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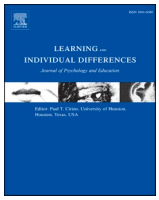

Adaptive learning, instruction, and teaching in schools: Unraveling context, sources, implementation, and goals in a systematic review☆

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ABSTRACT

Adaptivity allows for meeting diverse students' needs. Building on the Ada-LIT framework, this review systematically investigates 1) in which contexts, 2) based on which sources and types of assessment, 3) through which operationalizations and types of delivery, and 4) with which targeted outcomes adaptations are made in schools. We identified 69 publications double-screening 555 empirical research articles published between 2018 and 2022. Most research was conducted in elementary schools, particularly in math, and adaptivity was mainly delivered by systems. Performance was the most frequent adaptive source and targeted outcome, with less emphasis on emotions or demographic characteristics. Assessment of the adaptive source relied primarily on trace data. Operationalizations were mainly on a micro-level, specifically adaptive navigation, support, and difficulty progression. Studies typically do not report on all six components of adaptivity as outlined in the framework. The Ada-LIT framework can guide rigorous designs and reporting of studies investigating adaptivity in schools.

Educational relevance: The Ada-LIT framework integrates six essential components of adaptivity in schools: context, source, assessment, delivery, operationalization, and outcome. The review showed adaptivity is primarily based on performance and implemented to improve performance, delivered mainly by systems, and mostly investigated in math. This highlights underexplored areas, accentuating an agenda for future research that taps into other essential components of adaptive learning, instruction, and teaching (LIT) in schools. The framework can guide consistent and comprehensive reporting of future research, fostering the clarity and comparability of findings and, thus, enhancing a collective understanding, robust evidence generation, and an actionable implementation model of adaptive LIT in schools.

Each student enters school with specific learning prerequisites. Thirty students in a classroom often represent 30 unique combinations of learner characteristics, emphasizing the importance of addressing their individual learning needs in the classroom, as well as the underlying challenge. Adaptive learning, instruction, and teaching (LIT), a student-centered approach grounded in constructivist ideas, is a promising approach that creates customized learning environments and offers support tailored to students' needs and prerequisites (Hariyanto et al., 2020; Prediger et al., 2022; Swidan et al., 2022).

Although lacking a uniform definition, there is agreement that adaptive LIT encompasses adjusting aspects of instructional environments and teaching practices to cater to each student's needs by acknowledging individual cognitive, meta-cognitive, emotional, motivational, demographic, sociocultural and socio-economic characteristics. The primary goal of adaptive LIT is to optimize the learning experience for each student (Bernard et al., 2019) and equip everyone with the necessary competencies for societal participation (Dumont & Ready, 2023). This definition of adaptivity may overlap with the definitions of personalization (e.g., Tetzlaff et al., 2021) or individualization (e.g., Bernard et al., 2019) approaches that also aim to address individual learners' needs through tailored instruction. Consequently, the terms are sometimes used together or interchangeably in the literature (e.g., Özyurt & Özyurt, 2015). At the same time, some researchers also point out their differences (Xie et al., 2019).

Research on adaptivity, for example, in the form of one-on-one tutoring, began decades ago (Bloom, 1984; Cohen et al., 1982; Wang,

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1980), showing how centering teaching on the individual learner's needs effectively fosters learning (Nickow et al., 2020). Recent technological advances offer new ways of implementing and scaling adaptive LIT (Cavanagh et al., 2020; Kerr, 2016; Martin et al., 2020; Muñoz et al., 2022), rekindling interest in the topic and emphasizing its potential to transform teaching and learning in schools (Mulford, 2014; Rane et al., 2023).

Given the renewed interest in adaptive LIT, the technological advancements that now make its implementation in schools more feasible, and the fact that adaptivity in schools can be implemented in various ways (Bardy et al., 2021), it is timely and necessary to assess the current state of research on this topic. This includes bringing together research on teacher-delivered and system-delivered adaptive LIT to advance a holistic understanding of adaptivity in learning contexts. Traditionally focusing on different agents (teachers versus technologies), these two research strands share the core goal of tailoring LIT to students' needs and characteristics to enhance learning experiences and outcomes. Despite their shared goal, they have developed more in parallel than in dialogue—likely due to their distinct methodological foundations (ranging from design-based and computational approaches in system research to qualitative, observational, or interpretive methods in classroom-based studies). This divergence makes integrating the two methodologically ambitious. Yet, bridging these strands reveals underlying principles of adaptivity that transcend specific delivery modes. Moreover, their integration offers valuable opportunities for cross-pollination. Insights from adaptive system research can inform how teachers use data or automate aspects of instructional decision-making. Conversely, research on teacher-delivered adaptivity provides rich, contextualized understandings of adaptivity in practice, offering crucial insights for designing more human-centered and pedagogically grounded adaptive systems. As learning increasingly occurs in blended environments where teacher- and system-delivered adaptivity co-exist and interact, this integrated perspective becomes even more relevant. In summary, by bridging these strands, this framework-driven systematic review not only integrates two distinct bodies of literature but also advances the conceptualization of adaptivity itself, moving beyond siloed definitions toward a unified, transferable framework that informs both instructional practice and technological design. This review synthesizes the existing knowledge, identifies research potential, and provides a foundation for future research and practical application of adaptive LIT in classrooms.

1. Ada-LIT: A framework for research on adaptivity

We identified six essential components of adaptive LIT—source, assessment, delivery, operationalization, outcomes, and context—and consolidated them in the Ada-LIT framework (Adaptive Learning, Instruction, and Teaching; Fig. 1). As such, the Ada-LIT framework is a comprehensive, integrative model that organizes adaptivity-related research in a structured manner around these six components.

This framework serves as a guide for designing studies on adaptivity and provides a standardized structure for reporting such research, thereby facilitating transparency, comparability, and the generation of cumulative knowledge. We believe that addressing these six core components is crucial for synthesizing existing research, understanding current practices, and advancing knowledge on adaptive LIT. However, these components are not exhaustive and should be understood as the minimum elements that must be considered and reported in studies of adaptive LIT. Explicit consideration of other relevant components would surely lead to even more detailed reporting, further advancing transparency, and rigorous evidence generation and synthesis.

Each of the six components of the framework has various sub-components (e.g., performance and interest as sub-components for adaptive source). For five of the components (source, assessment, delivery, operationalization, and outcome), the sub-components are universally applicable to adaptivity research. However, the sub-components of the sixth component, context, need to be adjusted to the specific context in which the research takes place. Since this review focuses on adaptivity in schools, we identified sub-components particular to the school context that are essential (not exhaustive) for investigating adaptivity in schools. As the sub-components are specific to the chosen context, these would look different, for example, for investigations of adaptivity in higher education.

Using the Ada-LIT framework, we systematically examined research on adaptive LIT in schools published between 2018 and 2022, shedding light on each of the six components. In the following sections, we introduce and explain each component further. We also exemplify how the framework guided the data coding and analysis, and use it to report and discuss our findings.

1.1. Component 1: The adaptive source

The adaptive source comprises the learner characteristics based on which LIT is adapted (Martin et al., 2020; Vandewaetere et al., 2011). As the characteristics central to learning are diverse, numerous characteristics can serve as a source for adaptations. In their review, Afini

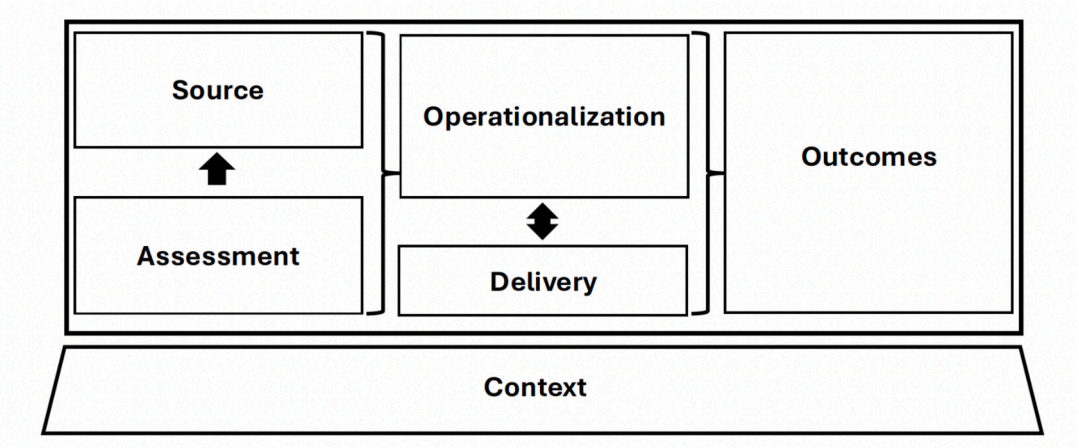

Fig. 1. Ada-LIT framework for research on adaptivity.
Note. The Ada-LIT framework outlines six essential components—source, assessment, delivery, operationalization, outcomes, and context—that should be carefully considered in the design of studies on adaptive LIT and explicitly reported in research papers.

Normadhi et al. (2019) categorize these characteristics into three areas: cognition (e.g., working memory capacity), affect (e.g., engagement), and behavior and psychomotor (e.g., performance). Cognition encompasses student characteristics such as information processing or prior knowledge. Affect includes motivation and emotions that may arise during the learning situation. Behavior and psychomotor include physical movement or interactive behaviors such as help-seeking. Of the three areas, cognition appears to be the most considered, with cognitive variables serving as the basis for adaptation in more than half of the studies on adaptive learning environments (Afini Normadhi et al., 2019).

In accordance with these three proposed areas, Martin et al. (2020) identified nine more fine-grained learner characteristics that can guide adaptation: learning style, cognitive and thinking style, prior knowledge, background knowledge, metacognitive knowledge, learner preference, learner behavior, learner profile, learner ability, and learner interest. Furthermore, Plass and Pawar (2020) highlight that students' demographic and sociocultural or -economic variables, such as gender and migration history, are also relevant learner characteristics for adaptive LIT and, thus, potential sources.

The source can be stable learner characteristics (e.g., students' preferences for content presentation, Zulfiani et al., 2021). They can also be characteristics obtained from static pretest data (e.g., students' prior knowledge in a pretest; Baker et al., 2018) that allow distinguishing one student from another, i.e., interindividual differences. However, students are dynamic entities that change and develop different needs over time (Aleven, 2011; Tetzlaff et al., 2021). As such, an instructional intervention or support measure appropriate for a student in one moment may not meet their needs in the next. Thus, the source can also be dynamic characteristics that change over time (intraindividual differences).

1.2. Component 2: Assessment of the adaptive source

Assessment, the second component of the framework, is strongly tied to Component 1. It describes the method used to measure the source. Different types of assessment might be appropriate for different sources. Here, the strong connection between formative assessment and models of adaptive learning becomes apparent, as it highlights the multiple functions that assessment can serve, not only as a means of evaluation, but also as a tool for using assessment information to support further learning (Black & Wiliam, 1998; Black & Wiliam, 2009; Wiliam et al., 2004) by adjusting LIT to meet the learners' needs.

1.2.1. Self-reports, tests, and trace data

Self-report questionnaires enable the assessment of emotions and other variables, such as students' preferences for how content is presented. Classic knowledge, cognitive ability, and performance tests (Hariyanto et al., 2020) can be used to assess performance and abilities objectively. Performance can, however, also be assessed with trace data that give more insights into students' learning behavior and processes (Stadler et al., 2020). Trace data are generated automatically while students work in a digital learning system (e.g., time on task, number of errors). As such, trace data are good predictors of students' performance (Lerche & Kiel, 2018) and a suitable way to dynamically assess students' cognition, behavior, and psychomotor variables.

1.2.2. Teacher dashboards

Teacher dashboards present the assessed trace and test data to teachers, allowing them to deliver adaptive instruction. The system monitors the students while they work in a technology-enhanced learning environment and then prepares the data in an accessible way (Molenaar & Knoop-van Campen, 2017). Accordingly, using teacher dashboards facilitates class-wide monitoring and, in particular, recognizing when students are off-task, confused, or overwhelmed and might need the teacher's support (Aslan et al., 2019). Teachers receive real-time information about their students via the dashboard and can base their actions on it (Aeiad & Meziane, 2019).

1.2.3. Teachers observations

Furthermore, teachers routinely gather information about their students during regular classes without relying on technological support (Helm et al., 2022; Heritage, 2007; Shepard, 2005). Trained as adaptive experts, teachers are skilled in observing and being aware of student differences (Brühwiler & Blatchford, 2011; Edelenbos & Kubanek-German, 2004). Accordingly, they observe and listen to the students in the classroom, potentially looking over their shoulders as they work or observing general class dynamics. These observations give them insights into the students' performance, emotions, and motivation. This core teacher practice is often called professional noticing (Gibson & Ross, 2016), and is a valid method to assess learner characteristics.

1.2.4. Adaptability (student choice)

In some cases, students can indicate their preferences and choices, which are then used to customize LIT. Such user-controlled adaptation is called adaptability (Oppermann & Rashev, 1997), which has been found to promote students' self-regulated learning (She et al., 2023). Specifically, in a technology-enhanced learning platform, the system can provide an adaptable framework, allowing students to choose between different options and adjust certain aspects of the learning situation (Chou et al., 2015). Additionally, in a regular classroom, a teacher may offer students various options from which they can choose. Their choice can be seen as an indicator of their learner characteristics (e.g., interest, performance level). In contrast to adaptivity, the students have complete control, and the adaptation is entirely based on their choice.

1.3. Component 3: Operationalization of adaptive LIT

Operationalization, the third component of the framework, describes how adaptivity is implemented, including what is being adapted and how (Martin et al., 2020; Shute & Towle, 2003). For example, the process, content, and, when using a system, the interface can be adapted in response to learner information (Moré et al., 2015). More precisely, adapting LIT involves customizing teaching materials, including the topic, modality, difficulty levels, pacing, support measures, individual feedback, and guidance (Bardy et al., 2021; Reinhold et al., 2020). Moreover, "the dosage (duration, frequency, or amount), type, or delivery mode of an intervention" (i.e., when is which type of feedback given by whom; Nahum-Shani & Almirall, 2019, p. 2) can be adapted. Furthermore, several aspects in the content presentation can be customized to improve the students' user experience and learning experience (e.g., picture-driven or text-driven presentation, choice of avatar; Cha et al., 2006; Mazlan & Burd, 2011).

1.3.1. Level of operationalization

Adaptations can happen at the macro- and micro-level (Corno, 2008; Corno & Snow, 1986; Plass & Pawar, 2020). Macro-adaptations refer to adaptations on a higher level, often made in advance, including lesson planning, curriculum design, or the creation of schoolwide programs directed at specific groups of students. According to the definition by Corno (2008), these adaptations can be tailored to groups of students with common learner characteristics, such as gifted students with exceptionally high cognitive skills (Johnsen et al., 2002) or those with a similar sociocultural background (Au & Blake, 2003). For instance, macro-adapting can mean planning the structure of a lesson or an online learning path, including its content and methods, based on prior assessment of learner characteristics (Warwas et al., 2011).

In contrast, micro-adaptations focus on ongoing learning activities and are more short-term and on the fly. As such, they are also often based on more dynamic sources and assessments (Plass & Pawar, 2020). Similarly, Corno (2008) describes them as a "direct response by the teacher to individual learners" (p. 163). She emphasizes the individual

level of micro-adaptations, which focus on specific students, in contrast to macro-adaptations that are often tailored to groups of students with similar characteristics. Accordingly, micro-adaptations aim to meet students' needs at a particular moment, for example, by supporting students with specific difficulties at a specific time. Plass and Pawar (2020) noted that micro-adaptations include scaffolds, cues, feedback, and difficulty progression. As such, micro-adaptations do not change the entire learning path but are moment-by-moment reactions from a teacher or system based on interactions within the classroom or learning environment (Gibson & Ross, 2016; Nahum-Shani & Almirall, 2019; Prediger et al., 2022). Due to their nature, micro-adaptations are often relatively small interventions and not always formal, but rather natural forms of responsiveness, such as how a teacher communicates with a student (Gibson & Ross, 2016).

1.4. Component 4: Delivery of adaptive LIT

Even though the topic of adaptivity has gained momentum in recent years due to technological developments, adaptive LIT in schools does not necessarily require technology to be delivered (Walkington & Bernacki, 2020). Teachers' responses to their students' observed behavior and performance are probably the earliest form of adaptive LIT. Moreover, one does not exclude the other, as the system and teacher can often complement each other (e.g., with the help of teacher dashboards) to facilitate adaptive LIT (Dumont & Ready, 2023). Despite being based on the same paradigms, teacher- and system-delivered adaptivity are often considered in distinct research strands to this day. Synthesizing both strands as the fourth core component of the Ada-LIT framework thus presents a novel contribution.

1.4.1. System-delivered adaptivity

Adaptive hypermedia systems (Brusilovsky, 2001) or intelligent tutoring systems deliver system-based adaptivity (Brusilovsky & Peylo, 2003). According to Brusilovsky and Peylo (2003), the latter offers learners curriculum sequencing (an individual learning path of topics and tasks adapted to students' needs; e.g., Seki et al., 2005), intelligent solution analysis (explanatory error feedback based on students' mistakes, e.g. Roscoe et al., 2013), and problem-solving support (individual guidance and scaffolding; e.g., C.-H. Chen, 2014). Adaptive tutors based on natural language processing can even mimic human-like conversations with learners, considered a measure of individual support (Cai et al., 2015; Latham et al., 2014). Meta-analyses have shown that the effectiveness of intelligent tutoring systems is equal to that of human tutoring (Ma et al., 2014; VanLehn, 2011). Adaptive hypermedia systems support learners through adaptive presentation (i.e., adapting the displayed content to the needs of the students; e.g., Sayed et al., 2023) and adaptive navigation support (i.e., adapting visible links for next steps, comparable to curriculum sequencing; e.g., Hsiao et al., 2010). Adjustments are made based on predefined decision rules to ensure that appropriate adaptations, such as providing specific hints or offering easier/more challenging tasks, occur at the right time in response to specific student behaviors or assessment results (Bower, 2015; Hwang, 2014; Murray & Perez, 2015; Nahum-Shani & Almirall, 2019).

Generally, due to its automation, system-delivered adaptivity occurs mainly on a micro-level, and adjustments are made dynamically from moment to moment (Nahum-Shani & Almirall, 2019; Park et al., 2019). While utilizing systems for micro-adaptations leverages their full potential, these systems can also be employed for macro-adaptations. For example, students may be assigned to specific learning modules or course sequences based on a one-time assessment of their learner characteristics before they begin a lesson or course. Automation makes system-delivered adaptivity more scalable than teacher-delivered adaptivity, as it does not depend on human attention (Li et al., 2021) and has no limitations regarding the number of students it can monitor simultaneously (Alajlani et al., 2023).

1.4.2. Teacher-delivered adaptivity

Teachers' adaptive competence or expertise is their "ability to adjust planning and teaching to students' individual learning processes"(Brühwiler & Blatchford, 2011, p. 98). Many teachers consider the differences in learner characteristics between students as opportunities (Gibson & Ross, 2016), allowing them to challenge their instructional routines and refine their understanding of teaching, rather than as difficulties (Von Esch & Kavanagh, 2018).

Teachers commonly deliver macro-adaptations, such as lesson planning. Lesson planning can occur throughout the school year, during specific weeks, days, or sessions, but it should consistently precede a lesson being taught. In lesson planning, teachers prepare "content, materials, sequencing, timing, and activities" (Farrell, 2002, p. 31) in advance. Usually, different tasks are prepared on a group level, for example, for students with similar abilities. Such macro-adaptations are often referred to as differentiated LIT in research (Subban, 2006).

Typical examples for teacher-delivered micro-adaptations are "questioning, assessing, encouraging, modeling, managing, explaining, giving feedback, challenging, or making connections" (Parsons et al., 2017, p. 231). The complex process, ranging from assessment and observation to adapting their instruction, often occurs in a matter of seconds in everyday classroom situations and adaptations are, therefore, considered on-the-fly decisions (Nieminen et al., 2021; Sherin et al., 2008). Teachers sometimes deviate from their initial teaching plans and routines, responding to situations and individual behavior in the classroom, some of which are unforeseen, requiring them to improvise (Gallagher et al., 2020; Kim & Ward, 2020; Sawyer, 2004; Yoon et al., 2019). As such, the teachers adapt to the students, who in turn often react to instruction, thus enabling a "collaborative space between students and teachers" (Gibson & Ross, 2016, p. 181). However, observing and responding to all students in this way is impossible for classroom instructors who teach up to 30 students in one class (Alajlani et al., 2023). Teacher dashboards sometimes support teachers' decision-making and suggest suitable interventions that meet students' needs (Aeiad & Meziane, 2019; Martinez-Maldonado et al., 2015; Wiedbusch et al., 2021).

1.5. Component 5: Outcomes targeted with adaptive LIT

Component 5 describes the learning outcomes targeted by adaptive LIT. The core goal of adjusting LIT is to improve learning outcomes of different types (e.g., Hubalovsky et al., 2019). Past research has yielded mixed findings regarding the effects of adaptive LIT (Van Schoors et al., 2021). However, many studies demonstrate that adaptive LIT can lead to improved academic performance, as indicated, for example, by better grades (Alsadoon, 2020; Divanji et al., 2023; Verdú et al., 2008).

Beyond performance, adaptivity also aims to enhance engagement, or motivational and emotional outcomes (Wang et al., 2019). The influence on motivational-affective characteristics can be achieved through various mechanisms. First, adapting LIT makes students more likely to be met in their interests. For example, the content may become more relevant and engaging by tailoring the contexts of tasks and materials to align with students' curiosities, passions, or real-life experiences (Islam and Mares, 2014; Robertson & Padesky, 2020). Second, adjusting the difficulty level to students' ability levels ensures that students remain challenged but not overwhelmed (Murray & Arroyo, 2002; Su, 2017). That can foster a sense of accomplishment, boosting their academic self-concept and motivation (Biton et al., 2022; Cakïr, 2022). Moreover, responding to students' needs or challenges through individual feedback or other types of adaptive instructional support can motivate students, as they feel seen and acknowledged in their specific needs (Koenka & Anderman, 2019).

1.6. Component 6: The context of adaptive LIT

Component 6 outlines the contextual factors in which adaptivity is

being studied. Different sub-components characterize the context, depending on whether the focus is on adaptive LIT in schools or higher education, for example. This review focuses on the context of schools and identified four sub-components: school type, grade level, student age, and school subjects. These context variables must be considered to understand the generalizability of research findings on adaptive LIT in schools. This review aims to highlight which aspects of the school context have been most or least researched.

1.6.1. Types of school

Countries like Germany and Switzerland divide students into different types of schools based on their demonstrated performance (Cortina et al., 2008), which is often confounded with students' socio-demographic characteristics (Dustmann, 2004) Research on such tracking practices points to clear developmental and performance differences between students at different school types (Angelone, 2019; Scheeren, 2022). Thus, students at different types of schools may have different needs, and adaptive LIT may be implemented differently to meet these needs. Therefore, we consider the type of school an important sub-component that describes the context of adaptive LIT in schools.

1.6.2. Age and grade level

Next, students' age, also reflected in their grade level, influences how they learn and what needs they have (M.-L. Chen, 2014). For example, students' sustained attention improves with age (Betts et al., 2006). Furthermore, older children can have less intrinsic motivation (Lepper et al., 2005) but more sophisticated self-regulation strategies than younger students (Alvi & Gillies, 2023). Understanding the target audience of adaptive LIT in schools is essential, making information about participants' ages and grade levels crucial for contextualizing its implementation. Therefore, we argue that research on adaptive LIT in schools should obtain and provide information about the two sub-components, age and grade level.

1.6.3. School subject

Finally, we contend that the school subject is a critical contextual factor for describing the research landscape of adaptive LIT in schools. Each subject has subject-specific didactics outlining how content can best be learned (Grossman & Stodolsky, 1995). However, there are also learning principles and theories that apply across various school subjects (Hattie, 2008; Sweller et al., 2011). Adaptive LIT is likely to be most effective when it integrates both general learning principles and domain-specific principles. However, whether this is certainly the case remains an empirical question yet to be answered. This review examines the distribution of research on adaptive LIT across various school subjects. We argue that this contextual factor is crucial for understanding domain boundaries, comparing implementations across subjects, and informing future adaptive LIT research on underexplored school subjects.

1.7. The Ada-LIT framework in the context of adaptivity frameworks

Previous scholarly work has conceptualized LIT, developing and refining models and frameworks that have significantly advanced our understanding of adaptive LIT's constituent components, underlying processes, and operational dynamics. For example, Shute and Towle (2003) developed a learning management system framework for adaptive e-learning based on aptitude theory, which was further developed by Vandewaetere et al. (2011) and Martin et al. (2020). Vandewaetere et al. (2011) proposed a taxonomy for micro- and macro-level adaptivity delivered by systems. In contrast, Corno (2008) characterizes adaptive teaching with a focus on teacher-delivered adaptivity. The Ada-LIT framework has emerged from this prior work, integrating central components. Therefore, the most innovative aspect of the Ada-LIT framework is that, by integrating prior frameworks, we unite two historically distinct strands of research on adaptive systems and adaptive teaching. Thus, the Ada-LIT framework can be applied equally well to both system-delivered and teacher-delivered adaptivity research.

What Plass and Pawar (2020) classify under the Diagnostics/Assessment components is Component 1 (Source) in the Ada-LIT model. Shute and Towle (2003) refer to the adaptive source as the learner model, which also includes our Component 2 (Assessment of adaptive source). We separated the assessment from the learner characteristics to exemplify how assessment methods may vary between teacher- and system-delivered adaptivity. The adaptive engine or the pathway that translates or pairs learner information with instructional adjustments (Martin et al., 2020; Shute & Towle, 2003; Vandewaetere et al., 2011) as well as Plass and Pawar's (2020) taxonomy inspired our Component 3 (Operationalization). The Ada-LIT framework also relies on the conceptualization of adaptive teaching by Corno (2008), bringing together separate strands of adaptive research in Component 4 (Delivery) of the framework. Corno's (2008) definition is also reflected in our use of micro- and macro-adaptations which distinguishes between adaptations planned in advance and those made on a moment-to-moment basis. The Ada-LIT framework is complemented by Components 5 (Outcomes) which are also discussed in Plass and Pawar's (2020) framework and the model by Martin et al. (2020). Finally, Component 6 (Context) emphasizes that adaptive LIT does not occur in a vacuum but may also be adjusted to the context of the recipients. The context has often played a role in past frameworks in terms of descriptors, but this component was less emphasized as an equally important influencer, one that in itself provides information that should be considered when adapting LIT. Overall, by building on existing efforts while introducing central novelties, the Ada-LIT framework represents a significant contribution, enabling adaptivity to be comprehensively viewed, designed, investigated, and reported.

2. Synthesizing research on adaptive LIT in schools

2.1. Prior systematic reviews

Given the widespread interest in adaptive LIT, several efforts have been undertaken to synthesize research in this area. Most existing reviews have concentrated on education in general without specifying any particular educational context (e.g., Afini Normadhi et al., 2019; Chiotaki et al., 2023; Kabudi et al., 2021; Raj & Renumol, 2022). Reviews that specified a context primarily focused on adaptivity in higher education or professional development for practitioners (e.g., Barbosa et al., 2024; Fontaine et al., 2019; Muñoz et al., 2022). For example, Martin et al. (2020) found that almost 70 % of studies on adaptive technologies between 2009 and 2018 were conducted in the context of higher education, while less than 30 % were conducted in K-12 settings, indicating a general lack of existing research on adaptivity in schools.

We identified four prior reviews on adaptivity in schools (Table 1): Bernard et al., 2019; Gallagher et al., 2020; Heeg & Avraamidou, 2023; Parsons et al., 2017. While these reviews significantly added to our understanding of research on adaptive LIT in schools, no prior review extracted information regarding all six components of the Ada-LIT framework. For example, Gallagher et al. (2020) synthesized literature on adaptive LIT in math and Heeg and Avraamidou (2023) focused their review on adaptivity in science. Furthermore, all four reviews limited their scope to a single type of delivery. Heeg and Avraamidou (2023) focused on AI-enabled system-delivered adaptivity. As such, the authors included studies on various AI applications, including automated feedback, adaptive learning systems, intelligent tutoring systems, and chatbots. Contrarily, the other three reviews investigated teacher-delivered adaptivity, describing teacher-based adaptive instructional and pedagogical approaches: Bernard et al. (2019) included research on student-centered instruction, synthesizing studies on adaptive teaching practices such as individualized feedback, the pacing of instruction, and students' participation in instructional decisions. Similarly, Gallagher

Table 1
Existing syntheses on research on adaptive LIT in schools.

Authors	Year published	Article Title	Years covered	Included studies	Target Group	Review Focus
Heeg & Avraamidou	2023	The use of artificial intelligence in school science: a systematic literature review	2010–2021	22	All school types	Types of AI application, teaching content, impact of AI applications
Bernard, Borokhovski, Schmid, Waddington, & Pickup	2019	Twenty-first century adaptive teaching and individualized learning operationalized as specific blends of student-centered instructional events: A systematic review and meta-analysis	2000–2017	299	K-12	Effect of student-centered instruction on achievement
Gallagher, Parsons, & Vaughn	2020	Adaptive teaching in mathematics: a review of literature	1975–2014	19	K-12	Conceptualization of adaptive teaching in math, overview of research on adaptive teaching in math, presentation of relevant findings in the literature
Parsons, Vaughn, Scales, Gallagher, Parsons, Davis, Pierczynski, & Allen	2017	Teachers' instructional adaptations: A research synthesis	1975–2014	64	K-12	Conceptualization of adaptive teaching, presentation of relevant findings in the literature

et al. (2020) synthesized research on adaptive teaching and emphasized the importance of teachers' flexibility, attending, and noticing their students' actions and behavior to responsively react with questioning, encouraging, and explaining to promote mathematical understanding. Parsons et al. (2017) used the same search criteria and databases as Gallagher et al. (2020) but expanded their search to include research on adaptive teaching in subjects other than math to develop an overview of the conceptualizations and operationalizations of adaptive teaching from the '70s to 2014. Their understanding of typical adaptive teacher actions in school classrooms (e.g., feedback giving, encouragement), aligns with findings from the other reviews that focused on teacher-delivered adaptivity.

In sum, these four prior reviews of research on adaptivity in schools have provided important insights concerning the essential components of adaptive LIT in schools. Building on this foundation, we developed and used the Ada-LIT framework to synthesize research on adaptive LIT in schools. This framework-driven approach addresses six essential components, offering a comprehensive overview of the current state of research on adaptivity in schools. While some of these six components were explored in earlier reviews, others have not been systematically investigated or summarized.

2.2. The present review

Using the Ada-LIT framework, we systematically summarize empirical research on adaptive LIT in schools from 2018 to 2022 to examine 1) in which contexts, 2) based on which source and type of assessment, 3) through which operationalizations and types of delivery, and 4) with which targeted outcome adaptations are made. Two major differences set us apart from the previous reviews described above. First, we focus on the school context, in which there is comparatively little research (Martin et al., 2020). By school context, we refer to all types of schools and students at school age. Second, by adopting a framework-driven approach, we expand the scope to include both quantitative and qualitative studies on adaptive LIT across various school subjects and types of delivery. Typically, there are more quantitative studies on system-delivered adaptivity and more qualitative ones on teacher-delivered adaptivity. Moreover, we bridge research on system-delivered and teacher-delivered adaptivity, creating a novel integrative approach. This review will enable the recognition of similarities, differences, and specific research patterns between system-delivered and teacher-delivered adaptivity. Additionally, the review generally determines what the field knows most and least about and derives an agenda for future research on yet underexplored aspects of adaptivity in schools. Due to the conceptual ambiguity among related terms such as personalization or individualization, we deliberately chose to focus on adaptivity and stay within the boundaries of a single construct. In addition, personalized learning is frequently used as a broad, undefined buzzword in both academic and policy contexts. Compared to adaptivity, it is less commonly tied to established theoretical models or systematically developed frameworks. Our choice reflects a commitment to grounding the review in a conceptual and empirical tradition that has undergone substantial refinement over more than a decade of scholarship.

To present the status quo of research on adaptive LIT in schools based on five selected years of research on the topic, we take a descriptive approach to answer the following four research questions with a pre-registered systematic review:

RQ 1. In which school contexts is adaptive LIT implemented?

RQ 2. Which sources inform adaptive LIT in schools, and how are these sources assessed?

RQ 3. How is adaptive LIT in schools operationalized, and who delivers it?

RQ 4. Which learning outcomes are targeted with adaptive LIT in schools?

These research questions are guided by the Ada-LIT framework and address all six components, providing the review with a particularly high level of detail in mapping studies on adaptivity in schools. We do not assess the methodological rigor of each study, as it would not meaningfully alter the descriptive insights we seek to provide, and it would not serve the aim of mapping the conceptual and practical landscape of current research on adaptive LIT in schools. In the discussion of the results of this review, we will appraise the status quo to make suggestions for future research and derive implications for research and practice.

3. Method

We used the SALSA framework (Booth et al., 2012; Grant & Booth, 2009) for this review and followed the steps of search, appraisal, synthesis, and analysis. More precisely, and as suggested by the U.S. Department of Education (2017), we proceeded in five steps to 1) develop a review protocol, 2) identify relevant literature, 3) screen the search results, 4) review the selected articles, and 5) report the findings. This systematic review was pre-registered. The review protocol, search results, and coding rubrics are publicly available on the Open Science Framework (OSF; https://osf.io/6qwsk/?view_only=7c8db0a37a43462a95a1017ce347e196).

3.1. Data sources and search strategy

We searched the two databases ERIC ProQuest and PsycINFO for English-language articles on adaptive LIT in schools published between 2018 and 2022. By choosing the time frame from 2018 to 2022, we included research parts from before, during, and after the COVID-19 pandemic in almost equal parts. We believe the pandemic has boosted advances in educational technologies, including system-delivered adaptivity. Therefore, we assume that research on system-delivered adaptivity might be overrepresented in the last few years; consequently, we decided to include research from before the pandemic. To ensure the feasibility of the review, we limited the search to five years and two databases. We chose these two databases because they are among the most relevant for educational psychology research and are recommended by the U.S. Department of Education (2017) as routinely used databases. We created our search strings based on a combination of adaptive and different synonyms for learning, teaching, and instruction or related terms (e.g., education) that we retrieved from a variety of online dictionaries and websites for synonyms (Thesaurus.com, Marriam-Webster.com, Collinsdicitionary.com, and Wordhippo.com) and used the following Boolean search strings according to the database instructions:

PsycINFO: "adaptiv* learn* OR adaptiv* instruct* OR adaptiv* teach* OR adaptiv* class* OR adaptiv* school* OR adaptiv* educat* OR adaptiv* tuition NOT 'higher education' NOT university NOT adults".

ERIC: "adaptivity adaptive learning adaptive instruction adaptive teaching adaptive class adaptive school adaptive education adaptive tuition -„higher education"-university -adults -guidance -tutoring".

The "-" in front of some terms in the search string for ERIC indicates that the research should not focus on these specific contexts. For both databases, we further specified that we are only looking for peer-reviewed journal articles, thus excluding book chapters and dissertations. Therefore, we also did not conduct a community call to include unpublished studies. More specific information on the search strings and specific automated filters for the two databases is available in the Appendix (Table A1). The searches were performed on February 21, 2023, by the first and last authors and yielded 303 search results in ERIC and 302 in PsycINFO (see OSF for search protocol). After importing all 605 search results into the software CADIMA (Kohl et al., 2018) and running an automated duplicate check, we concluded our search with 555 unique records. The large number of records resulting from the systematic database search prompted us to not conduct any other forms of additional search (e.g., backward and forward search).

3.2. Screening

3.2.1. Title and abstract screening

The articles for the final data pool were chosen using a manual two-step screening procedure. First, titles and abstracts were screened using four screening criteria: Publication date, language, keywords, and population (Table 2 and OSF). Each criterion could be answered with either "yes", "no", or "unsure". Papers moved to the full-text screening if all four criteria were met.

For the title and abstract screening, the first and last authors, along with a student research assistant, trained applying the screening rubric (Table 2) by reviewing 20 randomly selected records to familiarize themselves with the criteria. Next, they independently screened 50 titles and abstracts until an interrater reliability of Fleiss' Kappa of 0.8 was established for each criterion (six rounds). Disagreements were discussed and resolved after each independent screening round, and the criteria were refined (mostly for keywords and population). Then, all 555 titles and abstracts were screened by two researchers who resolved final disagreements through discussion. Of the 555 unique records, 136 papers passed the title and abstract screening criteria (rated with "yes" on all four criteria) and were included in the full-text screening pool. Before proceeding, one record without access to the full text and one overlooked duplicate were excluded.

Table 2
Title and abstract screening criteria.

Criteria	Inclusion	Exclusion
Publication date	2018–2022	Prior to 2018; after 2022
Language	English language	Any other language
Keywords	Must include "adaptive" or "adaptivity" AND "learning", "instruction", "teaching", "education", "school", "class", "tuition", "teacher"; adaptive LIT is intentionally used as LIT method but does not have to be the focal investigation (investigation of technology acceptance but the instructional method is an adaptive game in math) Examples: adaptive competence/expertise, adaptive practices, adaptive curriculum, adaptive feedback, adaptive content	Keywords are not included; adaptive LIT is an implication or future suggestions (e.g., only mentioned in the discussion) Examples: adaptive assessment, adaptive behavior/strategies, adaptive skills, adaptive functioning, adaptive intelligence, adaptive beliefs
Population	Receivers of adaptive LIT are elementary to high school students (all types of schools); teachers who practice adaptive LIT in elementary to high school Examples: primary school, secondary, school, grades 1–8 or 1–12, pre-service or in-service teachers	People in any other (educational) setting; teachers who receive adaptive LIT in their training/professional development without the goal of implementing it in their own teaching; article is no original research (e.g., review/meta-analysis, essay) Examples: Kindergarten/pre-school, higher education (e.g., university, college), adult education (under)graduate students, faculty, extension program, students with minor/major in subject X

3.2.2. Full-text screening

In the full-text screening, the same criteria as those applied to title and abstract screening were used to confirm that the four criteria were indeed met (Table 2). Additionally, full texts were screened for an operationalization of adaptive LIT (i.e., description of how adaptive LIT was designed, implemented, or measured in the Methods or Results section of the paper). To be included in the final pool of papers, the full text had to meet the four screening criteria, describe empirical research, and provide an operationalization of adaptive LIT.

For the full-text screening, the first author and the student research assistant trained by applying screening criteria to the full text of three random papers. They then conducted additional training, consisting of two rounds of independent screening of approximately 10 % of the data (13 and 14 papers), to confirm the consistent use of the screening criteria, address any doubts or uncertainties, and refine the rubric. Following Higgins et al. (2011), we double-screened all full texts. This consensus approach made the calculation of Kappa redundant. Given the interpretive nature of several coding categories, the lack of reporting standards, and the methodological diversity of the included studies, chance-adjusted agreement metrics such as Fleiss' Kappa could have produced misleadingly high agreement based on straightforward cases, while obscuring discrepancies in more complex ones. Using such metrics to justify single-coder coding risks a reduction in rigor, especially in the face of unique or ambiguous papers. Double-coding all studies ensured the consistent application of the scheme and allowed for the collaborative resolution of challenging cases, providing a more robust and appropriate approach for our review (Higgins et al., 2011). Thus, during the two training rounds of independent screening, we focused on discussing the very few disagreements and ensuring a consistent

application of the criteria before screening all papers. Finally, both researchers independently screened all 134 full texts and resolved disagreements through discussion.

Of the 134 articles, 46 were excluded because they did not meet all four screening criteria, and 19 were excluded because they did not include an operationalization. Thus, 69 papers met all full-text screening criteria.

Fig. 2 illustrates the process from the initial search, screening for eligibility, to final inclusion, as outlined in the PRISMA guidelines (Moher et al., 2009).

3.3. Data extraction (coding)

Next, the first author and a research assistant extracted relevant data from the final data pool of 69 full texts to answer our research questions. Based on the Ada-LIT framework and prior literature on adaptive LIT, we developed a top-down rubric to code for the six components: context, source, assessment, delivery, operationalization, and outcome, allowing it to capture a wide range of studies. If a paper did not include the information for a component, it was coded with a 0. If the paper included the information for a component, the sub-component that applied (e.g., for the type of school, possible sub-codes listed the different types of school, such as elementary school, middle school, and secondary school) was coded for (multiple sub-components could apply to the same paper). The entire coding scheme for the components and sub-components used for data extraction is presented in the Appendix (Table A2). After two rounds of independent coding training on approximately 20 % of the data (13 and 14 papers), the first author and a research assistant coded all full texts using this coding rubric. They discussed all disagreements to reach an agreement and finalized the coding together.

To code the operationalizations of adaptive LIT, we used the software Dedoose (Dedoose, 2021). During the full-text data extraction, the first author and the research assistant independently annotated sentences or entire sections in the full-text PDF documents imported into the software with the code "operationalization" when these described how adaptive LIT was implemented or realized. All annotated sections were later downloaded, and the annotated text passages of the two researchers

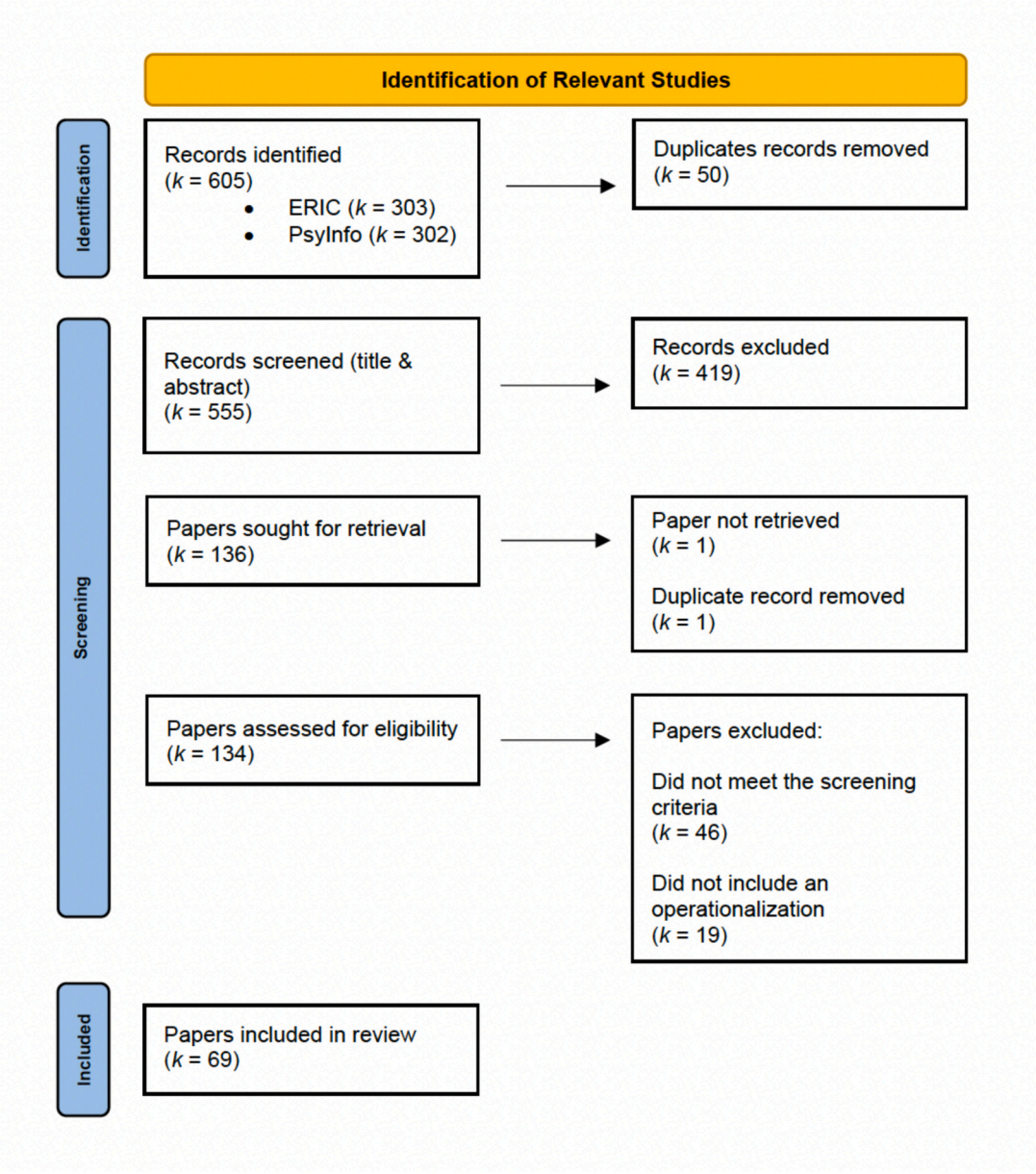

Fig. 2. PRISMA process flowchart.

were compared and discussed to determine the final set of text excerpts that best represented the operationalization as reported in each study. Only afterward were the operationalization excerpts analyzed in detail.

To capture a wide range of adaptive LIT implementations in detail, we developed a more fine-grained coding scheme for the ten subcomponents of operationalization (difficulty progression, adaptation of topic, adaptive avatars/chatbots, adaptive accessibility, mode of representation, adaptive feedback, adaptive support, adaptive lesson planning, adapting lesson plan, adaptive navigation (functionality), conceptive progression), using the adaptivity taxonomy by Plass and Pawar (2020) as reference. The coding scheme for the operationalization component is presented in the Appendix (Table A3).

Using this coding scheme, the first and last authors independently coded all excerpts of the operationalizations and discussed their disagreements to reach a final agreement.

3.4. Data analysis (synthesis)

To answer our four research questions, we calculated the absolute and relative frequencies (in percentage) for each component and subcomponent. Additionally, we conducted exploratory, descriptive analyses across components to illustrate similarities and differences between studies on system- and teacher-delivered adaptive LIT.

4. Results

We present the results organized according to our four research questions guided by the Ada-LIT framework. A summary of all results for each of the 69 papers, respectively, can be found in OSF.

4.1. Research question 1: Context of adaptive LIT

To answer our first research question regarding the context in which adaptive LIT is investigated (Component 6 in the Ada-LIT framework), we analyzed the school setting (school type, grade level, subject) in which adaptive LIT was implemented, as well as the population (age) for whom it was implemented.

4.1.1. School type, grade level, and age

Figs. 3, 4, and 5 provide information about school types, grade levels, and students' ages. Thirty studies (43.48 %) did not specify the school type, 20 studies (28.99 %) included no information about the grade, and 56 studies (81.16 %) did not indicate students' age. However, each study provided at least one type of context information. Most studies investigated adaptive LIT in elementary schools, followed by secondary schools (Fig. 3). Most of the research was conducted with fifth-grade students. The higher grades (11th and 12th) were the least represented (Fig. 3). In line with this, students aged eleven were the most represented in the samples, closely followed by those aged twelve (Fig. 5). Additionally,

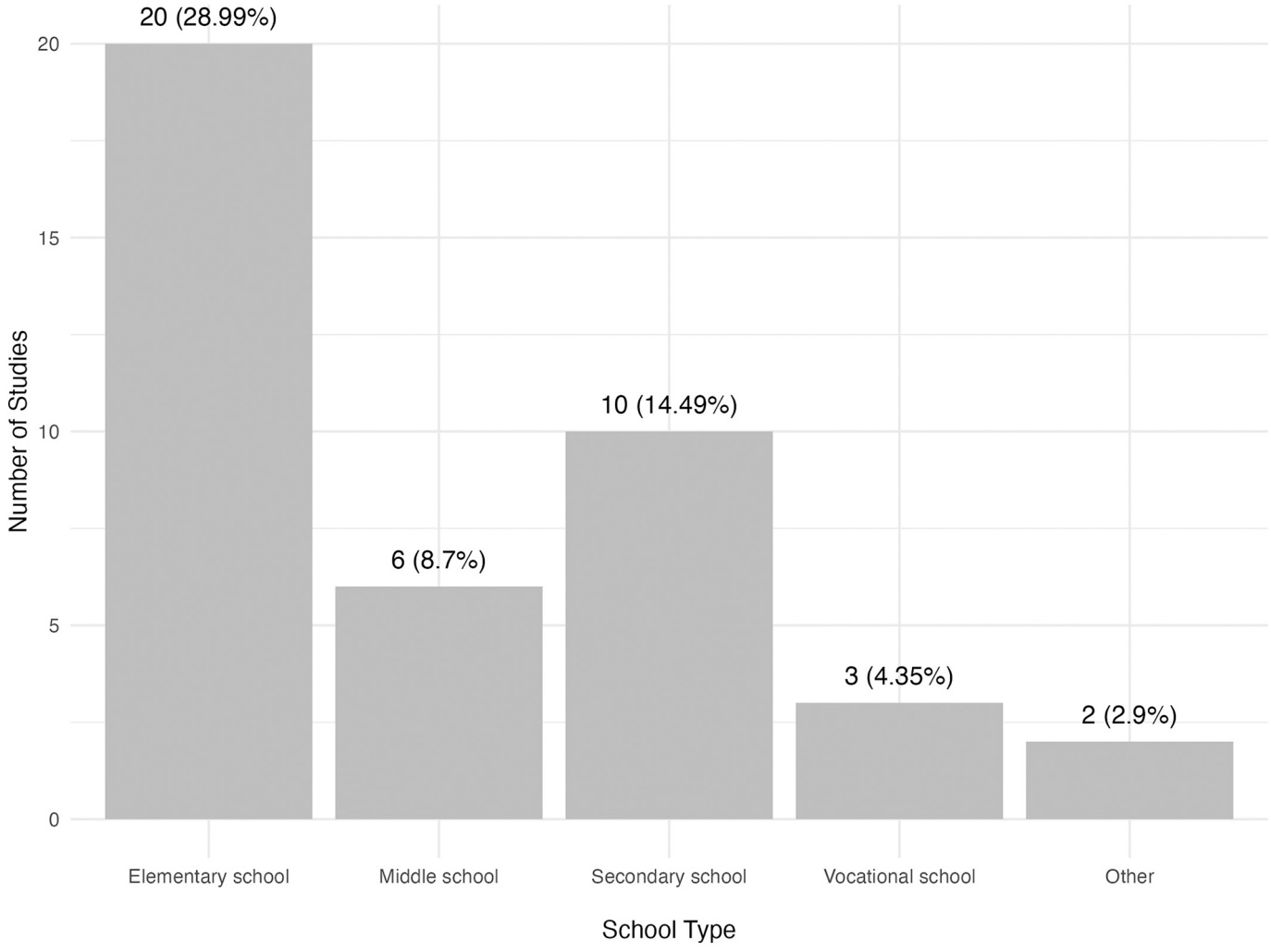

Fig. 3. School types in adaptive LIT research.
Note. The categories are not mutually exclusive; one study can be conducted at several school types. Thus, several categories can be applied to a single study.

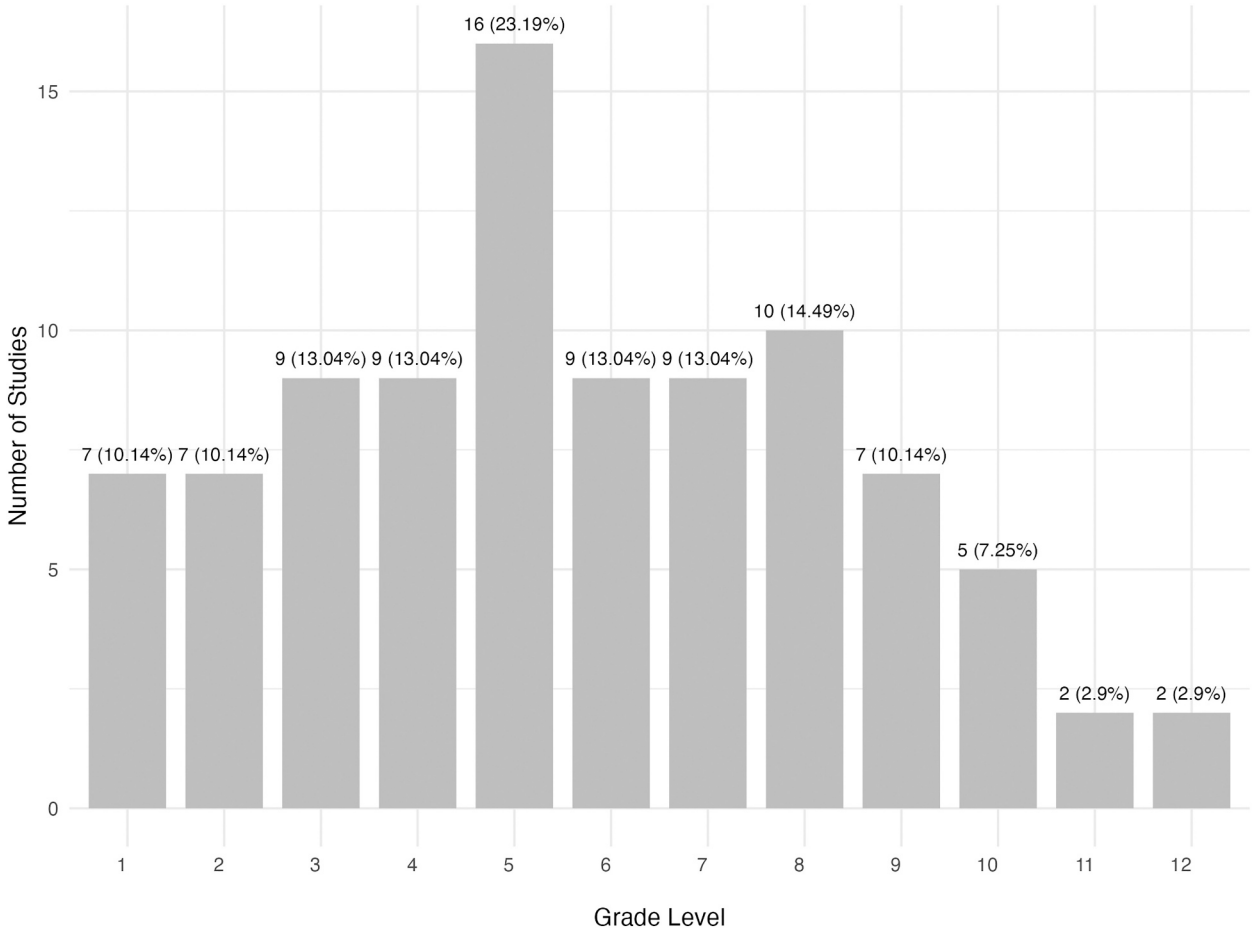

Fig. 4. Grade levels in adaptive LIT research.
Note. The categories are not mutually exclusive; a single study can be conducted across multiple grade levels. Thus, several sub-components can be applied to the same study.

two studies (2.90 %) focused on students with special needs, such as attention deficits and intelligence disorders.

4.1.2. School subject

Table 4 shows the school subjects in which adaptive LIT was implemented in the studies. Half of the studies are related to math, followed by science. Adaptive LIT was used the least in informatics. Nine studies (13.04 %) did not specify a subject, and four (5.80 %) researched adaptive LIT in more than one subject.

4.2. Research question 2: Adaptive source and assessment

To address our second research question, we explored the sources of adaptive LIT (i.e., students' characteristics) and how these are assessed (Components 1 and 2 of the Ada-LIT framework). For assessment, we coded the type of assessment, the frequency of assessment, and whether dashboards were used.

4.2.1. Adaptive source

The learner characteristics used as adaptive sources clearly show the high frequency of using performance as an adaptive source across studies (Table 5). In contrast, non-performance-related variables such as emotions and demographic characteristics were rarely used as adaptive sources. Fifty-one studies (73.91 %) used a single adaptive source, and three (4.35 %) used two. Moreover, 15 studies (21.74 %) included no information about the sources. Out of these 15 studies, ten still indicated a type of assessment.

4.2.2. Types and frequency of assessment

Most studies assessed the source with trace data (Table 6). The second most common type of assessment was observation. In a few cases, adaptivity was based on students' subjective ratings (i.e., adaptability). Traditional tests and physiological measures were used very rarely. Seven studies employed more than one type of assessment (10.14 %; i.e., multimodal assessment). Among these, six studies assessed one source using different types of assessments, while one study assessed two different sources using two types of assessments. Moreover, teacher dashboards were utilized in the assessment process in 15 studies (21.74 %). Nine studies (13.4 %) did not include any information on the type of assessment.

In line with the results for the type of assessment, we found that in most studies, data was assessed dynamically, meaning several times or constantly throughout the adaptive intervention. Static (i.e., one-time) assessments were used less frequently. In five studies (7.25 %), both approaches were applied, for example, because students were assessed at the beginning to be assigned to a specific path. Then, within this path, they were repeatedly assessed again for continuous adaptations in that path. Nine studies (13.04 %) did not provide information on whether the assessment was dynamic or static (Table 6).

4.3. Research question 3: Operationalization and delivery

Our third research question concerns the implementation of adaptive LIT in schools. It includes operationalization and the level and granularity of the operationalization (Component 3 of the Ada-LIT

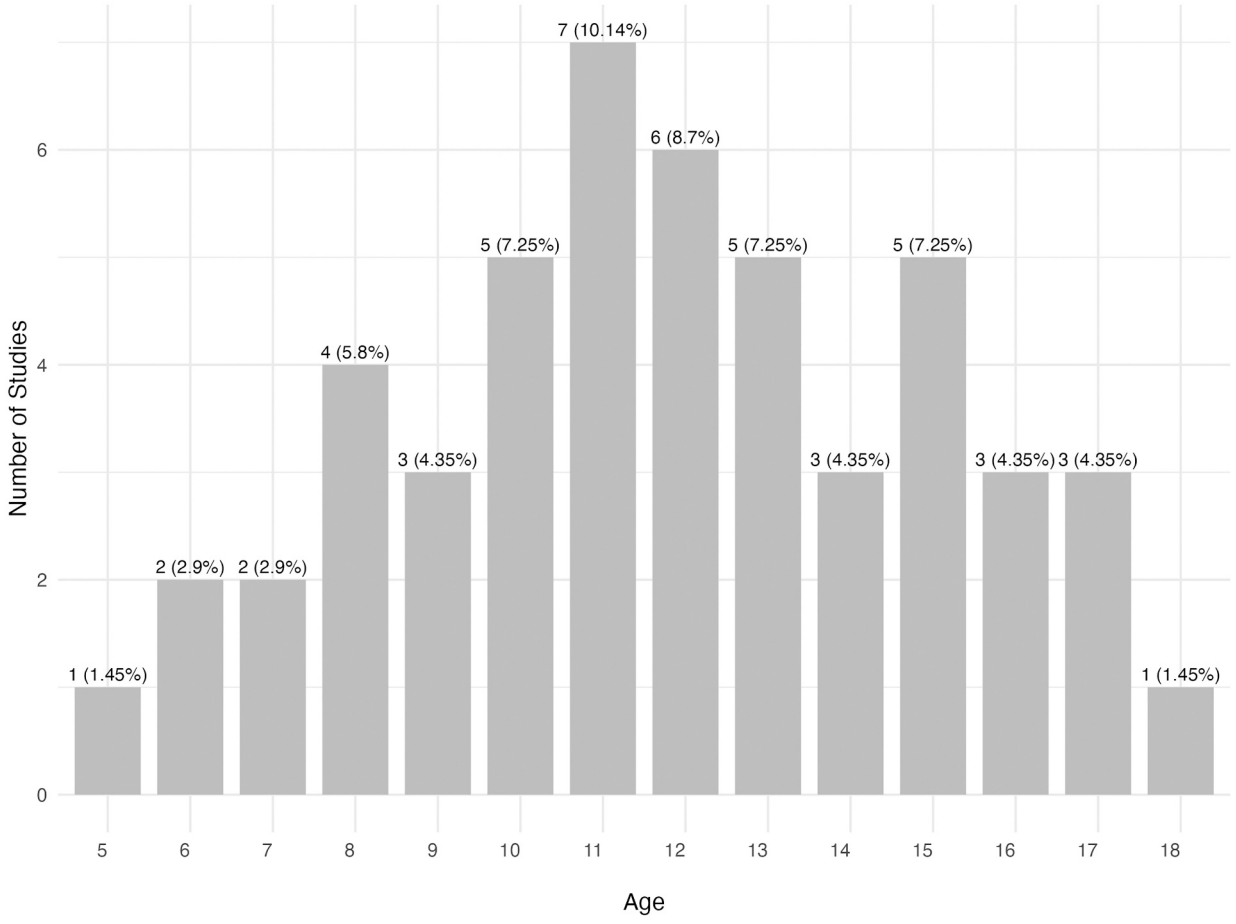

Fig. 5. Students' age in adaptive LIT research.
Note. The categories are not mutually exclusive; one study can be conducted with students of several ages. Thus, several categories of this sub-component can apply the same study.

Table 4
School subjects in adaptive LIT research.

School Subject	Number of Studies	Percentage
Math	35	50.72
Science	10	14.49
Literacy	10	14.49
L2/Foreign languages	7	10.14
Physical education	3	4.35
Informatics	2	2.90

Note. Categories are not mutually exclusive, and several subjects can apply to the same study.

Table 5
Adaptive sources as basis for adaptive LIT.

Adaptive Source	Number of Studies	Percentage
Performance	45	65.22
Cognitive abilities	6	8.70
Emotions and motivation	5	7.25
Demographic characteristics	1	1.45

Note. Sub-components are not mutually exclusive, and several sub-components can apply to the same study.

framework) and delivery (Component 4 of the Ada-LIT framework).

4.3.1. Delivery of adaptive LIT

Table 7 shows that most studies investigated adaptive LIT delivered

Table 6
Type and frequency of assessment of adaptive source.

Type and Frequency	Number of Studies	Percentage
Type of Assessment		
Trace	42	60.87
Observation	15	21.74
Test	3	4.35
Subjective rating	6	8.70
Physiological data	1	1.45
Frequency of Assessment		
Dynamic	59	85.51
Static	7	10.14

Note. Sub-components are not mutually exclusive; thus, several sub-components can apply to the same study.

Table 7
Delivery of adaptive LIT.

Delivery	Number of Studies	Percentage
System	43	59.15
Teacher	34	36.62

Note. Eight studies included both teacher- and system-delivered adaptivity.

by a system. Eight studies (11.59 %) included both teacher- and system-delivered adaptive LIT.

4.3.2. Operationalization of adaptive LIT

The most common operationalizations were adaptive navigation, followed by adaptive support, difficulty progression, and adaptive feedback. Twenty-two studies (31.88 %) used one form of operationalization, while most studies employed more than one operationalization to implement adaptive LIT. Fig. 6 shows the distribution of the types of operationalizations (sub-components) across all studies. Fig. 7 provides further insights into the different categories for each sub-component (for those sub-components with fine-grained coding, see Table 4).

4.3.3. Level and granularity of operationalization

Most operationalizations were micro-level adaptations, while macro-level adaptations occurred less frequently (Table 8). Three papers (4.35 %) investigated adaptivity on both the micro- and macro-levels.

Aligned with the operationalization level, most operationalizations focused on individual students rather than small groups or the whole class (Table 8). Nine studies (13.04 %) did not provide information on the level of granularity of the operationalization. Furthermore, eight studies (11.59 %) adapted on more than one level of granularity.

4.4. Research question 4: Targeted outcomes of adaptive LIT

To answer the fourth research question and determine the purpose of using adaptive LIT in schools, we examined the targeted outcome variables in the studies (Component 5 in the Ada-LIT framework). It became evident that the goal in almost half of the studies was to improve students' performance (Table 9). In comparison, motivational and affective characteristics were targeted rarely. More than one outcome was targeted in twelve studies (17.39 %). Overall, 14 studies (20.29 %) did not specify a targeted outcome.

4.5. Explorative comparisons of system- and teacher-delivered adaptivity

We examined the results of research on system-delivered versus teacher-delivered adaptive LIT for components 1, 2, 3, and 5 of the Ada-LIT framework to identify similarities and differences. Some papers contain both system- and teacher-delivered adaptivity (e.g., two interventions in one study or a combination of both types of delivery in one adaptive intervention). For completeness, we treat these articles as a separate category.

4.5.1. Comparison of source of adaptation (component 1)

A comparison of the sources of adaptation used shows that system-delivered adaptivity primarily relies on students' performance. There was no information on the source for three studies (8.57 %) on system-

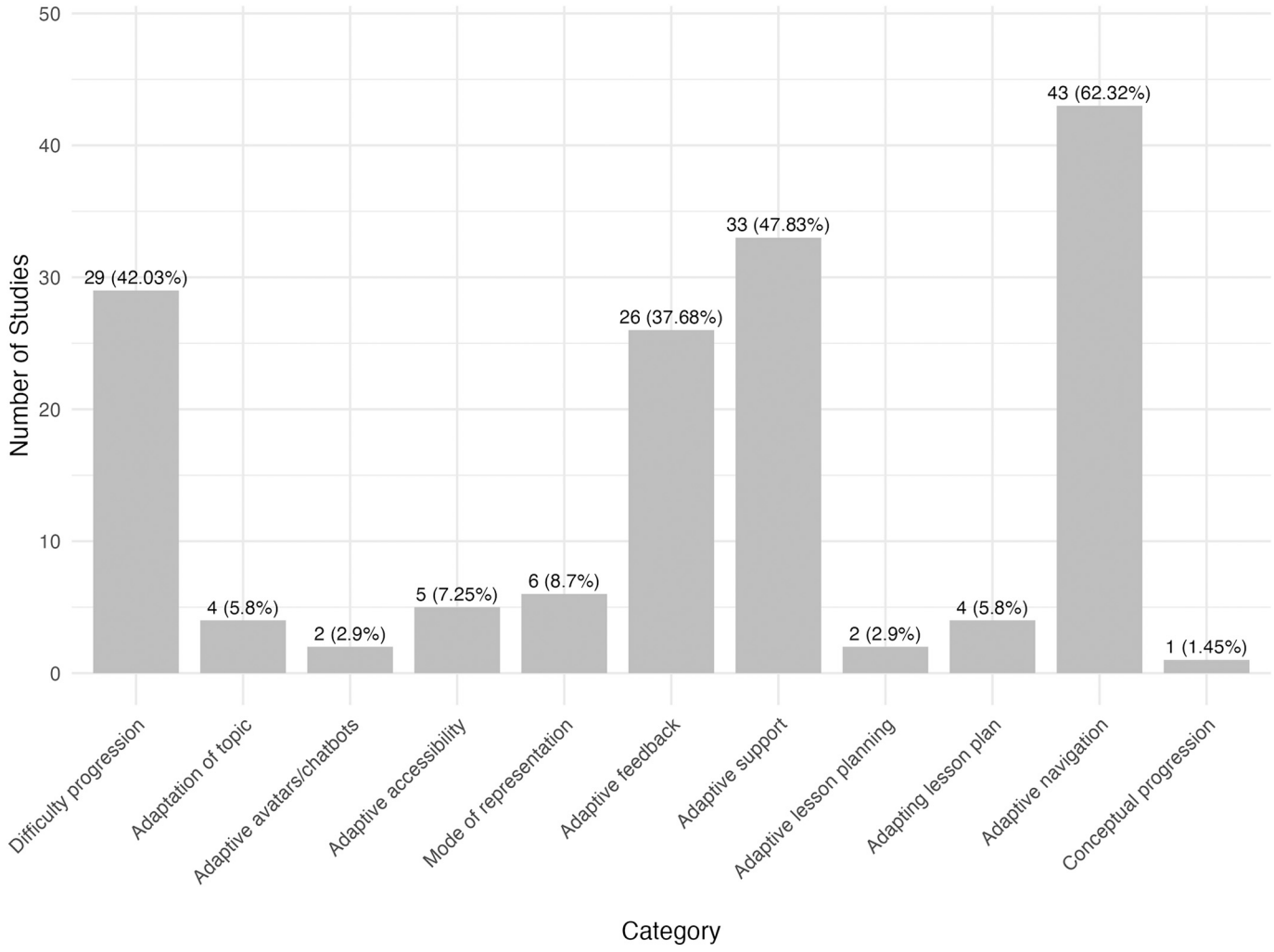

Fig. 6. Types of operationalization of adaptive LIT.
Note. Sub-components are not mutually exclusive; therefore, several sub-components of operationalization can apply to the same study.

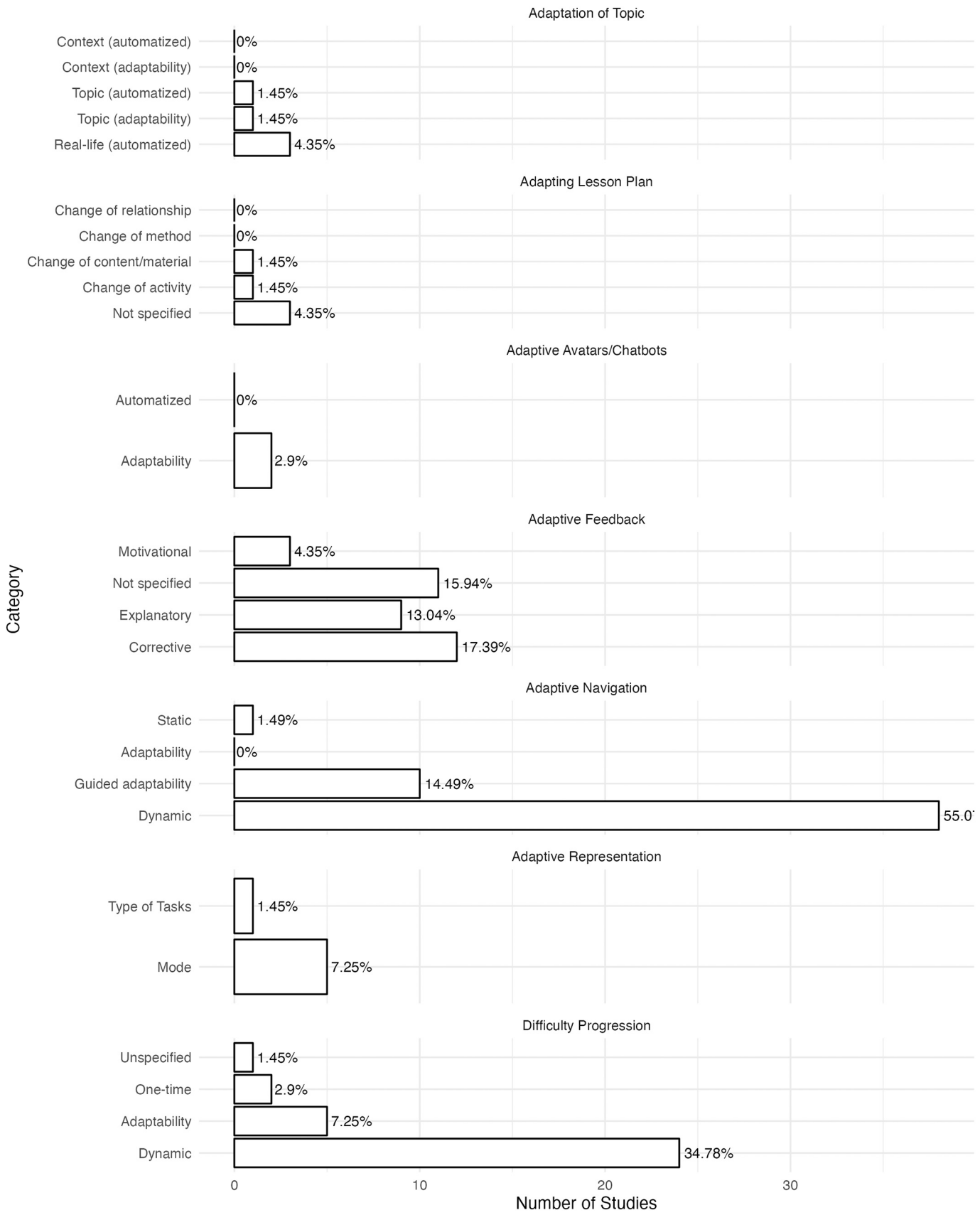

Fig. 7. Adaptive LIT operationalizations: sub-components and their categories.
Note. Sub-components and categories are not mutually exclusive, and several sub-components and categories can apply to the same study.

Table 8
Level and granularity of operationalization of adaptive LIT.

Level and Granularity	Number of Studies	Percentage
Level		
Micro	65	94.20
Macro	7	1.44
Granularity		
Individual	56	81.16
Small group	7	10.14
Whole class	5	7.25

Note. Sub-components of level and granularity are not mutually exclusive; thus, both levels and several levels of granularity can apply to the same study.

Table 9
Outcomes in adaptive LIT research.

Outcome Variable	Number of Studies	Percentage
Performance	31	44.93
Interdisciplinary/transferable skills	2	2.90
Cognitive skills	3	4.35
Computational skills	2	2.90
Cognitive load	1	1.45
Motivation	3	4.35
Engagement	4	5.80
Emotions	2	2.90
Self-efficacy	3	4.35
Learning attitude/satisfaction	4	5.80
Interest	2	2.90

Note. Sub-components are not mutually exclusive, and several sub-components can apply to the same study.

delivered adaptivity. Two studies included two sources (5.71 %). In comparison, teacher-delivered adaptivity was also based on performance in almost a third of studies, yet it played a much less central role (Fig. 8). There was no information on the source for almost half of the studies on teacher-delivered adaptivity (k = 12, 46.15 %). One study (3.85 %) included two sources. The groups had no relevant differences for the other sources due to their low occurrence.

4.5.2. Comparison of assessment of source (component 2)

When comparing the types of assessment of the source, it is noticeable that teachers assessed learner characteristics primarily with observations (Fig. 9). In contrast, system-delivered adaptivity almost exclusively relied on trace data. In six studies (17.14 %) on system-delivered adaptivity and in one on teacher-delivered adaptivity (3.85 %), data were assessed multimodally. Studies in which both systems and teachers delivered adaptivity relied entirely on trace data.

4.5.3. Comparison of operationalizations (component 3)

A comparison between different operationalizations of adaptive LIT in studies with delivery through teachers versus systems highlights clear differences. While most system-delivered adaptive LIT studies implement adaptive navigation, teacher-delivered adaptive LIT studies mostly describe adaptive support (Fig. 10).

4.5.4. Comparison of targeted outcomes (component 5)

The comparison of teacher- and system-delivered adaptivity showed no clear differences or trends regarding the targeted outcomes (Fig. 11). Performance was the most prominent outcome in both types of studies, although the proportion was comparatively higher in studies on delivery through systems. No outcome was defined in twelve studies investigating teacher-led adaptivity (17.39 %), while only nine studies investigating system-based adaptivity (13.04 %) specified no outcome. Moreover, 17 studies on teacher-delivered adaptivity (24.64 %) did not report the targeted outcomes, while only ten studies (14.49 %) on system-delivered adaptivity lacked this information. Studies with teacher- and system-delivered adaptivity targeted more than two outcomes in two studies (2.99 %) and lacked information on the targeted outcome in one study (1.45 %).

5. Discussion

Following a pre-registered protocol, this review systematically identified and analyzed 69 empirical studies on adaptive LIT in school settings, guided by four research questions: 1) in which contexts, 2) based on which source and type of assessment, 3) through which operationalizations and types of delivery, and 4) with which targeted outcome adaptations are made. We applied a dual coding strategy across all studies, focusing on the six components of the Ada-LIT framework: source, assessment, delivery, operationalization, outcome, and context. Coding was supported by the systematic tools CADIMA and Dedoose to ensure consistency and traceability. In line with the PRISMA guidelines, we provide a transparent account of our screening and coding procedures. Taken together, these elements contribute to the methodological rigor and replicability of our review and allowed us to present the full breadth of research on adaptive LIT in schools while highlighting the variations in each of the six components and their sub-components. The framework-guided approach also enabled us to extract highly nuanced descriptions of adaptive practices across multiple dimensions, and this level of descriptive granularity represents a unique contribution of our review.

Across all components of adaptive LIT, except delivery (Component 4), we observed that many papers lacked sufficient detail. Some papers completely missed information on the three key components source, assessment, and outcome. Although all papers reported on the type of operationalization, some provided this information in a superficial manner, which impeded the possibility of replication or a thorough understanding. For context, all papers included some information; yet, it is striking that more than 40 % did not include details on the type of school, and more than 10 % did not report the subject in which their research was conducted. Considering the relevance of different subject didactics (Rothgangel & Vollmer, 2022) and the differences between different school types (especially in countries where tracking is in place; Becker et al., 2017), it can be concluded that key information is missing here. This lack of comprehensive reporting in empirical studies highlights a central finding of our review: systematic and detailed reporting is necessary for effectively investigating and comparing research on adaptive LIT in schools.

First, researchers cannot properly compare or synthesize findings if publications that label their interventions as adaptive do not explain how adaptivity is implemented. Second, studies cannot be replicated if the implementations are not described in detail. Third, it is challenging to derive implementation strategies and principles if the information on all components is limited. Moreover, practitioners might struggle to build on research and implement adaptivity in their classrooms if research paints a nonspecific picture of adaptive LIT. The prevalence of incomplete information in publications and the potential consequences for research and practice stress the importance of adopting the Ada-LIT framework to facilitate rigorous investigation and transparent reporting thereof in this field of research.

The metrics reported in this review revealed clear research trends for the years 2018 to 2022, supporting the development of a forward-looking research agenda. We will discuss key findings for each component and derive future research implications for each component, respectively. We can only consider the papers that reported information on the respective components. Since the maximum percentage of papers lacking information was around 20 %, the results still give a representative overview of most included papers.

In our specific proposals for the research agenda, it is essential to consider the affordance tendencies of both teachers and systems. For example, we identified an overemphasis in current adaptive LIT research on performance-related outcomes, adaptivity research in math, and the

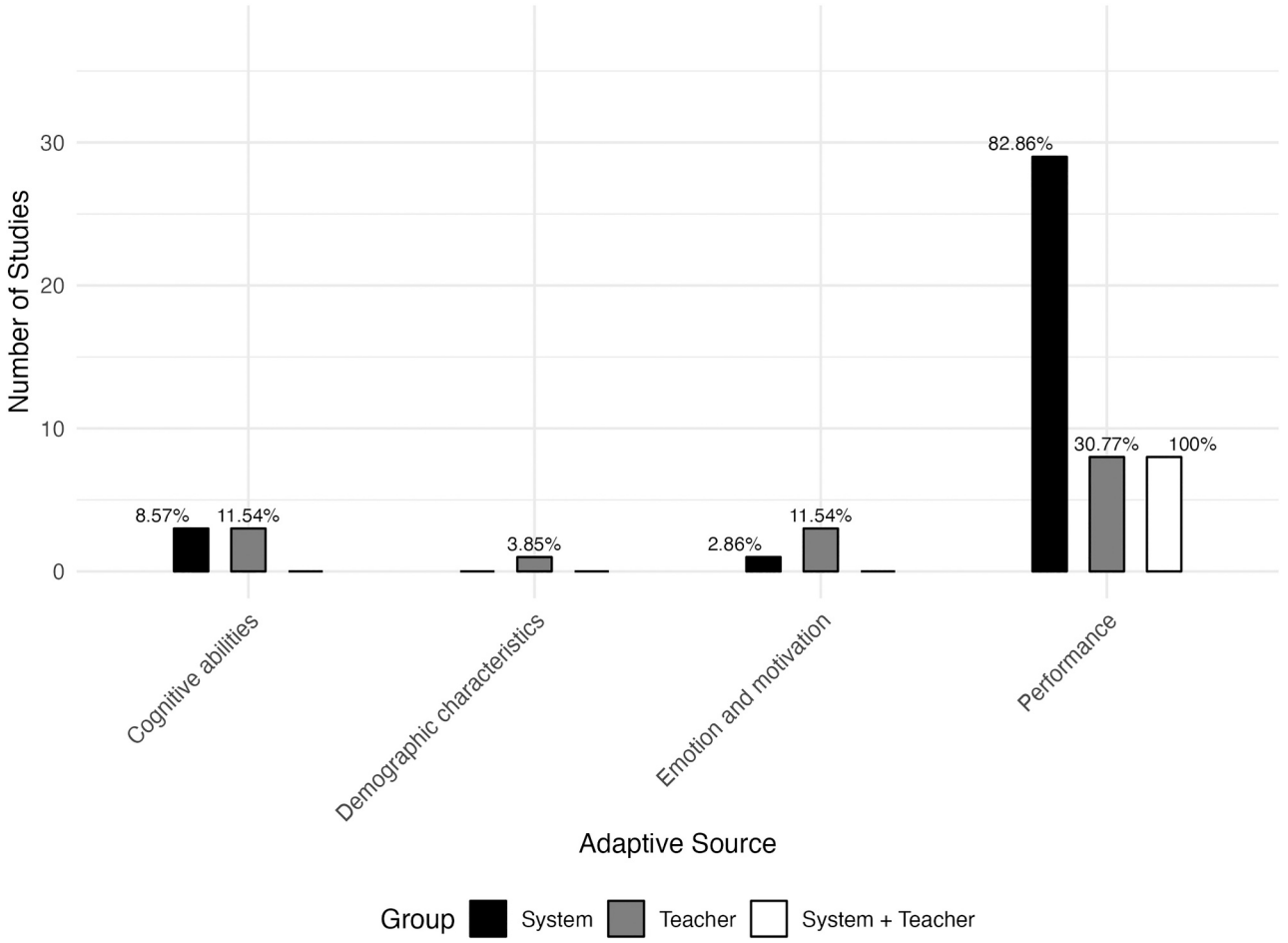

Fig. 8. Differences in sub-components of sources between system- vs. teacher-delivered adaptivity.
Note. Sub-components are not mutually exclusive, and several sub-components can apply to the same study.

predominant assessment of the adaptive source through trace data. However, we do not intend to imply conceptual neglect of other dimensions. Instead, these emphases may be caused by technological affordances and practical feasibility. For instance, performance in math and other subjects is more easily and objectively measurable than emotional engagement. Moreover, trace data are more readily accessible and less resource-intensive than physiological or observational measures. Thus, while we advocate for a broader exploration of underrepresented components and learner characteristics, we acknowledge that current trends may reflect what is most technically and logistically feasible, rather than what is considered most important. Highlighting the underrepresented aspects and comparing them to broader research trends prompts the field to engage in a broader discussion of their theoretical value for advancing adaptive research. This will illuminate whether their previous neglect stems from limited relevance or from methodological challenges and the affordances of current learning environments. In the discussion, we outline arguments in support of their theoretical relevance and reflect on the challenges that may arise when incorporating these aspects into future investigations. As technological possibilities evolve, new forms of adaptivity may become more prominent in both research and practice. Thus, we can assume that the limitations will decrease at least in the research strand for system-delivered adaptivity.

5.1. *The context of adaptive LIT (component 6)*

The context of adaptive LIT describes the school setting (school type, grade level, subject) and the population (age) for which adaptive LIT is implemented. In the studies included in our review, we noticed a lack of comprehensive contextual information across studies. Almost half of the studies did not specify the type of school involved, and around one-third omitted grade level details.

5.1.1. *Types of schools, age, and grade level*

Among the studies that specified their context, most research was conducted in elementary schools, and accordingly, with younger students in lower grade levels. A possible explanation for this is structural: as students progress in their academic careers, standardized assessments and regulations increase, especially in middle and high school. The pressure to meet these standards can limit flexibility for (participating in studies on) adaptive LIT, as deviations from the planned lessons can be challenging within a strict curriculum.

Another explanation may be the importance of addressing individual needs in early education, where foundational skills are established. Falling behind in elementary school can be difficult to overcome later, making adaptive LIT a crucial means to prepare students for secondary education without requiring additional time resources (Davison et al., 2004).

Few studies investigate adaptive LIT for students with special needs, despite their high demand for tailored support. However, adaptive LIT seems needed and feasible in inclusive school settings (Bryant et al., 2019) or special schools with smaller class sizes (Weishaupt, 2017). Thus, this finding might be an artifact of the search term adaptivity. Other research strands focusing on special (needs) education might partly overlap with adaptive LIT principles (Westwood, 2018) but operate under different labels. Bridging these research areas with

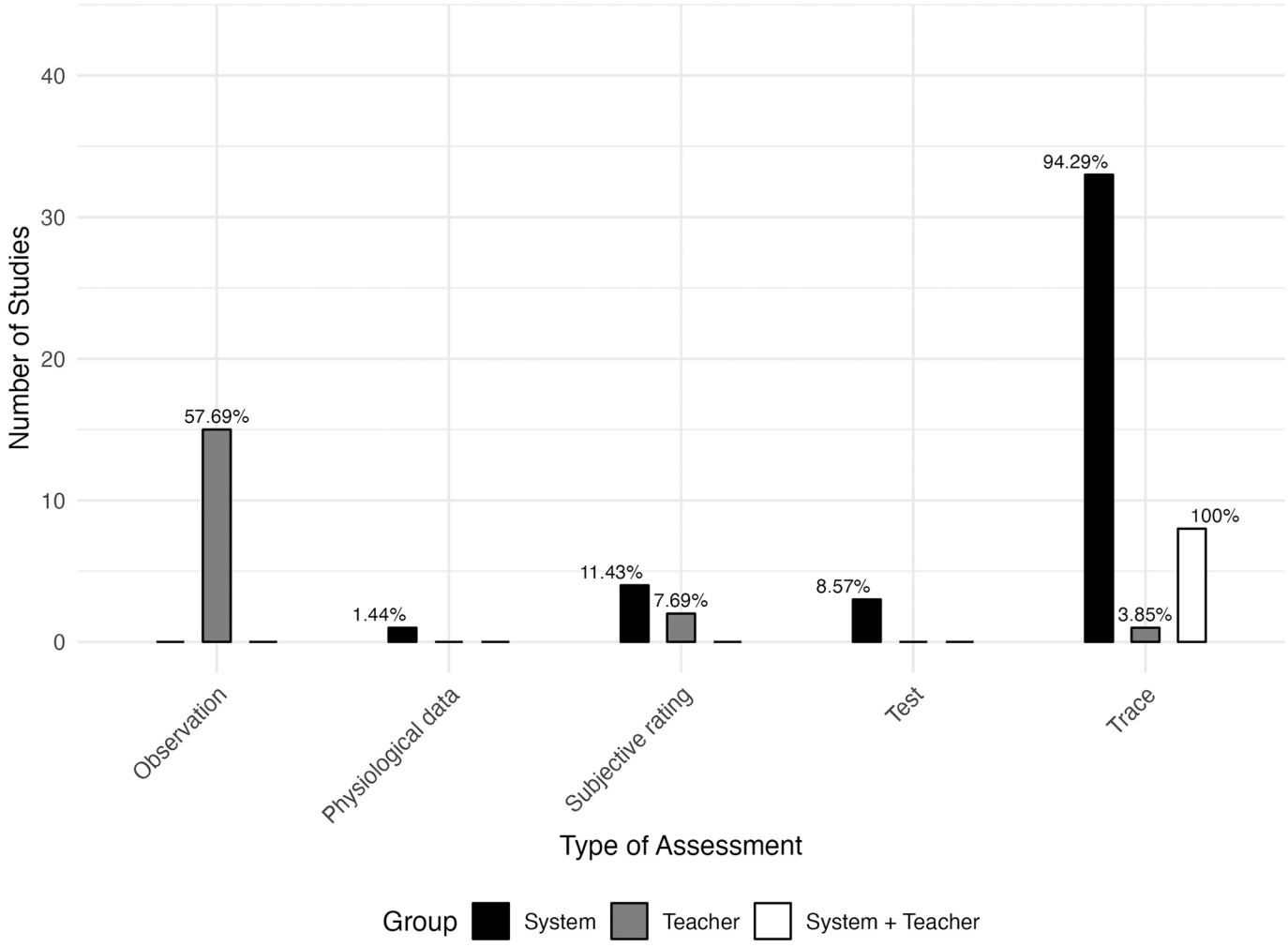

Fig. 9. Differences in types of assessment between system- vs. teacher-delivered adaptivity.
Note. Sub-components are not mutually exclusive, and several sub-components can apply to the same study.

consistent terminology could provide more comprehensive insights into adaptive LIT across diverse populations and, therefore, into adaptive LIT across various school contexts. However, there still seems to be a gap in creating inclusive adaptive systems upfront (Kazimzade et al., 2019), and future research should focus more on making systems more accessible for students with special needs.

5.1.2. School subjects

Regarding school subjects, math dominates adaptive LIT studies, with math instruction being adaptive in approximately half of the studies. Math is a subject in which it is comparably easy to measure objective performance, the most common source and targeted outcome of adaptivity. Math practice tasks often have one correct solution, and any error implies some misunderstanding. This clarity allows adaptive systems to identify performance gaps and adjust the instruction accordingly. In contrast, subjects like literacy often involve tasks such as essay writing that permit multiple valid approaches and solutions. This makes it more challenging to design system-delivered adaptivity, as programming an algorithm to interpret diverse responses and adapt instruction is more complex (Seßler et al., 2023). This may also explain why some school subjects, such as social sciences or music and arts, did not appear in any of the reviewed studies.

5.2. Learner characteristics as source (component 1)

5.2.1. Performance

The systematic analysis of the learner characteristics used as a source in the analyzed studies showed a strong reliance on performance data across all studies. Performance, as defined in our coding scheme, falls in the category of domain-dependent information and includes students' knowledge about and understanding of a specific topic or type of task (Shute & Towle, 2003). Several potential reasons explain why this finding is no surprise, considering the pivotal role of performance in educational research and practice.

First, research has repeatedly demonstrated that the effectiveness of instructional interventions varies as a function of learners' prior knowledge (Bach et al., 2025; Chernikova et al., 2020; Reinhold et al., 2020; Wang et al., 2010). For instance, the expertise-reversal effect suggests that learners with less prior knowledge benefit from more instructional support, while learners with more prior knowledge thrive, especially when less guidance is provided (Kalyuga, 2007). Accordingly, it seems plausible to use performance as a central source for adaptations and precisely target students' strengths and weaknesses in terms of (domain) knowledge.

Second, performance is often used to differentiate students in their educational journey. Many countries implement school tracking (Hallinan, 1994) or ability grouping (Tieso, 2003) based on students' (elementary school) performance to provide instruction aligned with their needs (Hattie, 2002). To a certain extent, this idea also corresponds

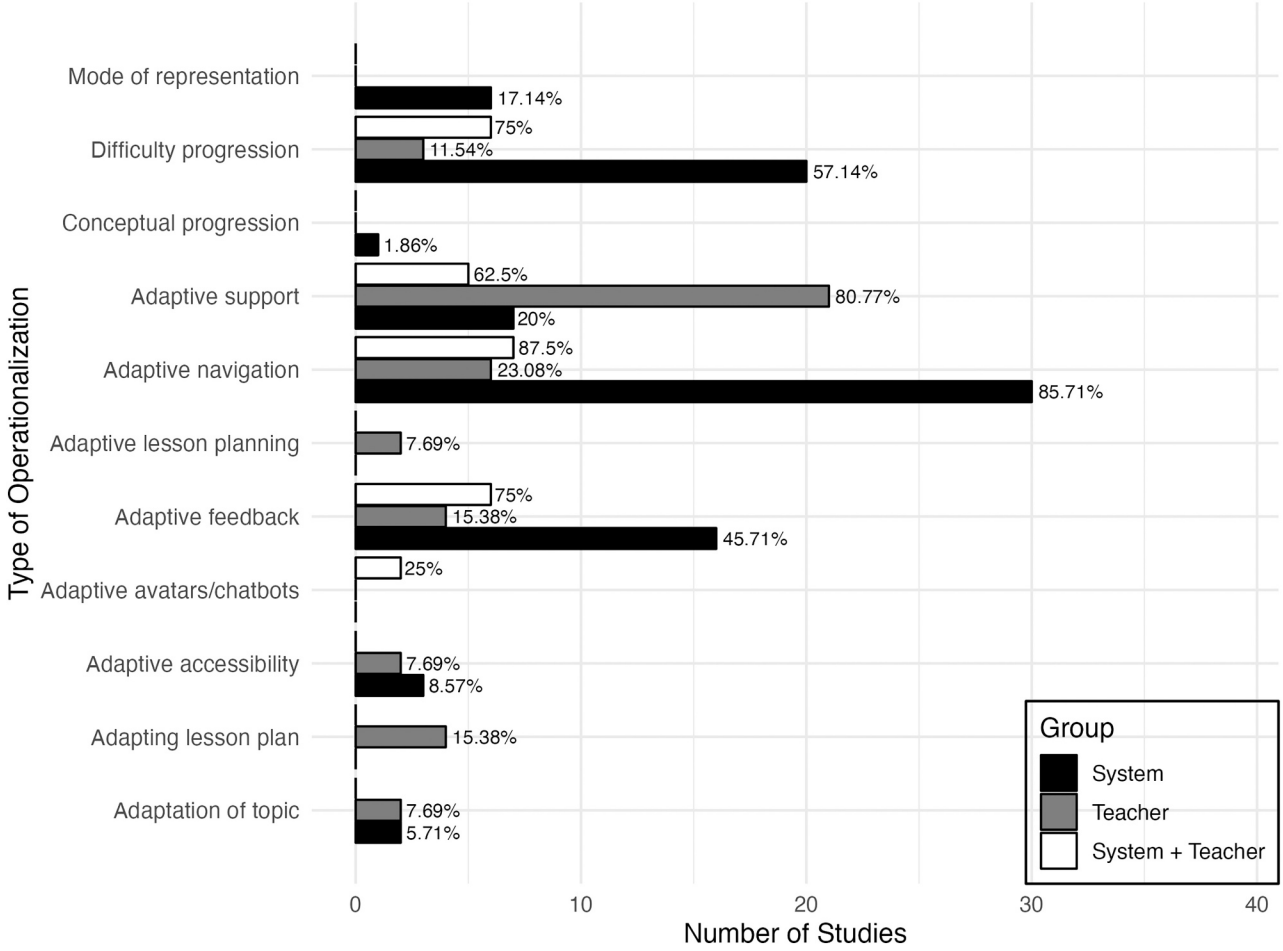

Fig. 10. Differences in sub-domponents of operationalizations between system- vs. teacher-delivered adaptivity.
Note. Sub-components are not mutually exclusive, and several sub-components can apply to one study.

to adaptivity in teaching, which aims to provide the most suitable instruction for each student's level of performance. However, while adaptive LIT is supposed to counteract educational inequity, tracking often perpetuates it, especially in the early stages of schooling. Tracking reinforces the so-called scissor-effect (Ditton et al., 2005), which implies that students at non-academic track schools fall behind compared to their equally performing peers at academic track schools (Herrmann & Bach, 2025). Moreover, it might create or reproduce segregated social groups that no longer meet often due to later career opportunities and the associated divergent SES (Ansalone, 2001; Oakes, 2005; Reichelt et al., 2019). Adaptive LIT with performance as the source allows instruction to serve different needs within the same school and classroom. Accordingly, its subtlety is an advantage of adaptivity informed by students' performance. Students are not overtly categorized based on their performance. Instead, in cases of system-delivered adaptivity, tasks are automatically assigned to students, so that they may not even realize they are working on different tasks than their peers. This can prevent feelings of segregation or stigma, often associated with performance-based tracking (Müller & Hofmann, 2016).

Third, performance can be assessed with accessible and easy-to-implement methods like tests or trace data, making performance data more accessible and a more routinely assessed source for adaptive LIT in schools than other sources, such as intelligence. Assessing the latter one in schools, for example, might also be challenging due to ethical or data protection reasons.

5.2.2. *Cognitive abilities*

As defined in our coding scheme, cognitive abilities encompass brain capacities for thinking, reasoning, information processing, and paying attention (Ones et al., 2013) and are thus closely related to performance (Bichler et al., 2020; Hofer et al., 2018; Schwaighofer et al., 2016; Strohmaier et al., 2022). Although less frequently used as a source, they still appear more commonly than non-cognitive abilities. Although cognitive abilities and their assessment, particularly intelligence, are often critically questioned and not typically measured in schools, they play a central role in school learning (Stern, 2024; Stern & Neubauer, 2016). Thus, considering them as a source for adaptive LIT would be appropriate. Nevertheless, test procedures, e.g., for measuring intelligence, (Wechsler, 2014) are often extensive and do not cover the specific abilities relevant to a particular instructional situation or task. Moreover, handling such information about students' cognitive abilities needs to be very sensitive, as it could have a substantial (and potentially detrimental) impact on their self-concept. Thus, using cognitive abilities as a source might be more complicated compared to other sources.

Furthermore, it is essential to note that many reviewed studies described cognitive abilities only vaguely, sometimes without a clear distinction from performance, which they naturally influence at least to some extent. Thus, in some studies, we cannot be sure whether cognitive abilities or, rather, performance were assessed.

5.2.3. *Emotional and motivational characteristics*

The influence of motivation on learning has been recognized since the first experiments with rats in the early 20th century (Leeper, 1935). However, emotional characteristics in teaching and learning have only been systematically studied much later (Pekrun & Schutz, 2007). Today, there is a growing awareness in research and practice that specific

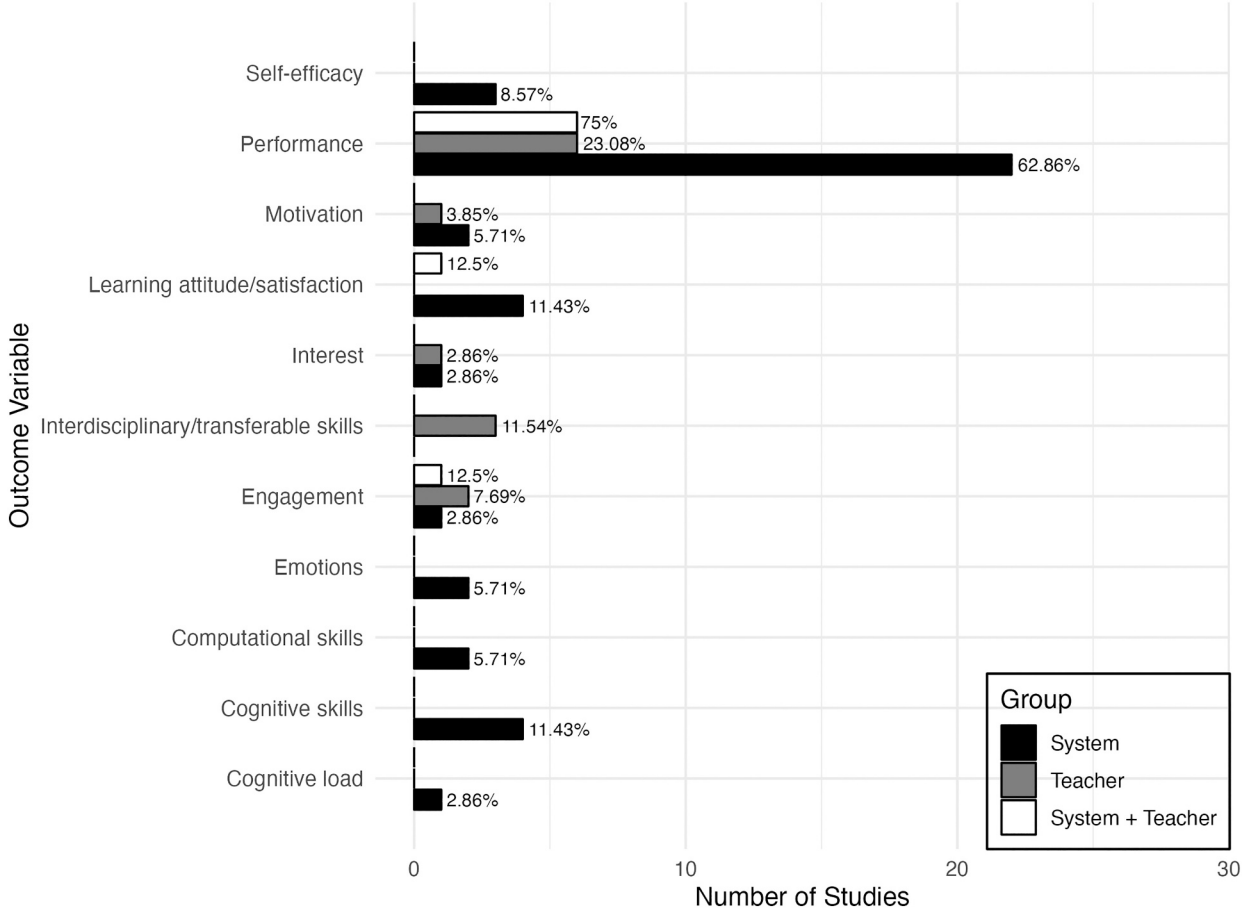

Fig. 11. Differences in outcomes system- vs. teacher-delivered adaptivity.
Note. Sub-components are not mutually exclusive, and several sub-components can apply to one study.

emotions positively affect performance (e.g., enjoyment and pride; Villavicencio & Bernardo, 2013) while others might harm it (e.g., anxiety or shame; Villavicencio, 2011). Positive and negative academic emotions can be addressed to achieve optimal learning (Tyng et al., 2017). Despite their importance, our review found limited use of emotions and motivation as sources for adaptive LIT. Their often indirect impact on learning outcomes (Hofer et al., 2022; Valiente et al., 2012) might explain this finding: For example, the level of interest, as one motivational variable, affects how intensively and often a student engages with a topic/subject, ultimately affecting their performance (Renninger, 2000; Wigfield & Cambria, 2010). This indirect influence might be considered less critical than fostering performance directly. It also requires outlining the complexity of learning processes, including developing a theory that explains how specific instructional features promote learning-relevant factors, which in turn influence learning outcomes. Testing such theories requires more sophisticated research designs and may complicate the isolation of the unique effects of adaptivity from the effects of other learning mechanisms. Moreover, assessing emotional and motivational characteristics can be more complex and less reliable (Mauss & Robinson, 2009), contributing to making them a less popular source due to practical challenges in their assessment. First, emotions are difficult to assess via subjective ratings in questionnaires. The results might be influenced by students' lack of familiarity with such questionnaires, which applies especially to younger students or those with a migration history (Elliott, 2004), making this a less reliable measure in the context of schools. Second, the assessment via physiological measures can be costly and effortful.

5.2.4. *Demographic characteristics*

Demographic characteristics, such as SES, do not have a direct (causal) effect on learning. Nevertheless, research has documented how they still influence learning through different pathways (Tan, 2024; Warren & Kersten-Parrish, 2023).

There is ample evidence for the (increasing) diversity of socioeconomic and sociocultural characteristics of students. For example, multilingualism has grown significantly among students across various countries (U.S. Census Bureau, 1973, 2014; Gogolin, 2021; Suni & Latomaa, 2012). Students with migration or refugee backgrounds often face additional challenges during instruction as they attend school in countries where they do not (yet) speak the language of instruction (Garrison & Kerper, 1999). Other research revealed that students from lower SES backgrounds may struggle with math tasks involving themes like food or money, which may be linked to real-life challenges (Muskens et al., 2024), or develop self-perceptions and characteristics that impair learning (Bach et al., 2025; Hofer et al., 2024). Similarly, learning environments can impact students' performance differently depending on their gender. Specific instructional characteristics often disadvantage girls, especially in subjects associated with the stereotype threat (e.g., in physics; Hofer & Stern, 2016; Hofer et al., 2018; Cwik & Singh, 2021). In contrast, gender-stereotypically adapted task contexts increased the performance of students of the respective gender in math (Zohar & Gershikov, 2008).

Despite this evidence, recent adaptive LIT research largely ignores demographic characteristics as sources of adaptivity. Similarly, another review in the context of adaptive computer science in higher education (Martin et al., 2022) also pointed out the marginalization of demographic information such as gender and race in designing and

evaluating adaptive systems. The authors interpreted that as an alarming finding, making the results less generalizable and potentially unsuitable for marginalized groups. Although some authors emphasize the importance of culturally inclusive adaptive systems, this aspect seems to have received limited attention to date (Kazimzade et al., 2019). Moreover, in the rare cases when such aspects are considered, there is consistent evidence of biases, such as gender stereotypes that are even enforced through AI, possibly leading to an exclusionary effect (Melis & Ullrich, 2004). Thus, the limited use of demographic information as a source of adaptivity might be a characteristic of the research strand of system-delivered adaptivity. Other research areas investigating forms of teacher-delivered adaptivity under different names prioritize these characteristics, such as research on culturally responsive teaching (Gay, 2002; Villegas & Lucas, 2007). Such research emphasizes the need to consider students' cultural backgrounds in instruction (Yamauchi et al., 2012) and shows that these factors are not entirely disregarded during school instruction.

Our review highlights a valuable opportunity for cross-pollination between these research strands, allowing each to benefit from the findings of the other and incorporate elements from one area into the other to enhance adaptive LIT in a way that respects and utilizes students' diverse cultural and demographic backgrounds. For example, adaptive learning systems could enhance accessibility by offering tasks in multiple languages or increase motivation and a sense of belonging by providing avatars that reflect diverse cultural backgrounds for students to choose from (Hayes-Roth et al., 2002).

5.2.5. Single source vs. multiple sources

The present review revealed that most studies relied on one learning characteristic as the adaptive source. However, research is increasingly moving toward learner-centered analyses, such as profile analyses (Edelsbrunner et al., 2025), which consider a variety of different characteristics of students in combination. Reducing students to a single characteristic might overlook the complexity of their needs. For example, students with less prior knowledge but high motivation may have different instructional needs than those with less prior knowledge and low motivation (Bach et al., 2025). Additionally, considering intersectional disadvantages (Loets, 2024), it might be central to acknowledge students' diversity as comprehensively as possible. Thus, once this research field has matured, it seems plausible to suggest that adaptive LIT should integrate multiple sources to adapt as precisely as possible and target specific outcomes more effectively.

Another more parsimonious option could be identifying the most relevant characteristic(s) considering the operationalization and targeted outcomes, enabling more targeted adaptive LIT (Hofer & Reinhold, 2025). Teachers are trained to possess the diagnostic competence to decide which source is most relevant or to examine different sources in parallel (Bichler et al., 2024; Shavelson & Stern, 1981). A system would need to be equipped with such diagnostic competence to act similarly to teachers. In addition, research is needed to investigate the extent to which operationalizations of adaptive LIT differ depending on which source or sources they are based on.

5.3. The assessment of the source (component 2)

Concerning the type of assessment, we discovered clear trends based on whether a system or a teacher delivered adaptivity.

5.3.1. Observation

In contrast to system-delivered adaptivity, teacher-delivered adaptive LIT primarily relied on observation as a type of assessment. Teachers' presence and role in the classroom position them ideally to observe many learner characteristics (Bowers et al., 2020; Prediger et al., 2022). For instance, teachers can infer whether students are bored or interested and whether they approach a task confidently or anxiously. Over time, they also gather information about the students' background, including their home learning environment and parental support (Leroy & Symes, 2001).

Despite its frequent use and mentioned advantages, observation as an assessment measure has limitations. Three of these are: First, accurately and in detail following and monitoring approximately 30 students in a class is challenging for one person to do. Second, expertise in diagnosing and interpreting student behavior is not innate, but rather requires practice through specific training interventions (Bichler et al., 2024; Edelenbos & Kubanek-German, 2004; König et al., 2022). Third, even after being well-trained in professional noticing, teachers' observations might be influenced by implicit biases (Staats, 2016). These biases can lead to overestimating or underestimating students' abilities based on personal affinity or other sociocultural or socio-economic characteristics (e.g., Bonefeld & Dickhäuser, 2018; Copur-Gencturk et al., 2023).

5.3.2. Trace data

The most typical assessment type for sources in the research on system-delivered adaptive LIT is trace data. Systems can assess and utilize trace data, giving real-time insights into the students' immediate characteristics. While trace data do not provide as comprehensive an assessment as teacher observations, this type is particularly effective in objectively evaluating performance. Trace data offer the distinct advantage of capturing every step and every action (including the completion of tasks) of the students in a digital learning environment. As such, systems usually track students' error rates, time on task, progression rates, and paths within a technology-enhanced learning environment. Thus, they provide insights into learning processes (Goldhammer et al., 2021; Reinhold et al., 2024) that might vary among equally performing students (Stadler et al., 2020). Therefore, trace data provide richer insights than traditional static (test) assessments (Goldhammer et al., 2017). At the same time, assessing via trace data is minimally or non-intrusive because it happens automatically during regular learning activities rather than through additional assessments that interrupt the learning process.

5.3.3. Dashboards

Dashboards aggregate data to provide teachers with a comprehensive overview of students' progress, performance, and behavior (e.g., Molenaar & Knoop-van Campen, 2017). Thus, they provide an opportunity to combine the advantages of observation and trace data, potentially mitigating the limitations of each assessment type. Due to this advantage, a notable trend has emerged in recent research that integrates dashboards, as observed in the studies included in the present review. With their affordances, trace data presented in dashboards can be a good complement to teacher observation, as they might balance out some of the limitations of observation: assessing and evaluating trace data is scalable and not restricted to a limited number of students, and based on a trained algorithm. Accordingly, it does not rely on teachers' professional noticing and may therefore be less sensitive to potential biases. If a dashboard presents trace data in a clear and comprehensible way, teachers can more easily apply their expertise, focusing on making pedagogical decisions based on the data, and allowing them to invest more of their resources in adaptive interventions, as they save resources on monitoring.

5.3.4. Tests

In recent adaptive LIT research presented in the present review, classic tests were less commonly used to assess learner characteristics. Unlike trace data, tests require students to complete an additional instrument, which might represent an extra task and a potential burden to students. Furthermore, using tests to assess, for example, cognitive abilities in the school setting would also add work for the teachers, who must analyze the results. Moreover, such tests may also underestimate the performance of selected groups of students, thereby limiting their access to adequate LIT. Past research has shown that standardized

knowledge and intelligence tests might disadvantage certain groups, such as students with lower SES or marginalized cultural backgrounds (Dolean & Cãlugãr, 2020; Ford, 2004; White et al., 2016). Another disadvantage of tests assessing the source is that data is usually only collected at one point in time. Accordingly, not all possibilities of dynamic adaptivity can be exploited; for example, changes and developments happening during learning are not considered. Given that more adaptive LIT was implemented via systems, the reliance on automated and repeated measures follows naturally.

5.3.5. Subjective ratings

Subjective ratings were rarely used in adaptive LIT research. When included, self-reports often asked students about their preferences, allowing them, for example, to choose or navigate freely across tasks (Geden et al., 2021; Hariyanto et al., 2020). In these cases, it was more a form of adaptability (Oppermann & Rashev, 1997) or is at least confounded with choice as a form of operationalizing adaptive LIT. According to the self-determination theory (Deci & Ryan, 2012), providing autonomy can increase students' motivation (Alley, 2019). However, past research has highlighted that students often make choices that do not lead to optimal learning outcomes when they are solely responsible for decision-making (Scheiter & Gerjets, 2007). That might explain the small number of studies on adaptive LIT that rely on students' subjective ratings as the source.

5.3.6. Physiological measures

Despite their potential usefulness, we found only one instance of physiological measures being utilized to assess motivational-affective characteristics. In recent years, automatic emotion detection methods have emerged to record and evaluate facial expressions (Dagar et al., 2016). However, to date, there is still limited research on physiological measures in the context of learning (Horvers et al., 2021). Even though wearable devices would be suitable and not intrusive in the school context (Thammasan et al., 2020), their widespread use during classroom learning seems unrealistic due to the high costs. Therefore, researchers need to find and examine feasible alternatives that extend the assessment of sources.

5.3.7. Multimodal assessment

Similarly, our finding that only one source was used is also reflected in the fact that most studies included in the present review employed only one assessment method. Recent research discusses, however, how multimodal assessment (e.g., combining think-aloud and trace data) can provide a more nuanced picture of specific learner variables (Fan et al., 2023; Molenaar et al., 2023). Even a single source can be assessed using multiple methods to complement each other for more reliable results (e.g., Ketonen et al., 2023). Whether this is economically feasible in the context of schools remains an open question, as such methods can be costly. If multiple sources are included, multiple assessment methods must usually be used (e.g., emotions can most likely not be assessed with the same type of assessment as cognitive abilities), which presents the same logistical hurdles. Overall, the deeper and more comprehensive the understanding of the students' characteristics is, the more effectively teachers or systems can adapt LIT to meet their needs. Thus, multimodal assessment methods that make this possible and can still be realistically integrated into schools should be further investigated.

5.3.8. Frequency of assessment

Regarding the frequency of assessment, we found that most assessments were dynamic (i.e., several, repeated, or constant assessments) and not static (i.e., just one assessment time). Dynamic assessment is a central feature of observation and trace data, the two most frequently employed types of assessment. Moreover, to implement micro-level adaptations—whether delivered by a system or a teacher—the data used as a source must be as current and dynamic as possible (Tetzlaff et al., 2021). Tests or self-reports often represent more stable query options that allow the assessment of more stable traits, making them less suitable for real-time adjustments. Data should be granular and reflective of ongoing learner characteristics to facilitate on-the-fly adaptations.

5.4. The operationalization of adaptive LIT (component 3)

Many studies lack detailed descriptions of how the adaptive LIT was implemented. Often, it is briefly mentioned that the teacher supported the students or that the system assigned them to the following tasks without further details on the specific adaptations or their pedagogical justification. This lack of in-depth information leaves gaps in understanding whether these adaptations appropriately match the context, source, and targeted outcomes. Moreover, we noted occasional confusion and a lack of discriminatory power between inquiry-based (Pedaste et al., 2015) and adaptive learning. Although both approaches share similarities due to their strong student focus (Haber-Curran & Tillapaugh, 2013), we suggest a more precise distinction in research publications.

The systematic investigation of operationalizations revealed adaptive navigation as the most frequent one, followed by difficulty progression, adaptive support, and adaptive feedback. Aligned with that, adaptivity was mainly implemented at the individual level, tailored to each student's needs rather than those of small groups or the entire classroom. On the surface, these four most frequently studied operationalizations focus specifically on enhancing student achievement. Through adapted practice, scaffolding, or other support, students receive assistance to correct errors, overcome misconceptions, and better understand content without being over- or under-challenged. However, these four operationalizations can also affect other aspects, such as promoting students' motivation or self-concept. For example, difficulty progression, similar to adaptive navigation, can be considered motivational scaffolding (Hofer & Reinhold, 2025), as it can reduce anxiety (Hwang et al., 2020) and promote a positive attitude toward the learning content (Ma et al., 2014). Learning at one's own pace or following a customized sequence is, thus, conducive to students' motivation and interest.

Interestingly, less emphasis was placed on other operationalizations related to the type of presentation and context of LIT. For example, students have limited opportunities to receive tasks precisely aligned with their interests, work with an avatar that resembles or appeals to them, or access content in a language with which they feel most comfortable. This finding may be related to the learner characteristics primarily used as sources. Only rarely was information about interests, demographic information, and other emotional and motivational student characteristics assessed, which would be a necessary basis for such operationalizations.

Only a few studies included options for students to choose, for example, their difficulty level. Future research should examine the differences in the effects of adaptivity and adaptability in school, particularly in terms of performance and motivational outcomes.

5.4.1. Levels of operationalization

The results for the operationalization also showed a predominance of micro-level adaptations, which were investigated significantly more frequently than macro-adaptations. On the one hand, this may also be due to conceptual ambiguities, as the division into different learning tracks from the outset is often referred to as differentiation (Eikeland & Ohna, 2022). On the other hand, there may also be conceptual reasons for this, which we would like to consider from the perspective of education equity, instructional scalability, and teacher autonomy. The more fine-grained you can respond to individual (dynamic) needs, the better you can find those students who might otherwise be left behind, and the more specifically you can respond to individual needs. Therefore, adaptivity, especially micro-adaptation, is considered a measure to foster educational equity (Dumont & Ready, 2023). Students'

performance, characteristics, and associated needs are re-evaluated momentarily, allowing for adequate inputs (i.e., instruction) as Dumont and Ready (2023) call it.

That way, it contrasts with macro-adaptivity, where students are initially categorized, for example, into low- and high-performing groups, and then placed into different learning tracks or given different tasks. While the intention is to provide students with adequate instruction, research on ability grouping has shown that this can be particularly disadvantageous for underserved students, who are more often assigned to lower-ability groups, regardless of their actual abilities (Hallinan et al., 2003). Moreover, micro-adaptivity is more subtle, which can be beneficial for students' motivational-affective characteristics (Müller & Hofmann, 2016).

However, it is crucial to be aware that neither type of adaptivity necessarily leads to a decrease in the educational gap. Adaptivity might be equally beneficial for more privileged students or, if misused, even miss its actual purpose, as in the case of misplacements in learning tracks as a form of macro-adaptivity. Nevertheless, at least it ensures that all students are supported in reaching basic skills in literacy and numeracy, increasing their chances on the job market and for societal participation.

Regarding instructional scalability, it is essential to distinguish between system-delivered and teacher-delivered adaptivity. While micro-adaptivity is particularly prevalent in technology-enhanced learning platforms because they can easily adjust their content, presentation, and learning paths based on dynamically recorded student variables (e.g., performance assessed via trace data) using algorithms, it is a greater challenge for a single teacher to monitor an entire class and respond immediately to each student. It may therefore be easier for a teacher to prepare different worksheets (e.g., with varying difficulty levels) in advance, which they can then hand out to students based on their level. Nevertheless, we found that teachers also often implement micro-adaptivity, for example, when providing feedback or motivational support in one-on-one conversations with students. Systems specifically afford micro-adaptivity, whereas research on teacher-delivered adaptivity often observes and studies teaching behavior in the classroom. Accordingly, the search terms we used may not have captured research that focuses more on macro-adaptivity.

In terms of teacher autonomy, micro-adaptivity offers considerable flexibility for teachers, albeit alongside the challenges it presents. Teachers can (or must) decide on the fly how to organize their lessons to meet the needs of their students, rather than having everything planned beforehand. Nevertheless, we need to emphasize that, regarding teacher autonomy, we view adaptivity, with its variety of operationalizations, as a toolbox from which teachers can choose the operationalizations they consider most suitable for their lessons, utilizing both micro- and macro-adaptivity. Based on this review, it is not possible to determine whether micro- or macro-adaptivity is more effective; conclusions should not be drawn solely because one has been investigated more extensively than the other. We believe that selecting the respective operationalization of adaptivity should be coordinated with the learning objectives (e.g., fostering performance versus motivation) and the desired forms of learning (e.g., individual work versus group work). Thus, overall, teachers must also be adaptable when deciding between the levels of operationalization or combining both.

5.5. The delivery of adaptive LIT (component 4)

The review results indicate that adaptivity is delivered through a system in approximately two-thirds of the included studies. This fits well with the recent rise in new educational technologies and artificial intelligence, which have a significant influence on (research on) learning and teaching (Hirsch-Kreinsen, 2023; Zhang & Aslan, 2021). Systems have distinct capabilities that allow them to implement adaptivity in ways that can complement or even substitute the teacher's role, particularly in delivering micro-adaptations. For example, they can easily incorporate adaptive navigation, difficulty progression, or feedback based on algorithms that analyze the constantly assessed learner characteristics (e.g., Kazakoff et al., 2018).

The primary advantage of system-based adaptivity is its almost limitless scalability. While teachers can only observe and respond adaptively to a few students at a time, a system can simultaneously monitor the entire class and offer adaptive instruction (Bimba et al., 2017). Every aspect of a system, from assessing learner characteristics to delivering adaptive interventions, is automated. This efficiency makes systems appealing for widespread, real-time adaptivity in schools.

Moreover, as global challenges such as pandemics, crises, and wars prevent students from attending school for long periods, well-researched adaptive technologies offer a promising alternative to traditional schooling, as past research has particularly demonstrated for higher education (Bordoloi et al., 2021; Matviichuk et al., 2022; Reinhardt et al., 2021). With the rising demand for online learning (e.g., Hawkridge, 2022; Picciano et al., 2010; Wong, 2023) and an ongoing teacher shortage in many industrialized countries (e.g., Nguyen et al., 2022; O'Doherty & Harford, 2018; Seeliger & Håkansson Lindqvist, 2023), it is essential to establish the effectiveness of adaptive systems, including their optimal integration within classroom settings. Additionally, designing these systems to align with expert teaching practices is critical to ensuring they can supplement or even replace teacher-delivered instruction when needed (e.g., outside-of-school learning or during crises). However, in most cases, adaptive systems cannot (and should not) replace teachers. Their effectiveness hinges on being integrated into larger instructional or educational settings, in which learning with and without technologies is orchestrated by experts (Dillenbourg & Jermann, 2010).

5.5.1. Similarities and differences of system- and teacher-delivered adaptivity

Therefore, the present review highlights the similarities and differences between system- and teacher-delivered adaptivity. Systems are powered by algorithms that classify and adapt instruction based on preset rules and thresholds, but lack pedagogical knowledge (e.g., Badaracco & Martínez, 2013; Long & Wu, 2012). As their adaptivity is rigid and limited to pre-defined decision paths, they rely heavily on their programming and the quality of input data. Conversely, teachers usually draw on years of pedagogical training, which equips them with a toolbox of pedagogical and didactic tools and prepares them to respond pedagogically appropriately to students' needs (Anthony et al., 2015). Unlike systems, teachers' decisions are guided by professional judgment and pedagogical expertise rather than fixed rules, allowing them to navigate complex classroom situations more flexibly.

To improve adaptive systems, the involvement of pedagogical experts (e.g., teachers) in algorithm design is essential. Teachers can provide valuable insights into adaptive decision-making, helping refine system rules to better mirror effective adaptive LIT. Based on the insights gained from this review, we suggest exploring the areas of productive cross-pollination between system- and teacher-delivered adaptivity to identify what systems and teachers can learn from each other to enhance their capabilities in implementing adaptive LIT. Similar to the assessment of the source, combining teachers and systems in operationalizing adaptive LIT seems beneficial, as it leverages the scalability and automation of systems while maintaining the relational and pedagogical strengths that teachers bring to the classroom.

5.6. The targeted outcomes of adaptive LIT (component 5)

We found that the outcome primarily targeted in adaptive LIT research is performance (in almost half of the studies). The results reflect the education system's strong emphasis on academic achievement, often at the expense of other qualities. Schools are incentivized to meet standardized performance benchmarks (e.g., on standardized tests such as the Scholastic Aptitude Test in the USA). Students' career choices and future SES heavily depend on their school performance (Salamon,

2020), and performance-based adaptivity might serve as a potential tool to improve their chances.

However, it is essential to remember that the performance category in our coding scheme is broad and combines several potentially distinct outcomes. This sub-component covers a spectrum ranging from short-term performance in a post-test to lasting and transfer learning. Given the strong emphasis on performance as a targeted outcome in adaptive LIT research, future studies could benefit from refining the coding scheme to distinguish between these types of performance outcomes, allowing for more precise insights.

Still, the review points out a significant gap: other potential beneficial outcomes, such as specific skill development (e.g., computational skills) and motivational-affective characteristics (e.g., engagement) receive much less attention. Only a handful of studies focus on these outcomes, respectively. Despite their well-researched essential role in learning (Tyng et al., 2017), little attention is given to emotions and motivation as outcomes of adaptive LIT. Building on this, future research should emphasize how positively influenced emotions and motivations can indirectly enhance performance (Camacho-Morles et al., 2021) and, as such, be considered a lever for academic success, which has proved to be a popular targeted outcome.

Additionally, future research should systematically address the measured impact and effectiveness of different operationalizations on different outcomes. To do so, it would be crucial to investigate in as much detail as possible which operationalizations work for whom, in which context, based on which source(s), and toward which outcome(s). More quantitative studies with measurable outcomes must be conducted to enable such comparisons.

5.7. Limitations

For feasibility reasons, we limited our search to two major databases. While these are widely used in educational psychology, we acknowledge that this approach may have excluded relevant publications on adaptive LIT in schools from other disciplines. As a result, our sample may not fully represent perspectives from fields such as computer science, educational technology, or instructional sciences, which are often published in databases more prominent within those disciplines. Furthermore, we limited our review to English-language papers for practical reasons. We encountered a few publications in other languages (e.g., Spanish) that we had to exclude despite potentially including relevant content. Moreover, we have only included papers from the five-year time span 2018 to 2022. This timeframe spans research conducted before, during, and after the COVID-19 pandemic, which may have influenced the development and implementation of adaptive technology. Considering the rapid technological advancements, there may be continuous updates on implementing adaptive LIT in schools, which have already been researched and published since we conducted our search at the beginning of 2023. We, therefore, highly encourage other researchers to systematically investigate the years after 2022, using our open-source materials (e.g., search strings, coding scheme).

Furthermore, the findings of this review are limited, as we may have missed research that would fit our conceptualization of adaptive LIT if it did not use adaptivity as a descriptor in the title or abstract of the publication. For example, formative assessment definitions strongly overlap with the definition of adaptive LIT that we followed in this review (Black & Wiliam, 2009). Moreover, research on teacher noticing or responsive instruction also conceptualizes these constructs similar to how this review conceptualizes adaptive LIT (e.g., König et al., 2022; Robertson et al., 2015). Thus, while our results indicate a lack of research on a specific component, numerous investigations may exist in a different research strand. Furthermore, studies on system-delivered adaptivity might be overrepresented in this review as technology-driven research may more often operate under the label of adaptivity than teacher-delivered adaptive LIT (Martin et al., 2020; Shute & Zapata-Rivera, 2007; Shute & Zapata-Rivera, 2012).

Moreover, we could only code what was reported in the papers. It is necessary to recognize that some publications might not have explicitly or adequately reported on all the adaptivity components that we considered relevant in the Ada-LIT framework, despite considering them in their research (design). That might have led to potential under-reporting in specific categories, which could have affected our results. These limitations highlight the potential of using a common framework such as the Ada-LIT framework.

5.8. Practical implications

Overall, this review is descriptive, outlining current research. We appraise these results to derive practical implications for research, practice, and design.

The review highlights the usability of the Ada-LIT framework in empirical studies on adaptivity in schools. As our results showed, in part, poor reporting practices, we encourage researchers to use the framework when designing their studies as a checklist of components they need to consider, and later in the reporting of their study. This may be especially useful when structuring the Methods and Results section to ensure that all aspects are covered. Ensuring comprehensive reporting will facilitate the readers' understanding, as well as the conduct of meta-analyses and potential replications. Creating research within the Ada-LIT framework will avoid definitional inconsistencies and a lack of standardization in reporting.

Furthermore, the Ada-LIT framework not only serves as a research tool but can also support teachers in designing adaptive instruction or planning adaptive classroom behavior. The framework can guide considerations on how they want to operationalize adaptivity, which adaptive sources they want to base it on, and how they can assess it (most likely through observation, but the review also emphasizes other options), and their aim of integrating adaptivity.

Beyond its relevance to research, this review highlights various possibilities for implementing adaptivity in schools. First, adaptivity can be introduced in schools without requiring significant structural changes. Teachers inherently possess and apply adaptive skills (Corno, 2008), as evidenced by this review. Several classroom observation studies have shown that teachers naturally adjust their instruction to meet students' needs, particularly through adaptive support. However, teachers' adaptive competence might be unrecognized by teachers, society, and the research community, because adaptive practices are often subsumed under routine or core teaching practices. In this review, we spotlight common adaptive practices by identifying the operationalization of adaptive LIT. While teachers may feel they need to take on additional tasks when asked to customize their teaching, this review demonstrates that many adaptive teaching practices are already embedded in their work. Making these practices explicit can increase their frequency and show that implementing them is often more achievable than it may seem. Moreover, methods are available to help teachers develop or refine their adaptive skills, such as lesson study and cogenerative dialogues (Luciano Beltramo, 2017; Schipper et al., 2020).

Second, our review suggests that multiple technologies can be adopted for classroom practice, primarily to introduce adaptive LIT in math. Thus, teachers who want to support student performance in math may utilize existing systems (e.g., Quaresma et al., 2018; Reinhold et al., 2020). However, as we did not investigate the effectiveness of these systems, we cannot recommend specific tools and suggest consulting the empirical research on this topic.

Third, we found that there are only a few investigations that focus on the teamwork of systems and teachers in classrooms. Thus, this review highlights the potential of combining teacher- and system-delivered adaptivity, emphasizing that adaptive systems offer an advantage in dynamic assessment, primarily due to their scalable and resource-efficient monitoring capabilities (e.g., via trace data) for many students in parallel. Moreover, the automated implementation of adaptivity in systems is also notable due to the speed and precision with which the

appropriate learning opportunities are dynamically offered to students based on algorithmic rules. As these systems may lack teachers' basic pedagogical skills and adaptive competence, these tools may be best integrated and combined with teachers' adaptive practices. Teacher dashboards that summarize assessment of relevant learner characteristics as adaptive sources could free up time resources, allowing teachers to focus on responding to students' needs, maybe especially those that a system cannot meet (e.g., Molenaar & Knoop-van Campen, 2017). Building on the strengths of both teachers and systems, we envision future classrooms where technology complements teachers rather than replacing them (e.g., Merikko & Kivimäki, 2022). This requires school-wide and system-level efforts to increase the access and use of adaptive technology in classrooms (e.g., Sibley et al., 2024). Nevertheless, these efforts seem worthwhile, given that adaptive technologies can empower teachers to meet students' needs, contributing to potentially more inclusive and equitable classrooms (Dumont & Ready, 2023).

Fourth, we emphasize the need for exchange between stakeholders to enhance the partnership between research and practice. Educators can contribute their perspectives and clarify their need to evaluate specific types of adaptive LIT or adaptive classroom practices. Policymakers can also emphasize their perspective and educational aims that might be targeted with adaptivity at a higher level. Moreover, instructional designers and researchers can work closely together to design interventions that will be evaluated and might eventually find their way into school practice. Regular exchange can ensure that research investigates relevant aspects and that practice can benefit from this research.

6. Conclusion

Using the Ada-LIT framework, this systematic review summarizes the current state of research on adaptive LIT in schools, identifying well-researched areas and research gaps and offering directions for future research. As such, it contributes to developing a research agenda for the future. Moreover, it presents the Ada-LIT framework to the field as a comprehensive model and guidance for the design and reporting of future studies, increasing standardization and comparability.

This review shows that some components or sub-components of the Ada-LIT framework have received substantial attention in recent studies, while others remain underexplored or underreported. Regarding the context, most studies were conducted in elementary school settings and focused primarily on math. Adaptation was predominantly based on performance as the adaptive source, most frequently assessed with trace data or through observation (assessment). This review also highlights the limited use of multi-source and multimodal assessment. Most studies relied on a single source and type of assessment without even addressing whether these were the most relevant ones or whether they were chosen for simplicity or pragmatism. Current research suggests that multimodal and multi-source assessment can provide the most accurate and comprehensive picture of students, laying a solid foundation for adaptive LIT. However, resource-efficient options still need to be investigated to make them viable for everyday school settings. Systems delivered adaptive LIT more frequently than teachers (delivery), with adaptive navigation, difficulty progression, feedback, and support being the most common operationalizations. Consistent with focusing on performance as the source, performance emerged as the most frequently targeted outcome.

We contend that our results must be integrated into the broader research landscape, as some aspects currently underexplored in adaptivity research are potentially investigated in research strands operating under different labels. The findings of this review thus highlight the potential for cross-pollination between adaptivity research and, for example, culturally responsive instruction or inclusive instruction research.

Furthermore, this review reveals that information on relevant components of adaptive LIT is often omitted. To address this, we recommend that future research adopt the Ada-LIT framework as a standardized guide for consistent and comprehensive reporting of methods and results in adaptive LIT studies. By doing so, researchers can enhance the clarity and comparability of findings, ultimately advancing the field's collective understanding of adaptivity in schools.

CRediT authorship contribution statement

Katharina M. Bach: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sarah I. Hofer:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Sarah Bichler:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://osf.io/6qwsk/?view_only=7c8db0a37a43462a95a1017ce347e196 and at https://doi.org/10.1016/j.lindif.2025.102781.

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