	2020, France	A three-month exploratory field study observing teachers to understand how teachers integrate a dashboard into their practices to articulate remote and in-class learning.	Quantitative and qualitative data taken from iterative and collaborative cycles for system design and development, 3-month field studies of system use and teacher practice adaptations. This study included 17+7 teachers teaching hybrid French courses (all grades).	The dashboard was created through interviews and collaborative iterative design cycles with seven teachers. They conducted a three-month field trial with 17 teachers who utilized the system in the classroom while collecting their logs, diaries, and interview data. The aim of developing PROGDASH was to investigate how teachers used the dashboard to monitor students' online activity and their progression in French grammar and spelling hybrid courses.	The design study has been done to support teachers in using a curriculum-integrated online learning platform, general understanding of how teachers integrate a dashboard in their practices to articulate remote and in-class learning, design implications for dashboards to bridge online and in-class learning and facilitate data-informed pedagogical practices and to suggest how the use of dashboards could bridge online and in-class learning (hybrid courses).
(6) Molenaar, I., Horvers, A., Dijkstra, R., and Baker, R.	2020, Netherlands	The learning path application was used by students in the experimental condition. They established goals at the start of each lesson and assessed their progress in the learning path application at the beginning of each lesson. To maintain total time investment equal in both circumstances, students in the control condition solved a	Quantitative and qualitative data taken from focus groups and quasi-experimental pre- and post-test consisted of 24 items, 8 items per subskill. This study included 92 grade-5 students (38 boys and 54 girls) from four schools located in the northeast of the Netherlands.	Using a learning path application that combines three PVs including "overview," "goal setting," and "learning path screen" to support young students' internal regulation process in Adaptive Learning Technologies (ALTs). The PVs are based on the MbMLC calculated based on ALT data.	PVs were used in the learning path application to better regulation of students' practice behavior, a reduction in complex MbMLC compared to the control group, and a reduction in monitoring accuracy overestimation. PVs increased practice behavior management, learning transfer, and altered the bias

(Study number) Author details	Year, Location	Intervention	Study design/ population	Study method(s)/ Study aim(s)	Outcomes
		puzzle at the start of each lesson.			in relative monitoring accuracy.
(7) Dickler, R., Gobert, J., Sao Pedro, M.	2021, USA	Inq-Blotter was used by the participating teachers while their students worked on virtual labs in Inq-ITS during scheduled science class sessions. After the study was over, teachers and students continued to use the student and teacher platforms in their science classes on a daily basis.	Quantitative and qualitative data were gathered from classroom observations and teacher interviews. The data collection took place during the regular science class periods of both the teachers and students. Each class section contributed data for a single class period. A total of 35 students from one class and 56 students from the other class were assisted in response to Inq-Blotter during the data collection sessions.	This research aims to fill the gaps in the existing literature by focusing on the absence of contextual alerting dashboards in science inquiry and the limited examination of alerting dashboards in relation to discourse within science inquiry classrooms. The study addresses two main aspects: the impact on student learning outcomes and the patterns of teachers' discursive supports influenced by the dashboard. The research investigates questions such as: Do students improve after receiving help from a teacher informed by dashboard analytics? Do students maintain that improvement over time? How does this improvement compare to students who were not helped by the teacher? Furthermore, the study explores teachers' responses to dashboard alerts and the types of discursive supports provided by teachers based on these alerts.	The Inq-Blotter dashboard assists science teachers in guiding students through inquiry practices by delivering real-time alerts, fine-grained data, and visualizations.
(8) Kondo, T., Yokoyama, K., Misono, T., Inaba, R., & Watanabe, Y.	2021, Japan	In September 2020, a survey was conducted on two classes: one utilized the learning visualization function of NoTAS ("visualization"), while the other session did not include the learning visualization function ("non-visualization").	Quantitative and qualitative data were gathered from experiments, surveys and questionnaires. The second author conducted a survey in two mathematics classes consisting of first-year high school students, totaling 89 students (34 males and 55 females). The number of valid responses amounted to 86, as students who were absent from the class were not included.	A learning strategy feedback system called NoTAS has been created to enhance learning strategies among students in the classroom by utilizing nudges and offering feedback on note-taking. This system incorporates three main functionalities: a note-taking function, a learning log function, and a learning visualization function.	The effectiveness of NoTAS for high school students was assessed from two perspectives: 1) the potential disruption caused by NoTAS usage in the classroom; and 2) the level of encouragement towards the implemented nudge within the class. Based on the questionnaire findings, it was determined that students were able to maintain focus on learning in the classroom with the help of NoTAS.
(9) Lee, A. V. Y.	2021, Singapore	Over a period of two weeks, a collection of 101 online postings (notes) written by students on the Knowledge Forum was compiled. These notes captured the students' reflections, discussions, and debates pertaining to an authentic issue closely related to the scientific topic of the "human circulatory system"." The online conversation took place at the same secondary school over a period of two weeks in a computer-aided environment.	Quantitative and qualitative data taken from focus groups, and observations. In this paper, an investigation is conducted on a group of 20 Grade 8 secondary school students who actively participated in asynchronous online discussions for a duration of two weeks. The students were guided by a skilled teacher throughout the process.	The IPR tool functioned as a one-page summary presenting statistics and information about a student's idea trajectory as a member of the discourse community. Its' different sections contain critical details to inform students and acknowledge their contributions in generating and spreading ideas within the community. These details encompass an individual student's profile, the date-time and statistics of their knowledge-building efforts on the Knowledge Forum, a visual representation comparing the student's efforts to those of	A developed feedback tool to offer teachers comprehensive information and support, enabling them to make informed and timely interventions for students engaged in knowledge-building activities during classroom sessions. students can also access the IPR which make students' ideas available to them at any moment during an online discussion.

(Study number) Author details	Year, Location	Intervention	Study design/ population	Study method(s)/ Study aim(s)	Outcomes
				their peers, and significant contributions to the community highlighted through various indicators. The aim of this study is to demonstrate how the utilization of LA and ML methods can assist in examining ideas of different levels of promisingness in discourse, which is a complex task due to the unstructured nature of textual data. By doing so, it becomes possible to analyze the distribution and quality of ideas and link them to different kinds of talk that arise from online classroom discourse.	
(10) Rodríguez-Triana, M. J., Prieto, L. P., Dimitriadis, Y., De Jong, T., & Gillet, D.	2021, Estonia	This study outlines three DBR iterations that contain a range of studies and activities. These iterations include a survey study, eight case studies examining the implementation of IBL in real classrooms, four teacher workshops, and an analysis of the utilization of the Go-Lab authoring platform.	Quantitative and qualitative data taken from questionnaires, interviews, observations, focus groups, and log data gathering. A total of 95 STEM teachers actively participated in the study.	A four-year DBR project conducted by the researchers investigated the orchestration needs of teachers in Go-Lab, a widely used technological ecosystem for IBL among primary and secondary school teachers globally. The aim of the project was to address two key questions: "What are the orchestration needs of teachers implementing IBL in their classrooms?" and "To what extent do ADA solutions fulfill such orchestration needs?"."	This paper presents the findings from a four-year DBR study that explored the requirements for orchestrating IBL among primary and secondary school teachers in the context of Go-Lab. It also examined how the integration of learning design and analytics can effectively address these needs.
(11) Tlili, A., Hattab, S., Essalmi, F., Chen, N. S., Huang, R., Chang, M., & Burgos, D.	2021, China	During the academic year 2018-2019, a pilot experiment was carried out at a public primary school to verify the validity of two hypotheses. The first fifteen minutes were spent by the teacher introducing the game to the students in both experimental and control groups. Following that, the students in each group took 45 minutes to complete a pre-test and a pre-motivation. While the students in the control group used the non-smart version of the educational game (without LA), the students in the experimental group applied the smart collaborative educational game (with LA).	Quantitative and qualitative data taken from pre- and post-tests with experimental and control groups, pre- and post-motivation questionnaires, interviews, and Observations. This study involved the participation of 31 primary school students in the sixth grade, with 70% of them being boys and 30% girls. The students had an average age of 12 years. They were randomly assigned to two groups: the experimental group and the control group.	The main objective of the study was to validate two hypotheses: "H1: Students learning with the developed smart collaborative educational game (with LA) have significantly higher learning performance than students learning with the non-smart version of the game (without LA)" and "H2: Students learning with the developed smart collaborative educational game have (with LA) significantly higher learning motivation during the learning process than students learning with the non-smart version of the game (without LA)."	Development of a smart collaborative educational game considering LA approaches with the aim of improving the English vocabulary learning of primary school children. The game was designed to offer real-time learning dashboards to teachers, providing them with valuable insights into their students' progress and performance.
(12) Wilson, M., & Lehrer, R.	2021, USA	In order to estimate the item parameters, the researchers employed data collected from both the pre-test and the post-test. A sample comprising 1002 middle school students from various school districts was utilized to calibrate the learning progression.	Quantitative and qualitative data taken from pre- and the post-tests and observations. The project team collaborated with a sixth-grade teacher to replicate the learning progression four times, encompassing a total of four classes taught by the same	A learning progression was defined as an educational system aimed at analyzing the differences in student comprehension and engagement across different classes, measuring the degree of conceptual change among individual students within those classes as well as facilitating specific types of	The study involved development and implementation of a learning progression that outlined the progression of reasoning skills related to data and statistics as middle school students engaged in activities involving visualization, measurement, and modeling of inherent variability in

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			teacher and including 93 students.	conceptual change among students (and possibly teachers). This system encompassed descriptions of learning that were influenced by an epistemic perspective of a particular discipline. It also included resources and strategies to support these types of learning, comprehensive assessment schemes, and professional development initiatives that fostered pedagogical skills focused on promoting ongoing student advancement.	various processes, such as repeated measurement, production, and organismic growth.
(13) Bai, Y., Xie, Y., Luo, W., & Yang, M.	2022, China	The research study focused on four fourth-grade mathematics lessons as the main experimental framework. To enhance the teaching practice, additional data visualization tools were incorporated based on the specific teaching context. The selected lessons covered topics such as Hectares and Square Kilometers, The Measure of Angles, Parallelogram and Trapezoid, and Bar Chart.	Quantitative and qualitative data taken from pre- and post-tests with experimental and control groups, questionnaires, and observations. A primary school in Guangzhou was chosen as the setting for teaching mathematics practices. The research focused on a total of 71 students, specifically from Class 1 Grade 4 and Class 2 Grade 4. Class 1 Grade 4 was designated as the experimental group, while Class 2 Grade 4 served as the control group.	In this study, an action research method was utilized to gather and analyze data through two iterations of the Plan-Action-Observe-Reflection cycle. Throughout this process, the researchers identified and reflected upon the challenges encountered during the experiment, aiming to continually enhance the application of data visualization strategies in promoting effective learning among primary school students.	The purpose of this study was to assess the effectiveness of learning in both the experimental and control groups using constructed evaluation indexes specifically designed for primary school students. By employing a data visualization strategy, the study examined how this approach could significantly impact the occurrence of effective learning behaviors among primary school students.
(14) Chen, C. M., Li, M. C., & Liao, C. K.	2022, Taiwan	Using a quasi-experimental design, the researchers recruited 50 Grade 8 students from a junior high school in Taipei City to participate in an instructional experiment focused on collaborative writing.	Quantitative and qualitative data taken from pre- and post-tests with experimental and control groups, questionnaires, and interviews. A group of 50 Grade 8 students from a junior high school participated in an instructional experiment on collaborative writing. One class, consisting of 26 students, was assigned as the experimental group and utilized CWS-VINA for collaborative writing. The other class, comprising 24 students, served as the control group and used a CWS-NVINA.	investigating 3 research questions: “Are there significant differences in the learning performance of learners and learners with distinct prerequisite writing abilities and CMC competence who respectively use CWS–VINA and CWS–NVINA supported online collaborative writing to assist collaborative writing?”, “Are there significant differences in the technology acceptance of learners and learners with distinct prerequisite writing abilities and CMC competence who respectively use CWS–VINA and CWS–NVINA supported online collaborative writing to assist collaborative writing?” and “What are the experiences and suggestions of learners using CWS–VINA for facilitating group collaborative writing performance and reducing uneven participation?”	In this study, the effects of collaborative writing supported by CWS-VINA and CWS-NVINA on students’ learning performance and technology acceptance are examined. Additionally, the study investigates the differences in collaborative writing outcomes and technology acceptance between students with varying levels of prerequisite writing abilities and CMC competence.
(15) Hu, L., Wu, J., & Chen, G.	2022, China	In order to assess and enhance the design of iTalk–iSee, it was employed in a project centered around	Qualitative data taken from focus groups, surveys, and interviews. To test the effectiveness of the iTalk–	iTalk–iSee is an interactive visual learning analytical tool that actively involves students in enhancing their	iTalk–iSee was developed as an interactive VLA tool, specifically designed to support students in their

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		teaching students' effective communication skills in collaborative problem-solving. This project was implemented as an independent elective course called "Mathematics Dialogue and Thinking"."	iSee-supported course, one class (N = 59) was randomly selected. The participants, aged between 9 and 10 years, included 59% male and 41% female students.	competencies in DCPS. It achieves this by facilitating the learning of specific productive peer talk tools and providing an opportunity to experience the benefits of authentic dialogue. The name "iTalk" emphasizes the tool's focus on cultivating and supporting a culture of dialogue. Meanwhile, "iSee" holds a dual meaning: it enables students to visualize collaborative discourse, allowing them to intuitively observe their own communication, and it assists students in comprehending their collaborative performance and identifying areas for improvement by visualizing their dialogue.	learning process and encourage the utilization of effective peer talk techniques in collaborative problem-solving discussions (referred to as DCPS).
(16) Sancenon, V., Wijaya, K., Wen, X. Y. S., Utama, D. A., Ashworth, M., Ng, K. H., Cheong, A. & Neo, Z.	2022, Singapore	A randomized controlled trial was conducted at a physical tuition center in Singapore during a school holiday within a period of two weeks to compare the impact of studying personalized content versus non-adaptive material on academic outcomes.	Quantitative and qualitative data taken from pre- and post-tests and observations. The study recruited a group of 43 voluntary participants, consisting of fifth-grade primary school students from a tuition center in Singapore.	The study aimed to achieve the following objectives: 1) implementing and assessing the effectiveness of an e-learning platform that incorporates a recommendation system driven by LA. The system generates personalized content adaptively to enhance learning outcomes; 2) Developing a skill level metric based on online trace data to effectively monitor the progress of students using the e-learning platform; 3) evaluating the correlation between the skill level metric and formal exam outcomes to determine its validity as an indicator of academic performance; and 4) investigating whether the provision of personalized content through the adaptive system leads to improved learning outcomes compared to non-adaptive materials.	A developed web-based personalized tutoring system uses trace data and LA from users to create customized assessment worksheets based on each student's proficiency level.
(17) Vrugte, J. T., & Eshuis, E. H.	2022, Netherlands	They conducted an experimental study using a pre-test (domain knowledge test), intervention (two sessions in a digital learning environment), and post-test (domain knowledge test) design, with two different conditions.	Quantitative and qualitative data taken from pre- and post-tests and interventions. They involved the participation of 40 students (all male) enrolled in secondary vocational education who successfully completed all four sessions of the experiment.	An investigation on the developed Visualization and Reflection Tool is carried out to examine the impact of combining visualizations of performance with guided reflection on students' accuracy in time management and their acquisition of knowledge.	The findings revealed a positive association between increased accuracy and learning gains, suggesting that the additional support potentially influenced an adjustment in time management.
(18) Wang, P., Chen, G., Tong, Y., & Yang, C.	2022, China	The study was carried out in a public aided primary school in Hong Kong for the duration of three months, involving two 6th-grade classes. One class utilized the platform for their GS subject, while the other class utilized	Quantitative and qualitative data taken from pre- and the post-tests, interviews, and questionnaires. A total of 2 teachers and 54 students took part in the study, with each	Develop a post-flipped classroom pedagogy that uses a VBVL approach, leveraging recorded lesson videos from emergency remote teaching, in order to address students' learning	Transforming the recorded lessons into tailored learning resources for students and facilitating active learning via discussion forums and quizzes.

(Study number) **Author details**	**Year, Location**	**Intervention**	**Study design/ population**	**Study method(s)/ Study aim(s)**	**Outcomes**
		it for mathematics. Both classes underwent pre- and post-tests, assessing subject knowledge.	class consisting of 27 students.	loss and facilitate remediation.	
(19) Yang, Y., & Song, Y.	2022, China	The study spanned approximately seven months and was divided into two main phases: the pre-stage, which took place from October to November 2021, and the implementation phase, which occurred from November 2021 to May 2022. During the pre-stage, three one-hour orientations were conducted to introduce the students to the Vocab+ app. Throughout the implementation phase, it was expected that students would dedicate a minimum of one hour per week to utilizing the tool.	Quantitative data taken from pre-, mid- and post-vocabulary tests. The study included a total of forty-four Grade 4 EFL students, comprising 20 boys and 24 girls, who were between the ages of 10 and 11. These students were from a class in a primary school located in Mainland China.	The researchers examined how primary school students engaged in SRVL behaviors while using a mobile app, employing LA to analyze their English vocabulary learning outcomes. The study aimed to answer the following research questions: “Did students display different SRVL behaviors that characterized them into distinct groups mediated by the Vocab+ app?”, “What were the different SRVL behavioral patterns among students?”, and “To what extent did students with different SRVL behavioral patterns differ across their English vocabulary learning outcomes?”	This study provides valuable contributions to the existing literature on SRL in English vocabulary learning. It achieves this by analyzing primary students’ SRVL behaviors on the Vocab+ mobile app through LA and linking them to their learning outcomes. Additionally, it enhances the understanding of primary students’ SRVL behaviors on a mobile app using LA.
(20) Zamecnik, A., Kovanović, V., Grossmann, G., Joksimović, S., Jolliffe, G., Gibson, D., & Pardo, A.	2022, Australia	The eight teams engaged in a 20-week blended learning environment with the goal of enhancing their collaboration, problem-solving, and lifelong learning skills. Throughout this period, the teacher provided coaching and guidance.	Quantitative and qualitative data taken from surveys, interviews, observations, and experiments. A total of 21 high school students were involved and were divided into eight teams, with three to four members in each team.	The aim of the study was to evaluate how high school students utilize VLA tools to monitor and regulate their teamwork and collaboration activities. The study aimed to answer the following research questions: “To what extent did teams utilize the learning analytics dashboard, and what were the nature of their interactions with the provided visualizations?”, “How did students perceive the usefulness of the dashboard while engaging in team-based learning?”, and “How did students perceive the impact of the dashboard on their collaborative learning experience within the team-based learning context?”	A developed K-12 VLA tool to assist students in their collaborative work. They assessed the perceived usefulness of the VLA tool among students and examined its relationship with their course performance.

Table B.2. Description of the VLA Tools Presented in the Included Articles (By Publication Year in Alphabetical Order)

Name of the VLA Tool	Short description/Purpose	(Study number) Authors
LA Tool (Moodle-based)	Monitor students' learning processes and detect early symptoms of academic challenges, provide task and process feedback, offer insights to help teachers intervene.	(1) Rosmansyah et al. (2017)
WiREAD	Collaborative critical reading and learning analytics, monitor student progression in reading, self-awareness, self-regulatory learning dispositions, social networking.	(2) Tan et al. (2017)
Snappet	Adaptive learning for mathematics and spelling, aid teachers with virtual learning analytics tools, monitoring students' progression, reflection and sense making, performance results.	(3) Molenaar & Knoop-van Campen (2018)
WIoTED	Boost student participation in class, determine student engagement in learning and students' behaviour patterns, performance results.	(4) Camacho et al. (2020)
PROGDASH	Monitor students' activity and progress in French grammar and spelling; Blend remote and in-class learning, login trends, and performance results.	(5) Ez-Zaouia et al. (2020)
Learning path application (PV)	Support Self-Regulated Learning in adaptive learning technologies, self-awareness, regulation of students' practice behaviour, monitor learning paths, learning motivation and engagement, and performance results.	(6) Molenaar et al. (2020)
Inq-Blotter dashboard in Inq-ITS.	Provide real-time notifications about students' inquiry competencies and monitoring of students' progression, promote student improvement and motivation, support learning.	(7) Dickler et al. (2021)
NoTAS	Provide feedback on note-taking, promote effective learning strategies, self-awareness, learning motivation and engagement, and promoting connective literacy among students.	(8) Kondo et al. (2021)
Idea Progress Report (IPR)	Provide information about students' contributions in discourse communities, feedback, understanding of engagement progress, reflection, and sense making, and monitor student's idea trajectories.	(9) Lee (2021)
ADA support in Go-Lab	Facilitate Inquiry-Based Learning orchestration in a technology-enhanced environment, monitor real-time students' activity, and promote awareness, assessment, and reflection.	(10) Rodríguez-Triana et al. (2021)
Smart collaborative learning dashboard	Teach English vocabulary through collaborative learning strategy, monitor real-time, promote student improvement and motivation, and support learning.	(11) Tlili et al. (2021)
Bear Assessment System Software (BASS)	Promote conceptual shifts within a discipline, deliver items and provide analysis for classroom utilization, monitor learning progression, measure the degree of conceptual change, and support comprehensive assessment schemes.	(12) Wilson & Lehrer (2021)
ClassDojo and Dydate.	Support effective learning through data visualization. For student: support self-awareness, learning motivation and engagement. For teacher: monitor student learning behaviours, manage group, and provide timely statistics and feedback on behavioural data results.	(13) Bai et al. (2022)
CWS-VINA and CWS-NVINA systems.	Display students' contribution and interactions in collaborative writing, enhancing group awareness, and reduce uneven participation to improve learning performance.	(14) Chen et al. (2022)
iTalk–iSee	Promote peer talk strategies in Dialogic Collaborative Problem-Solving, self-awareness, and group awareness, facilitate student learning, and promote connective literacy among students.	(15) Hu et al. (2022)
Web-based personalized tutoring system.	Provide adaptive content in the Singapore education system, support self-awareness, learning motivation and engagement, and adaptive learning, and monitor students' progression.	(16) Sancenon et al. (2022)
Visualization and reflection tool.	Support students' time management and guided reflection and self-awareness.	(17) Vrugte & Eshuis (2022)
Platform with classroom discourse analyzer (VBVL)	Support video-based visualization learning. For student: support self-awareness, facilitate active learning, and performance. For teacher: monitor the discussion forms and encourage extended classroom discussions.	(18) Wang et al. (2022)
Vocab+	Support self-regulated vocabulary learning and self-awareness, monitor students' progression, motivation, and performance.	(19) Yang & Song (2022)
K-12 LAD	Support students in collaborative activities. For student: support awareness, monitor and regulate teamwork and collaboration activities. For teacher: monitor students' progression, offering timely interventions for student support.	(20) Zemecnik et al. (2022)