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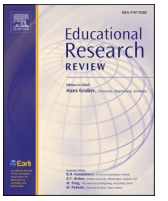

Review

Prerequisites for teachers' technology use in formative assessment practices: A systematic review

Kristin Børte [a,*], Sølvi Lillejord [a,b], Jessica Chan [b], Barbara Wasson [a,c], Samuel Greiff [a,d]

[a] Centre for the Science of Learning and Technology (SLATE), University of Bergen, PO Box 7807, N-5020, Bergen, Norway
[b] Department of Education, Oxford University, 15 Norham Gardens, Oxford, OX2 6PY, Oxford, UK
[c] Department of Information Science & Media Studies, University of Bergen, PO Box 7800, N-5020, Bergen, Norway
[d] Department of Behavioural and Cognitive Sciences, University of Luxembourg, 11 Porte des Sciences, 4366, Esch, Luxembourg

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ABSTRACT

While researchers promote the interactive learning potential of digital tools, studies reveal that teachers adapt technology to existing practice instead of using the tools' potential for student active learning. Researchers also argue that formative assessment enhances students' learning, while studies find formative assessment difficult to implement. To investigate these paradoxes and better understand how teachers use digital tools in formative assessment and with what result, we conducted a systematic review of teachers' technology use in formative assessment practices in primary and secondary education. Systematic searches identified 22 relevant articles that are included in the review. We found unclear definitions of formative assessment across studies and document challenges teachers encounter when they use technology for formative assessment purposes. We conclude with three prerequisites for teachers' successful technology use in formative assessment practices: 1) clear definitions of formative assessment, 2) alignment between digital tools and pedagogical practice, and 3) data literacy to examine and interpret information and use this to improve students' learning. The review also documents knowledge gaps in current research.

1. Introduction

For decades, researchers in the field of technology-enhanced learning have promoted the learning potential of technology in education (Cavanaugh, 2001; Kennewell, Tanner, Jones, & Beauchamp, 2008; Tondeur, Van Braak, Ertmer, & Ottenbreit-Leftwich, 2017). In a parallel research tradition, it is argued that formative assessment benefits students' learning (Black, Harrison & Lee, 2003; Black & Wiliam, 2010; Earl, 2012). Both strands of research aim to support teachers' work. However, studies reveal that teachers do not utilize the interactive potential of technology in their teaching. They struggle with how to use digital tools to support student active learning and instead adapt technology to their existing practice (Lillejord, Børte, Nesje & Ruud 2018; Blikstad-Balas & Klette, 2020; Børte, Nesje, & Lillejord, 2023). Starkey (2010) asked if this can be related to the – often implicit – assumption that teaching is a process of passing knowledge on from teacher to students instead of a more active, continuous process of student self-assessment.

Assessment researchers have repeatedly argued that formative assessment benefits students' active learning in schools (Black &

* Corresponding author.
E-mail address: kristin.borte@uib.no (K. Børte).

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Wiliam, 1998; Stiggins, 2002; Stobart, 2008,; Yan et al., 2021). However, after reviewing 907 articles on 'assessment for learning' (AfL), Baird, Hopfenbeck, Newton, Stobart, and Steen-Utheim (2014) concluded that most studies were small-scale and reported positive teacher and student experiences as effects of AfL, but few examined the effect of introducing AfL to the classroom on a more granular level. When Black & Wiliam (1998) introduced the term 'assessment for learning, it was rapidly picked up by policymakers, teachers and researchers and turned into a 'big business,' with lots of time, money and energy invested in countries such as England, Wales, the US (Taras, 2007) and Norway (Hopfenbeck, Petour, & Tolo, 2015). The Assessment Reform Group (ARG, 2002) formulated principles for formative assessment practices, and digital tools such as Assistudy (Rodrigues & Oliveira, 2014) and TI-Navigator (Shirley & Irving, 2015) were developed to support these practices. Following the rapid and rushed introduction of AfL to the classroom, researchers have noted inconsistent and unclear concept use in AfL research (Evans, 2013; Schellekens et al., 2021). In addition to the unclear definition, factors that hinder the successful implementation of formative assessment in the classroom remain undiscovered (Heitink, Van der Kleij, Veldkamp, Schildkamp, & Kippers, 2016). However, the success of formative assessment depends on how practitioners perceive and implement these activities (Yan et al., 2021). Hence, there is a need for conceptual clarification and more research on how teachers in primary and secondary education perceive formative assessment and use technology pedagogically in their teaching activities.

A broad range of digital tools have been developed to support teachers' assessment practices. However, these tools often have a summative intent (Adams & Clough, 2015) and do not support formative practices. Additionally, research on technology-supported formative assessment practices primarily aims at determining the tools' effectiveness for learning, not how technology is used to support formative assessment in practice (Zhan & So, 2017). A systematic literature review on how teachers prepare for the digital age concluded that teachers need *generic* digital competence, *digital teaching* competence, and *professional* digital competence (Starkey, 2020). Central to all categories was teachers' knowledge about assessment.

As the interactive and formative potential of technology appears to be underutilised in schools, we formulated the research question: *How do teachers use technology in formative assessment practices in schools?* To answer the question, we conducted a systematic review, as this methodology allows for in-depth investigation of existing research across research fields, traditions, and disciplines, thus providing a comprehensive interpretation of results across research traditions (Gough, Oliver, & Thomas, 2017). Conducting a systematic review resembles the reverse triangle approach: The work begins with broad searches and selection of relevant articles. Then, a group of researchers assess quality and relevance, reducing the number of articles. In the end, some articles stand out as contributing more to answering the research question than others. This systematic review provides an overview of and synthesizes research on how teachers use technology in formative assessment practices in primary and secondary education, identifies challenges and knowledge gaps in the research. To answer the research question, we assessed studies in terms of 1) how formative assessment is defined and/or described, 2) which digital tools are being used, and 3) how characteristics of teachers' technology use are described.

The ambition of this systematic review is to contribute to existing research into how teachers use technology in their formative assessment practices in primary and secondary education and what they need for successful implementation, which goes significantly beyond merely adapting technology to their existing assessment practices. The article highlights the inconsistent terminology use in existing assessment research and shows that many studies on teachers' technology use in formative assessment reveal challenges associated with these practices.

The article is structured as follows: Section 2 presents ongoing discussions in assessment research, outlines previous research on technology use in formative assessment practices and previous research on challenges teachers encounter when they use technology in formative assessment practices. Section 3 describes the method of conducting systematic reviews with predefined inclusion criteria, the search and sorting process to identify studies that can contribute to answering the research question, and the process of analysing and synthesizing the included articles.

In the discussion, we elaborate on whether the fuzzy use of definitions and concepts of what constitutes formative assessment (a core finding of this study) might have blurred studies and/or research findings as well as hampered implementation. We conclude with a set of prerequisites that must be in place for teachers' successful use of technology to support formative assessment practices and provide recommendations for future research in the field.

2. Background

2.1. The intended purposes of assessment

When studying how technology can be used to support formative assessment practices, the various purposes of assessment must be considered. Scriven (1967) distinguished between summative and formative assessment and argued that summative assessments, such as grades, judge performance against pre-defined criteria and standards. This is followed by formative assessment, which aims to close the 'gap' between criteria or required standards and what is achieved (Sadler, 1989; Scriven, 1967; Taras, 2005). Taras (2009) found the dichotomy between formative and summative assessment that emerged in the research after Scriven (1967) confusing because summative and formative assessment should be perceived not as antagonistic, but *interdependent* practices. All assessment, she argued, begins with summative assessment, which is a judgement, and formative assessment is summative assessment *plus feedback*, which is intended to be used primarily *by the learner*, not the teacher.

Black and Wiliam (1998), however, state that formative assessment "encompasses all activities undertaken by teachers and/or students, which provide information to be used as feedback to modify teaching and learning activities in which they engage" (p.7). Advocating for changes in teachers' instruction, they were primarily concerned with what they called *weak practice*, i.e., that classroom practices generally encouraged superficial and rote learning. While their work significantly contributed to encouraging more learning

and less assessment, it also introduced an inefficient and contradictory theory of assessment for learning, argued Taras (2010), because they confused formative assessment with feedback and developed the term assessment for learning as guidance for the *teacher*, not the student.

As indicated above, *firstly*, formative assessment is not the opposite of summative assessment but *presupposes* summative assessment (Sadler, 1989; Scriven, 1967; Taras, 2009). *Secondly*, unclear definitions of formative assessment hamper successful implementation (Evans, 2013; Taras, 2005; Torrance, 2012) and *thirdly*, whether formative assessment "works" or not is an empirical question. However, it has been normatively promoted as a means of improving teaching, not assessment (Black & Wiliam, 1998).

To meaningfully document the effect of formative assessment, Bennett (2011, p. 8) argued that a clear definition of formative assessment needs 1) a theory of action identifying characteristics of what formative assessment is and how these characteristics work together to achieve a specific outcome (and also pose a sufficiently strong connection to theories on learning and instruction), and 2) a concrete instantiation 'that illustrates what formative assessment built to the theory looks like and how it might work in a real setting'.

This systematic review shows that many studies on technology use in teachers' formative assessment practices do not follow Bennett's guidelines and reveals the inconsistent use of concepts and terminology in existing assessment research.

Section 2.1 has shown different interpretations of formative assessment in the research and that authoritative definitions are lacking.

2.2. Technology use in formative assessment practices

Research on the use of technology to support assessment practices dates back to the 1950s and Skinner's mechanical teaching machine,[1] based on his learning theory, which gave immediate feedback to students as to whether their answer was correct or not. The idea was that '*If the subject is correct, he/she gets reinforcement and moves on to the next question. If the answer is incorrect, the subject studies the correct answer to increase the chance of getting reinforced next time*[2]'. Computer-aided instruction systems, first developed in the 1960s and 1970s, provided interactive feedback as to whether a students' answer was correct or not and influenced what task a student was given next. With the advancement of artificial intelligence techniques in the late 1970s, intelligent tutoring systems (ITS) were developed with the goal of providing individualised tasks and feedback through cognitive diagnosis and adaptive remediation (Shute & Psotka, 1994; Wasson, 1997). Adaptive learning systems were set up to diagnose what a student did wrong while solving a problem (cf. making a judgement) and then provided appropriate feedback such as suggestions, guidance, or an explanation. These early digital tools had a technical orientation and binary thinking about right and wrong built directly into the tool, with little focus on different types of feedback and instructional theories.

More than a decade ago, Pachler et al. (2009, p. 1) defined the use of technology to promote assessment for learning, also called *formative e-assessment*, as "the use of ICT to support the iterative process of gathering and analysing information about student learning by teachers as well as learners and of evaluating it in relation to prior achievement and attainment of intended, as well as unintended learning outcomes, in a way that allows the teacher or student to adjust the learning trajectory." The 'e' primarily added technical functionality that supported the processing of a large amount of data in a short time. They identified the following roles that 'e' adds to formative assessment: 1) speed of response and iteration, 2) storage capacity and access to large amounts of data, 3) processing automation (e.g., system-generated feedback), scalability (due to some level of automation), and adaptivity (to students), 4) communication, 5) construction and representation.

Recently, more sophisticated methods such as educational data mining and learning analytics have been used to provide data-driven feedback (Pardo, 2018; Pardo, Jovanovic, Dawson, Gašević, & Mirriahi, 2019; Tsai, Mello, Jovanović, & Gašević, 2021) based on the analysis of large data sets (from sources such as activity data from interaction with a tool, video engagement, assessments, student information systems, electronic textbooks, discussion forums) to generate semi-automated feedback to help 'teaching staff in providing more contextualised, written feedback' (Tsai et al., 2021, p. 511) about students' learning strategies. Learning Analytics Dashboards (Schwendimann et al., 2016; Verbert et al., 2014, 2020) provide visual feedback on student learning (e.g., behaviour, achievement, progress, etc.) either to a student to improve their awareness and self-regulation of learning (Jivet et al., 2020; Santos, Govaerts, Verbert, & Duval, 2012) or learning performance (Park & Jo, 2015), or alternatively, for teachers to improve their teaching, feedback, classroom management or evaluation/grading (Park & Jo, 2015). Students and teachers using such dashboards need feedback and data literacy skills to make sense of the data and visualisation skills to take action based on this type of data (Jivet, 2021).

Existing studies on the use of technology in formative assessment practices (Misiejuk, Wasson, & Egelandsdal, 2021; Pardo, 2018; Pardo et al., 2019) report their potential to provide adaptive or personalised feedback, motivate or promote engagement, support self-regulation or facilitate self- and peer assessment. This is accomplished by analysing student data (e.g., log activity data, learning outputs, quizzes and tests, discussion forums, etc.) and either generating automated feedback or recommending feedback to be given by the digital tool itself or by the teacher, by collecting learning outputs in portfolios for evaluation, or by visualising learning behaviour and learning processes for learners or teachers. Hence, data literacy is understood as interactive inquiry cycles, the ability to "transform information into actionable instructional knowledge and practices by collecting, analysing, and interpreting all types of data (assessment, school climate, behavioural, snapshot, longitudinal, moment-to-moment, and so on) to help determine instructional steps" (Gummer & Mandinach, 2015, p. 2). In this description, data literacy stands out as a prerequisite, a necessity for successful use of digital tools in assessment practices on the student, side but maybe even more so on the side of teachers who want to utilize

[1] http://www.skeptically.org/skinner/id1.html.
[2] https://chip.web.ischool.illinois.edu/people/projects/timeline/1954teaching_machine.html.

technology-supported formative assessment to optimize their students' progress. Thus, the core question in this systematic review is how and how systematically teachers have used technology in their formative assessment according to the included articles, and based on this, what teachers need to make full use of the formative potential of interactive digital assessment tools.

2.3. Challenges when implementing technology and formative assessment in teaching

Existing research on formative assessment has identified gaps between intended implementation of formative assessment practices and actual implementation (Heitink et al., 2016; Yan et al., 2021). In teacher evaluation, the intention is to support teachers' professional learning by using summative information formatively (Lillejord, Elstad, & Kavli, 2018). However, research reveals that instead of fulfilling its formative intention, the teacher evaluation process is often reduced to administrative and summative technicalities (Lillejord & Børte, 2020). Thus, there seem to be broader barriers to successful implementation of formative assessment practices in education. Heitink et al. (2016) identified prerequisites for the successful implementation of assessment for learning in classrooms related to teachers, students, assessment, and context. They identified teachers' knowledge and skills (assessment literacy) as teacher-related prerequisites i.e., teachers must be able to interpret assessment information on the spot and rapidly translate this into instructional activities. Among assessment-related prerequisites were alignment with instructional tasks and that feedback should be focused, constructive, and substantial. Additionally, students should be actively engaged in the assessment process. Their review concluded that professional development is crucial when implementing new practices such as assessment for learning.

In a similar vein, when identifying factors that influence formative assessment practices, Yan et al. (2021) revealed a gap between teachers' intentions and their actual implementation. *Personal* factors related to implementation were self-efficacy, education and training, teaching beliefs, and instrumental attitude. *Contextual* factors were internal school support, external policy, school environment, cultural norms and working conditions. Education and training, along with how schools are organized and led, therefore strongly impact both teachers' intentions and actual implementation. Consequently, the success of formative assessment depends on how it is defined, perceived, and practiced in schools.

Challenges when using technology in teaching are also identified in research on technology use in higher education teaching and learning, as technology is more frequently adapted to traditional teaching practices, instead of being used to support student-active learning (Børte, Nesje, & Lillejord, 2023). Implementation barriers can be related to technology, pedagogy, teachers, and students. A systematic review of learning and teaching with technology in higher education (Lillejord et al., 2018) revealed little or no student-active learning, a persistent behaviourist mindset, and prescriptive practices. In fact, teachers rarely used technology to innovate their teaching but instead primarily used it administratively and for one-way communication, thus neglecting its interactive potential.

These findings indicate that implementing formative assessment and the instructional use of technology is no easy task and that our investigation into how teachers use technology to support formative assessment practices is important.

3. Method

This systematic review was conducted to better understand how teachers use digital tools in formative assessment and with what results. Page et al. (2021) argue that systematic reviews serve many purposes: "They can provide syntheses of the state of knowledge in a field, from which future research priorities can be identified; they can address questions that otherwise could not be answered by individual studies; they can identify problems in primary research that should be rectified in future studies; and they can generate or evaluate theories about how or why phenomena occur" (Page et al., 2021, p. 1). Key characteristics of systematic reviews are transparency, an explicit method that describes and determines their conduct and the identification of knowledge gaps (Gough et al., 2017). This systematic review followed guidelines for systematic reviews in educational research, such as using an explicit search strategy in which studies were excluded or included based on predefined criteria (Gough et al., 2017; Zawacki-Richter, Kerres, Bedenlier, Bond, & Buntins, 2020). PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[3] principles for reporting were followed (Brunton, Stansfield, Caird, & Thomas, 2017; Liberati et al., 2009; Page et al., 2021). The PRISMA statement was developed (in healthcare) to help systematic reviewers transparently report what authors did and what they found (Page et al., 2021). To answer the research question *How do teachers use technology in formative assessment practices in schools?* this review followed standard stepwise procedures for systematic reviewing in educational research: a) clarifying the problem, developing the research question and inclusion criteria, b) identifying relevant literature through systematic searches, c) screening search results based on predefined inclusion criteria, d) describing and mapping study characteristics (e.g., extracting data), and e) synthesizing (Gough et al., 2017; Heitink et al., 2016, Khan et al., 2003).

3.1. Search strategy and databases

Initial searches revealed that studies on technology use in formative assessment practices used a variety of descriptions and concepts to define formative assessment. As there is no agreed-upon definition of formative assessment, we use formative assessment as an 'umbrella term' for practices referred to in the articles as assessment for learning (AfL), feedback, peer and self-assessment. A search

[3] http://www.prisma-statement.org/.

string was developed based on terms and concepts used in research on formative assessment and technology-enhanced learning (Appendix A). This search string was used for systematic searches in six electronic databases: ERIC, Education database, ASSIA, IBSS, Psych Info and Scopus. These databases were chosen because they contain most publications within educational research. Two separate searches were conducted covering the period 2012–2021: 1) a first search performed April 03, 2017 covering the period Jan 1, 2012 to April 3, 2017, which resulted in 1377 hits (after removing 137 duplicates), 2) a second search performed June 20, 2019 covering the period April 1, 2017 to June 20, 2019, which resulted in 941 hits (after removing 255 duplicates). To bypass embargo and identify the most recent relevant publications, a hand search was conducted in March 2021 in the 14 journals (Appendix B) where the included studies from the previous two systematic searches were published, resulting in 3 relevant articles. Embargo means that articles in recent journal issues are not indexed in electronic databases immediately upon publication and thus not searchable until embargo is lifted. We therefore read the table of contents of newly published issues of relevant journals. The period June 2019 through July 2021 was chosen because the last electronic search was conducted in June 2019 and the last online first articles published in July 2021. Appendix C provides a list of included articles, type of journal and in which search they were identified.

3.2. Inclusion criteria and the sorting process

The research question informs what types of studies are likely to be relevant and thereby allows researchers to determine inclusion criteria (Gough et al., 2017). To be included in the review, an article should meet all the predetermined inclusion criteria. Table 1 shows the predefined inclusion and exclusion criteria developed and applied in the screening process.

Fig. 1 illustrates the two-step search and sorting process. The EPPI Reviewer 4 software, developed for systematic reviewing by the EPPI Centre at University College London, was used in this process.

First, the title and abstract from the electronic searches, a total of 2321 hits, were read and assessed using the predefined inclusion and exclusion criteria. After the first screening, 75 articles with potential relevance for the systematic review were identified. Two researchers read the full text of and independently assessed all 75 articles on relevance and quality, following the predefined inclusion criteria in Table 1 and the quality criteria shown in Table 2. The data extraction forms were compared and differences discussed and resolved with the authors of the article.

It should be noted that as the inclusion criteria expected studies to address teachers' technology use in formative assessment practices, studies focusing on testing and validating technology for assessment purposes, testing the accuracy of teacher judgments (Zhu & Urhahne, 2018), training students to give peer feedback (Nicolaidou, 2013) or how teachers use assessment data to improve instruction (Förster, Kawohl, & Souvignier, 2018; Matuk, Linn, & Eylon, 2015) were categorised as outside of the scope of this review and excluded.

After reading and assessing the relevance and quality of the 75 articles, 22 articles remained and were included in the systematic review.

3.3. Data extraction and mapping of the included articles

In systematic reviews, the included articles are the data sources. To answer the research question, the 22 included articles underwent a comprehensive mapping and analysis in which data from the studies was extracted, described, summarised, and prepared for synthesis. The NVivo 12 software for qualitative analysis was used to conduct the coding, guided by these coding categories: 1) definition and/or descriptions of formative assessment, 2) digital tools, and 3) teachers' technology use. The coding showed how formative assessment was defined and operationalised in the articles as well as the different types of tools used to support formative assessment practices and enabled an analysis of the use of digital tools. Appendix D provides an overview of how the included articles describe or define formative assessment, the references used and how we categorised articles in the review. Only eight of the included articles defined formative assessment and clearly described teachers' technology use. Section 4, Table 6, therefore shows how these eight articles describe teachers' technology use and the challenges they face when doing so.

3.4. Configurative synthesis

Having read, coded, and categorised the included articles, we summarised the extracted data. As the studies are heterogeneous, we chose a configurative synthesis and used the entire article as data (Gough et al., 2017). The summaries allowed us to compare articles, identify patterns across articles, and elicit the meaning of the study, what Noblit & Hare, 1988 call *idiomatic translation*. The synthesizing process aims at translating the studies into each other (Noblit & Hare, 1988) or making them 'talk to each other' (Gough et al.,

Table 1
Predefined inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
1.	*Theme*: The study must address teachers' technology use in formative assessment practices	*No description of teachers' technology use and no formative assessment*
2.	*Context*: primary or secondary education	*Not primary or secondary education*
3.	*Publication type*: Published in a peer-reviewed journal after 2012	*Not peer reviewed or published before 2012*
4.	*Language*: English	*Not English*

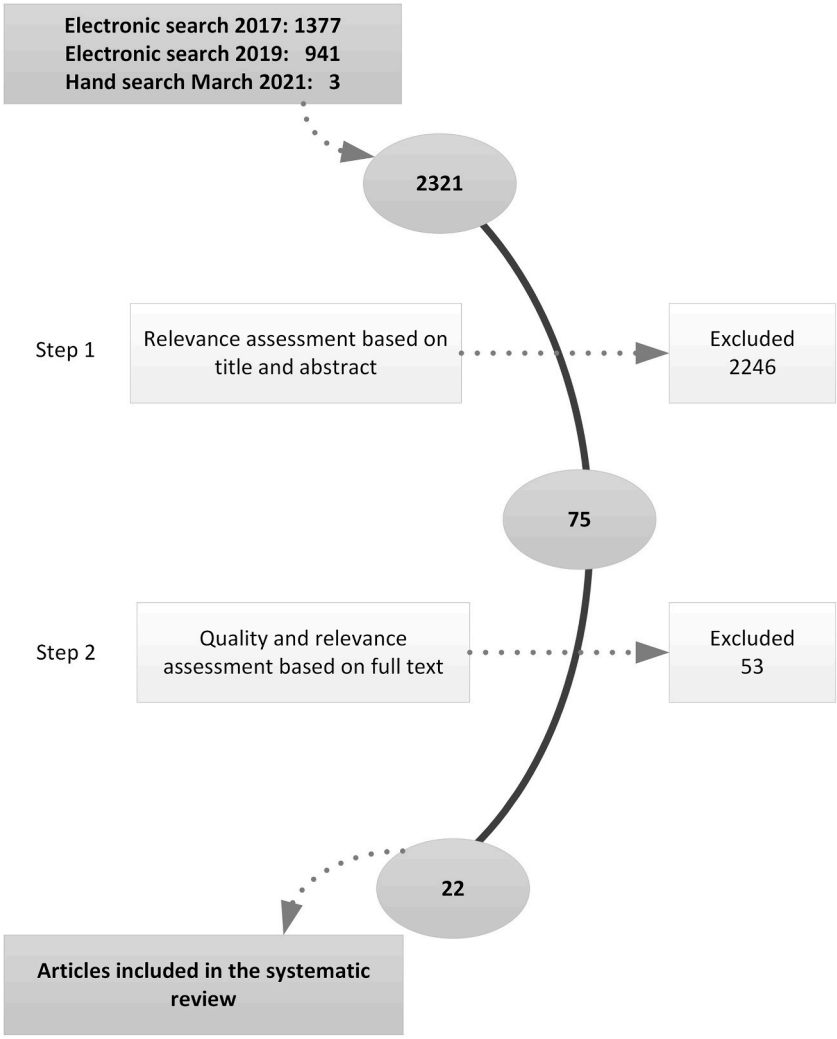

Fig. 1. Flow diagram of the sorting process.

Table 2
Criteria for quality assessment.

Criteria for assessing quality	Assessment value
• Validity • Reliability • Generalisation • Is the research question clear? • Are research method and research design specified? • Is there alignment between the research question and the study's findings?	*High*: Explicit and detailed description of method, data collection, analysis, and results; convincing connections made between interpretations/analysis and findings *Medium*: Satisfactory description of method, data collection, analysis and results; some connections found between interpretations/analysis and findings *Low*: Weak description of method, data collection, analysis, and results; little connection established between interpretations/analysis and findings

2017) and generate new knowledge that transcends each study's contribution. It can be compared to making a mosaic. When separate parts are brought together, they form a coherent whole that sheds new light on the topic investigated.

4. Findings

All 22 included articles provided broad overviews of previous research and reported on studies where teachers used technology to support their formative assessment practices. Table 3 shows the included articles, published between 2012 and 2020, from 15 different countries (based upon first author's affiliation). Taken together, the 22 articles report findings from >400 teachers and >5000

Table 3
Overview of included articles in the review.

	Reference[a]	Country	Method	Participants	School level	Subject	Tool	Assessment terms used
1	AbuSeileek and Al-Olimat (2015)	Jordan	Quantitative	1 teacher 72 students	Secondary	EFL	Word 2010	Corrective feedback
2	* Adams and Clough (2015)	UK	Mixed method	2 teachers 27 students	Secondary	Mixed	JuxtaLearn	Formative e-assessment
3	* Admiraal et al. (2020)	NL	Qualitative	5 teachers, 47 students	Secondary	Dutch language	Got it language	Formative assessment for learning
4	* Chen et al. (2020)	China	Quantitative	2 teachers 178 students	Primary	Math	Easicare software	Formative assessment
5	* Cusi et al. (2017)	Italy	Design-experiment	36 4th, 5th, 6th, and 7th grade classes over 2 consecutive school years	Primary	Math	Digital worksheet's	Formative assessment
6	* Dalby & Swan (2019)	UK	Design experiment	6 teachers N/A students 2 schools	Secondary	Math	iPad	Formative assessment
7	* Edmunds & Hartnett (2014)	NZ	Qualitative	3 teachers 88 students	Primary	All	Learning management system (LMS)	Assessment for learning
8	Engeness (2018)	Norway	Mixed method	2 teachers, 125 students	Secondary	English	EssayCritic	Assessment for learning Formative assessment Feedback
9	Faber et al. (2017)	NL	Quantitative	44 teachers, 1808 students	Primary	Math	Snappet	Formative assessment Feedback
10	Genlott & Grönlund (2016)	Sweden	Quantitative	23 teachers, 502 students longitudinal	Primary	Literacy and math	Write To Learn (WTL) method and Goggle Apps for education	Formative Feedback Formative assessment
11	Kjærgaard (2017)	Denmark	Quantitative	250 teachers	Lower secondary	EFL	Receive student work electronically	Feedback Formative feedback Formative assessment
12	Kongsgården & Krumsvik (2016)	Norway	Mixed method	14 teacher, 134 students	Primary and secondary	Across subjects	Tablets	Assessment for learning
13	Kralj & Glažar (2013)	Slovenia	Quantitative experiment	2 teachers, 686 students	Primary	Chemistry	TikTakTest - online program	Self-assessment Online assessment Knowledge assessment for learning
14	Molin et al. (2020)	NL	Quantitative experiment	13 teachers, 633 students	Secondary	Physics	Socrative	Formative feedback
15	Nikou & Economides (2018)	Greece	Literature review	N/A	N/A	N/A	Mobile based assessment	Formative assessment
16	Rodrigues & Oliveira (2014)	Portugal	Tool development and evaluation	2 teachers 723 students (longitudinal)	Secondary	History	AssiStudy	Formative assessment Summative assessment
17	* Shirley & Irving (2015)	USA	Qualitative	4 teachers	Secondary	Science	TI-Navigator	Formative assessment
18	Shute & Rahimi (2017)	USA	Review	N/A	N/A	N/A	Gives an overview of tools used in assessment practices	Assessment for learning Formative assessment
19	Wasson & Hansen (2014)	Norway	Qualitative	6 teachers, N/A students 3 schools,	Primary and secondary	Not specified	ICT - not a specific tool	Formative assessment, Feedback
20	Woodard et al. (2013)	USA	Qualitative	10 teachers 3 schools,	Secondary	Writing	Scholar - online writing app	Formative assessment, Peer feedback

(*continued on next page*)

Table 3 (*continued*)

	Reference[a]	Country	Method	Participants	School level	Subject	Tool	Assessment terms used
21	Zertuche et al. (2012)	USA	Quantitative	2 teachers, 236 students	Secondary	Science	Web-based Inquiry Science Environment WISE	Formative assessment
22	* Zhan & So (2017)	Hong Kong	Qualitative	30 teachers, 13 schools	Primary	Science	FAMLE	Formative assessment

[a] Articles marked with an asterisk (*) are core articles in the systematic review.

students. Eight studies are quantitative, seven are qualitative, three used mixed methods, two are design experiments, two are literature reviews and one study describes the development and evaluation of a tool.

To get an overview of how researchers defined formative assessment in their studies and how they presented teachers' use of digital tools, we then extracted and analysed data from the coding categories 'definition or description of formative assessment' and 'teachers' technology use'. The analysis revealed two transcending patterns: 1) challenges in defining formative assessment, and 2) challenges when teachers used technology to support formative assessment practices.

4.1. Challenges in defining and operationalising formative assessment

Most included articles use Black and Wiliam (1998, 2009) as authoritative sources for how to define, interpret and implement formative assessment (see Appendix D for details). Some authors make strong claims regarding the benefits of formative assessment for students' learning. For instance, Dalby and Swan (2019, p. 833) state – as a known fact – that 'formative assessment has a positive impact on learning'. Shirley and Irving (2015, p. 56) argue that formative assessment is 'demonstrated to result in increased student achievement'. However, it is unclear how well documented this is, as the definitions of formative assessment are deficient and unclear in several of the included articles.

Articles were grouped into four categories based on how they described formative assessment; Table 4 provides an overview of the articles in each category.

Articles in category one lack a definition of formative assessment. It is therefore unclear how the authors understand and practice formative assessment in their studies. Articles in category two describe formative *intentions* but do not define formative assessment. This can potentially cause confusion concerning how technology use can support formative assessment practices. For instance, AbuSeileek and Ali-Omat (2015) use the term *corrective feedback*, understood as a process of 'supplying the learner with knowledge about performance progressively' (p.5). While they claim that students receive formative feedback on both content and form, their study description reveals that the corrective feedback is *summative* feedback on student performance. Zertuche, Gerard, and Linn (2012) refer to Black and Wiliam (1998) but instead of defining formative assessment, they elaborate on the challenges of implementing formative assessment and propose a solution to these challenges in the form of what they call 'openers', i.e., brief class activities (p. 79). Citing Black and Wiliam (1998), Molin, Haelermans, Cabus, and Groot (2020) define formative feedback as a critical component of meaningful learning. Their study, however, uses polling technology that gives students immediate feedback about their performance. As this is feedback on a product and not feedback during a learning activity, it must be considered summative assessment. Both Engeness (2018) and Kongsgården and Krumsvik (2016) use the terms 'assessment for learning' and 'formative assessment' interchangeably. Engeness (2018) shows that instead of encouraging students to develop AfL skills, teachers rely on the automated feedback provided by technology. Kongsgården and Krumsvik (2016) do not define or conceptualise the terms up front but provide definitions to clarify results in a footnote and when reporting their findings in the result section.

Articles in category three define formative assessment as a process integral to teaching and learning. Both Faber, Luyten, and Visscher (2017) and Genlott and Grönlund (2016) refer to Black and Wiliam (1998; 2009) and define formative assessment as information used to change or modify classroom teaching practice. Rodrigues and Oliveira (2014) distinguish between formative and summative assessment with reference to Bloom (1974) and argue that formative assessment 'intends to provide the learning with direction, focus and guidance and occurs during the learning process' (p.32). In the two reviews (Nikou & Economides, 2018; Shute & Rahimi, 2017), formative assessment and assessment for learning are used interchangeably, and different forms of assessment are comprehensively described. Nikou and Economides (2018, p. 102) state that 'assessment refers to the process of measuring and/or

Table 4
How included articles are categorised according to description/definition of formative assessment.

Category		References – included articles
1	No definition or description provided; Unclear understanding and operationalisation of formative assessment.	Kjærgaard, 2017; Kralj & Glažar, 2013; Wasson & Hansen, 2014; Woodard et al., 2013
2	Describe formative intentions but lack definitions of formative assessment.	AbuSeileek & Ali-Omat, 2015; Engeness, 2018; Kongsgården & Krumsvik, 2016; Molin et al., 2020; Zertuche et al., 2012
3	Define formative assessment as a process taking place during teaching and learning.	Faber et al., 2017; Genlott & Grönlund, 2016; Nikou & Economides, 2018; Rodrigues & Oliveira, 2014; Shute & Rahimi, 2017
4	Conceptualise formative assessment as a process including summative assessment, supported by technology.	*Adams & Clough, 2015; *Admiraal et al., 2020; *Chen et al., 2020; *Cusi et al., 2017; *Dalby & Swan, 2019; *Edmunds & Hartnett; *Shirley & Irving, 2015; *Zhan & So, 2017

collecting and using evidence about the outcomes of students' learning'. They position formative assessment as taking place 'throughout the cycle of learning, gathering evidence of learning and providing teachers and/or students with feedback information to improve learning' (p.102). Shute and Rahimi (2017) found the term formative assessment vague, while assessment for learning is 'more prevalent among researchers in the area' (p. 3). However, in their introduction, they use the terms interchangeably.

Articles in category four discuss challenges of formative assessment practices and technology use and conceptualise formative assessment as processes that involve summative assessment. For instance, Adams and Clough (2015) describe formative assessment through technology as a whole-system approach, with summative assessment as a first step. They state that 'e-assessment systems have advanced the area of formative assessment' (p. 1) by providing students with new avenues for learning through automated feedback, confidence-based marking, or computer adaptive tests. Edmunds and Hartnett (2014) cite the Assessment Reform Group (2002) and define assessment for learning as a 'teaching and learning process that is based on interpreting evidence for use by learners and their teachers to decide where the learners are in their learning, where they need to go, and how best to get there' (p. 12). They operationalise AfL as personalised learning in a learning management system. Chen, Gamble, Lee, and Fu (2020), Cusi, Morselli, and Sabena (2017), Dalby and Swan (2019) all quote Black and Wiliam and use the same definition of formative assessment, as classroom practices where 'evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction' (Black & Wiliam, 2009, p. 9). Zhan and So (2017) use Black and Wiliam (1998) to argue that the current practice of formative assessment is weak and only partially successful due to implementation problems. Shirley and Irving (2015) found formative assessment in classrooms a weak aspect of teachers' practice. They refer to Black and Wiliam (1998) and Bell and Cowie (2001) to support their interpretation of formative assessment as a 'process of teachers uncovering levels of student understanding during the instructional sequence in order to adapt instruction' (p.56) and conceptualise formative assessment as a continuous cyclical process in which summative assessment is key for a new 'round'. Admiraal, Vermeulen, and Bulterman-Bos (2020) argue that teachers are crucial for both providing feedback and engaging students in learning activities that move learning forward. They distinguish between the formative and summative functions of assessment and describe the formative function as 'informing students about their performance and how to improve this' (p. 578). Citing Bennett (2011) and Black and Wiliam (2009), they argue that computer-based assessment can support the formative function of assessment by providing 'data that provide teachers with information about learning processes and outcomes' (p. 578) that teachers can use to improve instruction.

Our analysis has revealed that researchers interpret, define, and operationalise formative assessment differently. In addition, only the eight articles in category four described formative assessment in relation to technology. Based on this finding, we conclude that a prerequisite for enhanced quality in research on technology use in formative assessment is that researchers define the concepts they use.

4.2. Challenges when using technology to support formative assessment in teaching

In several of the included articles, researchers claim that digital tools effectively support formative assessment. For example, Dalby and Swan (2019) assume that digital technology can enhance student learning and contribute to richer and more efficient learning processes. Cusi et al. (2017, p. 756) argue that connected classroom technologies are effective tools for formative assessment to 1) monitor students' progress, 2) provide students with immediate feedback that keeps them on the path to deep conceptual understanding, and 3) encourage students to monitor their own progress. However, due to the variety of digital tools used in the studies, the included articles document processes differently. The mapping (Table 3) shows that digital tools used to support formative assessment practices range from iPads, tablets, large software systems such as learning management systems, Google apps for education or specific writing programs such as MSWord; to large web-based environments in which assessment is one of several components of learning processes, i.e., JuxtaLearn, FAMLE, or WISE; to more specific software developed for assessment purposes, i.e., Assistudy, Got it language, EssayCritic.

The analysis of the articles also revealed challenges related to technology use and alignment with formative assessment practices. From the analysis of the extracted data, three categories of technology use emerged, and Table 5 shows the included articles sorted by category.

Articles in the first category found that teachers adapt technology to their traditional practices, instead of using technology to support students' formative assessment practices. Even when students submit their work electronically (i.e., by e-mail, Intranet, shared Google Docs or Dropbox), Kjærgaard (2017) found that 54% of teachers report that they often print it and work on paper. Some teachers report that they use digital tools but instead move their paper-bound practice to a digital format by using the 'insert comment'

Table 5
How included articles are categorised according to description of teachers' use of technology in formative assessment.

Category	References – included articles
1. Adapting technology to existing practice.	AbuSeileek & Al-Olimat, 2015; Engeness, 2018; Kjærgaard, 2017; Kongsgården & Krumsvik, 2016; Woodard et al., 2013
2. Report positive effect or positive student and/or teacher experiences of teachers' technology use in formative assessment practices but do not document how it is achieved.	Faber et al., 2017; Genlott & Grönlund, 2016; Kralj & Glažar, 2013; Molin et al., 2020; Nikou & Economides, 2018; Rodrigues & Oliveira, 2014; Shute & Rahimi, 2017; Wasson & Hansen, 2014; Zertuche et al., 2012
3. Document how teachers use digital tools in formative assessment practices.	*Adams & Clough, 2015; *Admiraal et al., 2020; *Chen et al., 2020; *Cusi et al., 2017; *Dalby & Swan, 2019; *Edmunds & Hartnett, 2014; *Shirley & Irving, 2015; *Zhan & So, 2017

Table 6
Overview of digital tools and description of teachers' use and challenges they face.

References	Digital tool	Description of teachers' technology use	Challenges
Adams & Clough (2015)	**JuxtaLearn**: a concept-driven e-assessment system supporting teachers in writing formative multiple-choice questions and creating quizzes tailored to students' learning pathways.	• The system is co-designed with teachers and students. The quiz feeds result back to learners and teachers to inform future practice. • The system supports teachers in creating questions to identify students' learning barriers. The quizzes helped teachers focus on specific needs. • Visualisations of results for whole cohorts helped teachers identify effectiveness of teaching, how to develop peer and student-directed learning, and their own future teaching activities. • The pedagogical connection between quiz questions and teacher-identified tricky concepts made this a tool for change. • Teachers' use of quiz data became more nuanced after visualisation. • Students use visualisations of results to understand their own learning and teachers use data and quiz results to plan ahead.	• The tie into learning design in creating the quiz and back to further learning activities upon results let loose the real value of formative assessment systems. This requires a shift in perceptions of the role of e-assessment in the learning process.
Admiraal et al. (2020)	**Got it Language:** adaptive assessment environment with embedded and extracted analytics – main function to provide learners with opportunities to practice skills at their own ability level and provide corrective feedback.	• Got it software provided a lot of information, but not the information teachers needed. More detailed student scores and more qualitative information on item and student responses was therefore provided. • Benefits of use: students were triggered to put effort into language learning by completing computer-based assessment; the computer-based tests provided additional learning opportunities; teachers valued detailed information on individual item responses as they learned how they could address students' misconceptions in class.	• Teachers struggled to interpret the available information, they preferred feedback and instruction aligned with their practice and beliefs about effective teaching and learning strategies. • Got it is less suited for formative assessment as it does not provide teachers with adequate information about student assessment. • Teachers need support in formative assessment. • Teachers need accurate and relevant information from computer-based assessment tools. They must learn how to deal with this information, how they can vary their feedback and how they can see the effects of their pedagogy. • The tool should be more focused on providing teachers with adequate information and teachers need support in how to connect tools to classroom teaching.
Chen et al. (2020)	**EasiCare software:** with functions for student grouping, use of commenting and award points, interactive response system, student performance data, competitive and collaborative gaming.	• Teachers and students could access current and historic formative assessment data to make instructional modifications or engage in self-directed learning. Immediate feedback was provided both by the EasiCare system and teachers' use of award points. • EasiCare allowed for formative assessment activities such as teacher and peer feedback, social and game-based learning, personalised and agentive learning.	• Teachers must learn how to use the Interactive White Board. • The key is *how* teachers use the IWB: if the teacher conducts FA using IWB-based activities and ignores principles for classroom interactions with students, some students may experience a decline in formative assessment performance. • If teachers use IWB-based formative assessment over a longer period of time, they must pay special attention to boys and those who hold high mastery-avoidance goals.
Cusi et al. (2017)	**Digital worksheets:** supported by connected classroom technology (IDMTClass) that connects students' tablets and teachers' laptop.	• Teachers send a problem worksheet containing tasks to be tackled by students from their computer to students' tablets. • Students write answers and send to teacher, who may display them on the interactive whiteboard for other students to comment. While students solve problems, the teacher may monitor their work through IDMTClass. • Teachers can create student polls, gather answers, and show the results immediately (individual or clustered) and choose to immediately correct students' answers.	• Digital worksheets are efficient when: 1) they are inserted into a teaching sequence that alternates and integrates a variety of worksheets, 2) teachers play a crucial role in handling the worksheets, managing the whole teaching sequence, and orchestrating the discussion.

(*continued on next page*)

Table 6 (*continued*)

References	Digital tool	Description of teachers' technology use	Challenges
Dalby & Swan (2019)	**iPad**	• iPads can facilitate peer feedback and be used to identify misconceptions, plan lessons, and adapt instruction. Teachers can display student work samples and initiate class discussion. • Technology provides an overview of class performance. Teachers interpret data and the success of the formative process depends on how they use available information about student achievement. • Teachers can use information from student responses to address common misconceptions and provide feedback. Teachers shape the formative process and determine the effect on student learning. • When technology is more actively used, teachers monitor and support student learning, providing more feedback directly to students and adapting questions to better suit students' learning needs. • When using technology in the classroom, teachers' actions and the functions of technology are closely bound together, particularly when technology is used for marking and summarising students' responses.	• When teachers use technology to provide effective support, their pedagogy must change. • Technical knowledge is necessary but teachers' ability to facilitate formative assessment processes and identify the functions they want the technology to fulfil are fundamental. The required pedagogical knowledge involves understanding formative assessment and how to apply this knowledge. • The greatest challenge for teachers in using technology is not the technology itself, but understanding the process by which it can enhance student learning.
Edmunds & Hartnett (2014)	**Learning Management System (LMS)**	• Teachers used information posted by students in the LMS to gain insight into what they had learned and what they needed to learn; asked questions about student needs; communicated student needs, goals and success criteria and posted it for students and parents. Teachers helped students place their learning goals in the LMS. • Teachers grouped students according to their needs and designed learning experiences to meet these needs. • Teachers used the LMS to post reflective questions and learning links connecting goals with learning intentions, success criteria and activities. This provided insight into students' needs, their learning reflections, and learning link questions. Learning journals were available for students to post pieces of work, videos, or reflections. • Teachers used AfL principles to personalise learning for students in the LMS and classroom:1) using evidence to identify needs, 2) communicating student needs, 3) differentiating instruction to meet student needs, 4) using ongoing monitoring to inform planning, 5) providing effective feedback and feed forward, 6) enabling student reflection on learning. • The tool was aligned with the pedagogy being used, i.e., AFL was the framework for the design and use of LMS.	• Comments functions can be used to give feedback, but minimal feedback and feed forward were seen as comment function was rarely used. • LMS has the potential to harness new ways of learning, but we need more knowledge about how digital technologies can support and enhance personalised learning.
Shirley & Irving (2015)	**TI-Navigator**: a connected classroom technology to facilitate classroom interaction, allowing teacher and students to transmit data back and forth, displaying students' response and graphic data in the classroom.	• CCT displays and interprets students' responses through the rapid aggregation of submitted data, allowing teachers to gather information about learning rapidly and accurately. • Teachers used CCT to collect and analyse data. • CCT allowed teachers to give spontaneous prompts during class discussions. • Teachers could check understanding during lessons and monitor the learning process.	• CCT provides teachers with data about student learning to make instructional decisions. Teachers must develop a repertoire of alternate instructional strategies and engage students in effective discourse. • Teachers who implement technology to promote student learning need support in developing the necessary pedagogical skills to make appropriate instructional decisions.

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Table 6 (*continued*)

References	Digital tool	Description of teachers' technology use	Challenges
		The system's interactive nature allowed teachers and students to uncover aspects of student learning that might otherwise have gone unnoticed. • Data collected through CCT helped identify students who were ready for the next instructional step as well as students who needed individual attention.	• Administrative support and technological support are important factors for successful use of CCT.
Zhan & So (2017)	**FAMLE:** Formative Assessment Multimedia Learning Environment	• Over three semesters, teachers participated in development and implementation by testing, identifying problems and suggesting improvements. • Teachers' use of FAMLE evolved through the study - from summative (Phase 1) and diagnostic use (Phase 2), to integrating FAMLE into their teaching in a pre/post-test model (Phase 3) consisting of five components: pre-testing, analysing, teaching, post-testing, and extended teaching. • Data were presented as Excel tables, bar graphs, line graphs. • Learning analytics were tried out, to provide a vivid track of learning to students and teachers.	• Teachers did not understand the scientific indicators or the platform's statistical results. • Teachers and students did not understand the enormous quantities of data generated. • Teachers lack assessment literacy to interpret assessment data and translate these into actions.

function or iPads to give handwritten comments in a PDF file. Kongsgården and Krumsvik (2016) show how the iPad becomes an add-on to traditional classroom pedagogy with no increase in feedback from teachers and limited contribution to pupils' learning progress. AbuSeileek and Al-Olimat (2015) and Woodard, Magnifico, and McCarthey (2013) show how teachers use technology to support *summative* assessment practices, not formative. Engeness (2018) noted that teachers depend on and trust technology to provide information about correct answers. Hence, studies in category one document instances in which technology use does not promote formative assessment practices.

Articles in category two report positive effects or positive student and/or teacher experiences of teachers' technology use in formative assessment practices. Beyond stating that technology "works", i.e., that digital tools contribute to increasing students' learning outcomes, the experimental studies do not provide rich explanations and descriptions of teachers' actual technology use. Molin et al. (2020) tested a tool intended to provide immediate formative feedback based on correct answers, thus confusing formative assessment with summative. Other studies such as Rodrigues and Oliveira (2014) and Wasson and Hansen (2014) investigated teachers' experiences with different digital tools. However, besides reporting that teachers invested substantial time in feeding the tool with information and had positive experiences with the tool, these studies do not document how teachers used the tool formatively in the classroom. The two reviews (Nikou & Economides, 2018; Shute & Rahimi, 2017) provide an overview of different digital tools that can support teachers' formative assessment practice, but focus on the *data* generated by the tools, whether they work and how they *can* be used, not on how they *are* used in teaching.

Articles in category three are labelled core articles because they define concepts, thoroughly document how teachers use digital tools in formative assessment practices and stress the importance of alignment between pedagogical practice and digital tools. Moreover, the articles document challenges faced when using the tools in formative assessment. Table 6 shows how the core articles describe teachers' use of the tools and the challenges they face.

Adams and Clough (2015) described the development of JuxtaLearn with teachers and students in co-design workshops over a period of 18 months. Cusi et al. (2017) used a design-based approach with cycles of design, enactment analysis, and redesign in close collaboration between researchers and teachers. Zhan and So (2017) described how researchers considered improvements suggested by teachers when they refined FAMLE. Involving teachers as co-creators, inviting them to test the tools and suggest improvements, appears to be crucial when developing systems that aim to support formative assessment practices. Admiraal et al. (2020) found that the data provided by the digital tool was insufficient for teachers because they lacked the competence to translate data into actionable knowledge. Shirley and Irving (2015) and Dalby and Swan (2019) argued that teachers must develop pedagogical skills to know when and how to implement technology to support students' learning and make the appropriate instructional decisions.

All of the 22 included articles are of high quality. Each contributes useful information that helps us answer our research question. Only eight studies, however, clearly defined formative assessment and described how teachers used technological tools to achieve their educational goal. The review combines studies from two research traditions, technology use and assessment. How articles contribute to answering our research question varies due to the clarity of definitions provided, methods used, study design, documentation, and reporting. In our synthesis, each article contributes a unique piece to the bigger picture. Articles were labelled *core* when they contributed more to answering the research question than other articles. While all included articles provide insights into the topic investigated, the core articles provided definitions, documentation, and richer information about procedures than the other included articles. We use a pyramid to visualise this (Fig. 2). The orange bricks at the bottom represent studies that lack definitions and do not explain how teachers use technology in their formative assessment practices. A lack of definitions and descriptions causes confusion,

such as confounding summative and formative assessment. The yellow bricks in the middle represent studies that lack some of the information we needed to answer our research question. These articles define formative assessment or report positive experiences of technology use but do not document how teachers use technology to support formative assessment. The articles contained within the orange and yellow bricks of the pyramid contribute to the review by revealing weaknesses in existing research on technology-enhanced formative assessment. The green brick on top of the pyramid contains eight articles that define formative assessment *and* document teachers' technology use. These eight articles constitute the core articles in the synthesis and are marked with an asterisk in Tables 3–5.

4.3. Prerequisites for successful technology use – a configurative synthesis

A configurative synthesis aims to find similarities between and transcending patterns across heterogenous studies. In this systematic review, we asked how teachers use technology to support their formative assessment practices. Having mapped and analysed the included articles, key challenges were revealed, such as the lack of a definition of what formative assessment constitutes conceptually, unclear understandings of formative assessment, and little documentation of how technology should be used to support formative assessment practices.

The configurative synthesis shows how each of the included articles describes these challenges. The eight core articles in the green brick at the top of the pyramid share these features: 1) They operationalise formative assessment as a theory of action (Bennett, 2011) and describe the assessment process. 2) They show awareness of the interdependence between summative and formative assessment, i.e., all assessment begins with summative assessment (Taras, 2009). 3) They understand formative assessment as a learning process with relevance for teachers' teaching.

The eight core articles also documented teachers' use of digital tools in formative assessment practices, as illustrated in Table 6. In three of the core articles (Adams & Clough, 2015; Cusi et al., 2017; Zhan & So, 2017), researchers developed and tested specific digital tools for formative assessment. Commonalities between these three studies are the involvement of users, i.e., teachers and students, in the process of developing the digital tools and targeting them to the actual needs encountered in everyday teaching. As already noted, the involvement of teachers and students in the development, testing, and improvement of the system is vital for tailoring processes to actual instruction in the classroom and students' learning needs. By acknowledging and taking teachers' professional knowledge into consideration, researchers gain information they need to improve the tools' quality and user-friendliness.

The other five core articles (Admiraal et al., 2020; Chen et al., 2020; Dalby & Swan, 2019; Edmunds & Hartnett, 2014; Shirley & Irving, 2015) investigated the use of existing digital tools or technologies designed to support teachers' assessment practices. Digital tools gather a massive amount of data about students' work and progress that is available for teachers. To use this information in teaching, however, teachers need a relatively high level of data literacy, i.e., knowing how to decode data and use it to improve instruction (Heitink et al., 2016; Jivet, 2021). In these five articles, authors noted the importance of alignment between the digital tool and teachers' instructional practice and stressed that teachers must know how to transform information into actionable instructional knowledge (Gummer & Mandinach, 2015). Three traits related to technology development and pedagogy were emphasised: 1) involvement of users, i.e., teachers and/or students should contribute to the design and development process; 2) alignment between digital tools and pedagogical practice; and 3) the pedagogical process of teaching and assessing students is more important than the technology.

Other technologies developed to support teachers' assessment practices appear to take teachers' data literacy skills for granted by

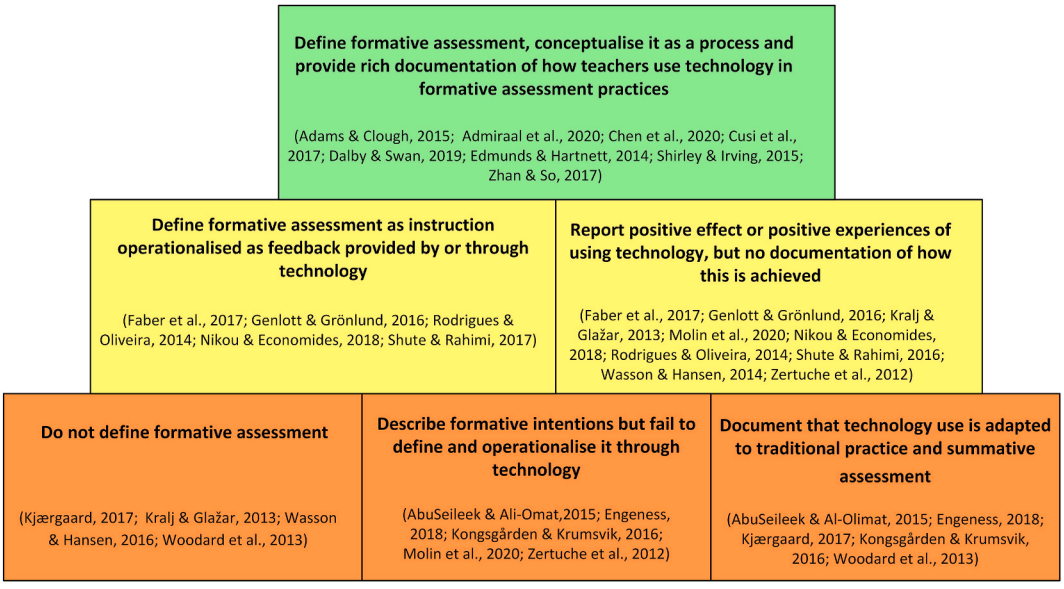

Fig. 2. Documentation pyramid.[4].[1]

assuming that teachers know how to utilize data about student learning. As Table 6 shows, the included studies find that this is an unfounded and often incorrect assumption. Admiraal et al. (2020), Zhan and So (2017) and Shirley and Irving (2015) all note a need for professional learning in this area, as teachers lacked the skills to interpret assessment data and translate it into successful educational actions (Morlà-Folch, Davis, Cuxart, & Valls-Carol, 2022), such as teaching activities.

The core articles reveal that the *process* of formative assessment is more important than the technology itself and that alignment between the digital tool and teachers' pedagogical practice is crucial for successful implementation. The gap between technology developers' *intended* use of a tool and teachers' *contextual* working conditions can explain why the interactive potential in digital tools is not used to innovate practice but tools are instead adapted to teachers' traditional practices. This systematic review revealed three main challenges, one related to teachers' professional knowledge and two related to teachers' use of technology in formative assessment practices. The synthesis therefore concludes with the following prerequisites for success in teachers' technology use in formative assessment practices, as illustrated in Fig. 3: 1) clear and well-operationalised definitions of formative assessment, 2) alignment between content, design and usability of the digital tool and pedagogical practice, and 3) data literacy to interpret and translate information to improve student learning.

5. Discussion

The review has three main findings: 1) Most studies lacked a clear definition of formative assessment. 2) Misalignment was observed between intentions about what *can* be achieved through interactive technology use and the actual *implementation* of technology-supported formative assessment (i.e., a gap between intended and actual practice). 3) Studies show that teachers need data literacy to interpret assessment data and understand how to utilize it. They also need improved understanding of how they can use technology interactively and benefit from the pedagogical potential inherent in digital tools. In the following section, we discuss these challenges and how the identified prerequisites for teachers' successful use of digital tools in formative assessment practices, shown in Fig. 3, can contribute to closing the gap between intended use and implementation.

Having summarised findings across studies, the analysis revealed problems caused by lacking or unclear definitions of formative assessment. Vague concept use can cause misinterpretations, simply because it is hard to figure out what studies have investigated and found. Conceptual confusion makes it difficult to compare findings across studies, as we cannot ascertain that researchers have investigated the same phenomenon. This can cause misinterpretations in research reviews. Acknowledging this problem, researchers have previously advocated for a precise definition of formative assessment (Bennett, 2011; Taras, 2009) and argued that definitions are needed to document the effectiveness of an intervention, summarize findings across studies in a meaningful way, and implement formative assessment as intended in classroom practice. This systematic review, however, revealed that despite previous calls for concept clarity, the lack of a clear definition persists and continues to hamper cumulative knowledge-building in the field of assessment.

The analysis also showed that researchers refer to 'formative assessment', 'assessment for learning', and 'feedback' interchangeably. This might be explained by the unwarranted dichotomy between formative and summative assessment that Taras (2009) identified in research after Scriven (1967). The term 'assessment for learning' (Black & Wiliam, 1998) added to this confusion because, as Taras (2010), noted, their prime concern was *teaching,* not assessment. When Baird et al., (2017) discussed the relationship between AfL and formative assessment, they therefore suggested better alignment between theories of learning and theories of assessment. Additionally, the included articles reveal how the operationalisation of formative assessment through technology is confused with feedback and gets 'lost in translation' (i.e., Molin et al., 2020). When confused with feedback, formative assessment is either automatically generated by the technology or provided online by students or teachers. Operationalisation of technology-supported formative assessment appears to pay little attention to feedback on task processing. For example, Engeness (2018) found that teachers relied on the automated feedback provided by technology instead of encouraging students to actively develop their skills.

Of note, the eight core articles all adhere to Taras' (2005) argument that any assessment begins with summative assessment and conceptualise formative assessment as a process in which summative assessment serves as a starting point for subsequent formative steps. These studies conceptualise formative assessment as a technology-supported learning process. As suggested by Bennett (2011), they also provide a theory of action and a concrete instantiation of how formative assessment should be practiced and how components work together to achieve a desired outcome.

Research on technology use in formative assessment practices often promotes the potential of computer-supported learning or assessment tools for student active learning and signals high ambitions about what can be achieved through technology-supported interactive learning. This systematic review, however, revealed gaps between intended use and actual implementation. Apparently, misunderstandings of what formative assessment is hamper formative intentions, resulting in traditional teaching and summative assessment practices. Teachers might at most adapt existing materials to technology rather than make use of the interactive potential inherent in digital technology. This can at least partly explain the identified gap between formative and interactive intentions and the continued prevalence of summative, teacher-led practices (Barak, 2017; Blikstad-Balas & Klette, 2020; Lillejord et al., 2018; Sinclair & Aho, 2018).

This systematic review reveals that technology is adapted to traditional teaching practices, while technology's interactive potential to support formative assessment remains heavily underutilised. Researchers have different explanations for why this happens. For

[4] The bricks in the pyramid are not mutually exclusive, so a study can be listed in more than one brick.

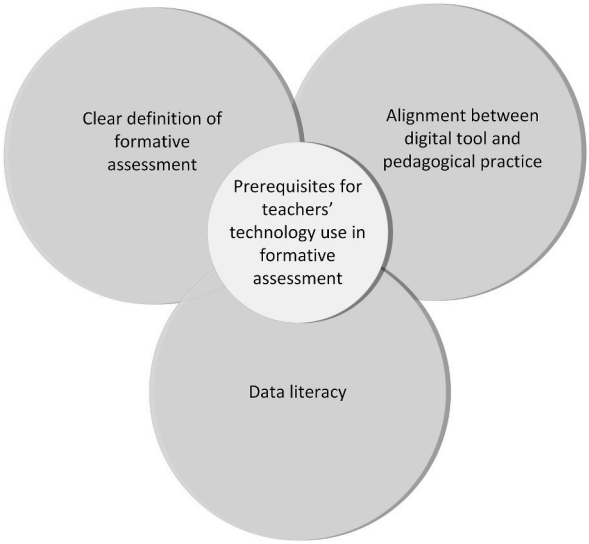

Fig. 3. Prerequisites for teachers' technology use in formative assessment.

instance, Kongsgården and Krumsvik (2016) found that teachers did not change their instructional practice when using technology. Engeness (2018) shows how teachers depend on and trust technology to provide information about correct answers and that the design of the digital tool used in her study failed to support students' skills in assessment for learning. This observation should be further studied to improve our understanding of the mechanisms at play.

The review has shown that clear definitions of formative assessment are needed for teachers to utilize the interactive potential of technology to support their formative assessment practices. In addition, better alignment is needed between teachers' formative intentions and the design of digital tools in order for teachers to use these tools pedagogically in their formative assessment practices.

Lastly, increasing teachers' knowledge and skills related to assessment and the use of assessment data, i.e., increased data literacy, would strengthen the teaching professions' understanding of how they can utilize the potential of technology in assessment practices. Bottom-up approaches "that include teachers as main stakeholders in data literacy projects, rather than end-users of data" (Ndukwe & Daniel, 2020, p. 4) could be a way forward, as this would increase teachers' use of learning analytics to make better-informed pedagogical decisions when using technology.

6. Conclusion

This systematic review answers the research question *How do teachers use technology to* support *formative assessment practices in schools?* Previous research has documented that the interactive potential of technology is underutilised (Chen et al., 2020; Lillejord et al., 2018) and that the "greatest challenge for teachers in using technology in the classroom is not the technology but an understanding of the process in which it can enhance student learning" (Dalby & Swan, 2019, p. 843). Indeed, the mapping, analysis, and synthesis of the 22 included articles revealed that many studies on technology use in formative assessment were more focused on platform/tool/features than on actual pedagogical uses of the technology and its integration into learning and instruction.

Related to this, the review revealed vague concept use and that researchers often use the terms formative assessment and assessment for learning interchangeably, without providing more accurate definitions of the concepts. More specifically, one consequence of the widespread and rather uncritical use of Black and Wiliam (1998) as the authoritative source, with little or no critical investigation of their reasoning, is that formative assessment is used synonymously with feedback, associated with teaching, and used to promote teachers' instructional activities. As studies show that teachers' technology use is dominated by traditional teacher-centered classroom practices, this review also found little student active learning (or even investigations into or references to this paramount question). This is unfortunate, as more investigative practices in schools would strengthen the teaching profession (Fisher et al., 2018; Lillejord, 2023). In formative assessment, it is therefore vital that teachers actively engage students, whether technology is used or not, as students must learn to both participate in productive learning processes and produce learning products (Lillejord & Dysthe, 2008).

In a similar vein, some studies describe formative intentions but fail to define and operationalise how formative assessment should be practiced. They anticipate successful practices, but do not document them. This review revealed challenges related to implementing technology designed to support formative assessment. It shows that cumulative knowledge development in this research field depends on clear definitions, but also that teachers must be well prepared for these activities.

The configurative synthesis identified three prerequisites for teachers' technology use in formative assessment practices: 1) clear and well-operationalised definitions of formative assessment, 2) alignment between content, design and usability of the digital tool and pedagogical practice, and 3) teachers' data literacy, i.e., knowing how to interpret and translate information to improve student

learning.

To enhance the quality of research on technology use in formative assessment, researchers must define formative assessment more precisely. Additionally, researchers are advised to engage teachers and students as co-creators in the development of digital tools, as alignment between digital tools and teachers' practice is crucial for productive technology use. Allowing co-construction with teachers and students will help overcome identified barriers to student active learning (Børte, Nesje, & Lillejord, 2023) and contribute to a more data literate teaching profession.

Lastly, the review shows that a strategic orientation point in technology development is to understand teachers' pedagogical practices and to simultaneously support students' and teachers' learning processes. It is also advisable to involve both teachers and students as co-designers of digital tools. These measures will ensure better alignment between tools and practice and ideally contribute to closing the gap between intended and actual technology use, which is undoubtably the future of 21st century education.

Implications of these findings for teaching are that teachers more readily will see the interactive potential of digital tools if they act as co-designers in the development process. More inquiry-based teaching has been found to support the shift towards student-active learning (Dobber, Zwart, Tanis, & van Oers, 2017). Therefore, students should not be positioned as passive recipients of knowledge from teachers but be actively engaged as co-creators in problem-solving processes. Teachers must know how to organize students as instructional resources for each other, allow them to collaborate on tasks, receive feedback from other students, teachers, or tools, and be more actively engaged in both classroom and online learning.

A vital part of systematic reviews is to identify knowledge gaps in the research. The following knowledge gaps were identified in this systematic review: 1) few studies have investigated teachers' actual technology use in formative assessment practices, 2) there is a need for more studies using teachers and/or students as co-designers of digital tools for teaching and learning, 3) more studies on teachers' data literacy related to technology use are needed.

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Kristin Børte: Conceptualisation, Methodology, Writing-original draft, Formal Analysis, Visualisation, Writing-Review & Editing, Project administration. **Sølvi Lillejord:** Conceptualisation, Method, Writing- Review & Editing, Validation. **Jessica Chan:** Investigation, Data Curation, Validation. **Barbara Wasson:** Writing - Review & Editing. **Samuel Greiff:** Writing - Review & Editing.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

Data availability

Data will be made available on request.

Appendix A. Search string

(TI,AB ("computer" OR "blended learning" OR "computer aided" OR "computer assisted assessment" OR "computer assisted learning" OR "computer based assessment" OR "computer based learning" OR "computer based teaching" OR "computer simulation" OR "computer supported" OR "computer technology" OR "computer use" OR "computer aided" OR "computer-assisted assessment" OR "computer assisted learning" OR "computer-based assessment" OR "computer-based learning" OR "computer-based teaching" OR "computerized instruction" OR "computers and learning" OR "computers in education" OR "computer-supported" OR "digital learning" OR "digital technology" OR "educational technology" OR "e-learning" OR "e-assessment" OR "electronic learning" OR "game" OR "ICT" OR "information communication technology" OR "innovative technology" OR "instructional technolog*" OR "intelligent tutoring system" OR "interactive learning environment" OR "interactive learning object" OR "interactive simulation*" OR "interactive white board*" OR "media in education" OR "mobile learning" OR "multimedia learning" OR "OLPC" OR "one laptop per child" OR "one to one computer" OR "one2one computer" OR "online learning" OR "online study" OR "simulation-based education" OR "simulation-based teaching" OR "simulation" NEAR "student" OR "simulation" NEAR "learn*" OR "tablet" OR "technology-enhanced education" OR "technology-enhanced assessment" OR "technology-enhanced learning" OR "technology use" OR "technology enhanced instruction" OR "technology enhanced assessment" OR "technology enhanced learning" OR "TEL" OR "tutoring system" OR "virtual learning" OR "virtual reality" OR "web-based instruction" OR "web-based learning" OR "web-based training" OR "CBAfL" OR "computer based Assessment for Learning" OR "computer-based Assessment for Learning" OR "learning analytics" OR "LA" OR "data driven" OR "educational data mining" OR "EDM" OR "tool" NEAR "student" OR "tool" NEAR "learn*" OR "game-based assessment" OR "game based assessment")) AND (TI,AB ("formative assessment" OR "assessment for learning" OR "AfL" OR "feedback" NEAR "student*" OR "peer assessment" OR "peer-assessment" OR "self-assessment" OR "assessment literacy")) NOT (TI,AB ("higher education" OR "vocational education" OR "early years education" OR "pre school" OR "pre-school" OR "medic*" OR "nurs*" OR "health"))

Filter: Peer-reviewed, published after January 01, 2012.
Search string used in ProQuest.

Appendix B,C,D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.edurev.2023.100568.

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