assess@learning

Digital Formative Assessment: A review of the literature

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Contents

1. Introduction

This literature review sets out the 'state of the art' in international research and policy studies on digital formative assessment (DFA). Its focus is on how digital technologies may support and strengthen classroom-based formative assessment, including peer- and self-assessment. It also examines how digital formative assessment can build on what students bring to the classroom – both in terms of their prior learning and experiences outside of the classroom.

This review supports the Assess@Learning policy experimentation, which aims to identify the conditions that inspire and empower all education stakeholders to adopt digital formative assessment. The review sets out a working definition of digital formative assessment and a typology with different technologies and their potential to support assessment of student learning (their learning environments, capacity to support individual student needs as well as their capacity to support student collaboration). The definition and typology will be used to guide case study selection and the development and testing of a Systemic Toolkit for teachers, school leaders, students (lower secondary level), parents and policymakers, according to their different needs. The ultimate aim of the Toolkit is to integrate digital formative assessment to empower students to self-direct their learning.

Research finds that digital learning and assessment have the potential to support more powerful student learning. Hattie, for example, in his widely cited review of meta-reviews in education research finds significant effect sizes for a range of formative assessment methods in ICT-based environments (e.g. intelligent tutoring systems, formative evaluation, and so on) [1] . Digital technologies used in education include student e-portfolios, social media, digital textbooks, mobile learning, classroom polling, digital games and integrated formative and summative assessment.

While digital formative assessment may have a significant impact on student motivation and learning, its effectiveness also depends on how it is used, and how it is integrated with teaching and learning aims. This includes how teachers design lessons to support learning aims, elicit

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[1] Hattie Ranking: 252 Influences And Effect Sizes Related To Student Achievement, https://visible-learning.org/hattie-ranking-influences-effect-sizes-learning-achievement/

evidence of student understanding, respond to identified learning needs, and support student reflection. Scaffolding of learning may guide learners as they develop their own learning aims and gradually become more autonomous.

Nevertheless, several studies have found that digital learning is used as a way to engage and motivate students, but that the pedagogical possibilities are not fully realised. This literature review presents research on different uses of digital technologies, and where possible, evidence of effectiveness. Section 2 of the review sets out the methods and scope of the review. Section 3 discusses conceptual approaches to formative assessment and research on the impact of different approaches. This section also highlights some key differences in how formative assessment is conceptualized in different education research traditions (e.g. English- and French-language literatures). Recent efforts to develop a 'theory of formative assessment' linked to 'theories of pedagogy' are noted. In section 4, a working definition of digital formative assessment is suggested, and a typology setting out different tools and uses proposed. This typology is intended to guide the selection and development of country case studies for the Assess@Learning policy experimentation. The fifth section, which is the core of the review, presents evidence from studies on the implementation of digital formative assessment to support learning aims. This section begins with a brief discussion on measurement technologies supporting effective digital formative assessment. This is followed by findings on research related to the use of different digital tools highlighted in the typology to support formative assessment and learning in different subject areas. Section 6 concludes the paper with policy recommendations.

2. Methods and Scope

More than 200 articles on the implementation and impact of digital formative assessment, primarily from peer-reviewed academic journals, were identified in a search of online databases (EBSCO and ERIC). Selected articles on the conceptual underpinnings of formative assessment – which also have implications for effective integration of digital formative assessment – were identified. In a second phase, the initial draft of the paper was revised following feedback from partners and associated experts participating in the Assess@Learning policy experimentation.

The online search has focused on research published in English (including a significant body of research on digital formative assessment in Taiwan. Our search for empirical research on digital formative assessment published in other languages represented in the partnership (Greek, Estonian, Finnish, Norwegian, Portuguese, Spanish) did not identify articles meeting our search criteria.

It should be noted that this is not an exhaustive review of resources. Rather, the studies highlighted in this review have been selected to provide relevant insights and to suggest approaches that may be adapted to the appropriate level and learning goals for the target group, and in different subject areas. While the Assess@Learning policy experimentation is focused on the lower secondary school level, studies for both younger and older students (including higher education) have been included.

This review features cases that involve relatively low investments in digital tools (e.g. off-the-shelf digital games or online platforms), as well as those involving much higher investments (e.g. requiring more expensive ICT hardware and better connectivity). While access to costlier technology is limited in many education systems (and raises questions related to equity and access), these studies nevertheless provide insight on the state of the art in research and development, as well as the affordances and limitations of a range of digital technologies. Concerns related to equity and access to digital tools will need to be

3. Formative assessment in the classroom

Formative assessment is not one specific practice, but rather an approach to teaching and learning. It may be best seen as a dynamic process, as teaching and learning are adapted according to conditions and needs identified in the assessment process (Clark, 2010). Black and Wiliam (2010) describe formative assessment as '…all those activities undertaken by teachers — and by their students in assessing themselves — that provide information to be used as feedback to modify teaching and learning activities. Such assessment becomes formative assessment when the evidence is actually used to adapt the teaching to meet student needs' (p. 82).

Approaches to formative assessment reflect education cultures, and thus vary across countries and research traditions. For example, research in the English-language tradition has focused on measuring the impact of different formative assessment approaches, looking to studies on mastery learning, the content and timing of feedback, scaffolding, peer and self-assessment practices and classroom discourse (Black and Wiliam, 1998; Hattie, 2009). This research has helped to identify evidence on effective practice, although as Bennett (2011) has cautioned, effectiveness ultimately depends on learning conditions, and impact may vary from one implementation to the next.

In the French-language literature, by contrast, Perrenoud (1998) emphasises that research on formative assessment has focused on '…the content of disciplines and differentiation in teaching around an integrated concept: the individualised regulation of learning.' (p. 85). Allal and Mottier-Lopez (2005), also working in French language research, describe formative assessment as being embedded in classroom cultures and activities, and includes classroom interactions, questioning, structured activities, and feedback aimed at helping students to close learning gaps.

The OECD (2005) synthesised different approaches to formative assessment based on international research (English, French and German language) and observations of classroom practices across several OECD countries, and suggested a general framework encompassing:

1. Establishment of learning goals and tracking of individual student progress toward those goals.
2. Use of varied approaches to assess student understanding.
3. Feedback on student performance and adaptation of instruction to meet identified needs.
4. Active involvement of students in the learning process.
5. Use of varied instruction methods to meet diverse student needs.
6. Establishment of a classroom culture that encourages interaction and the use of assessment tools.

Figure 3.1: The elements of formative assessment
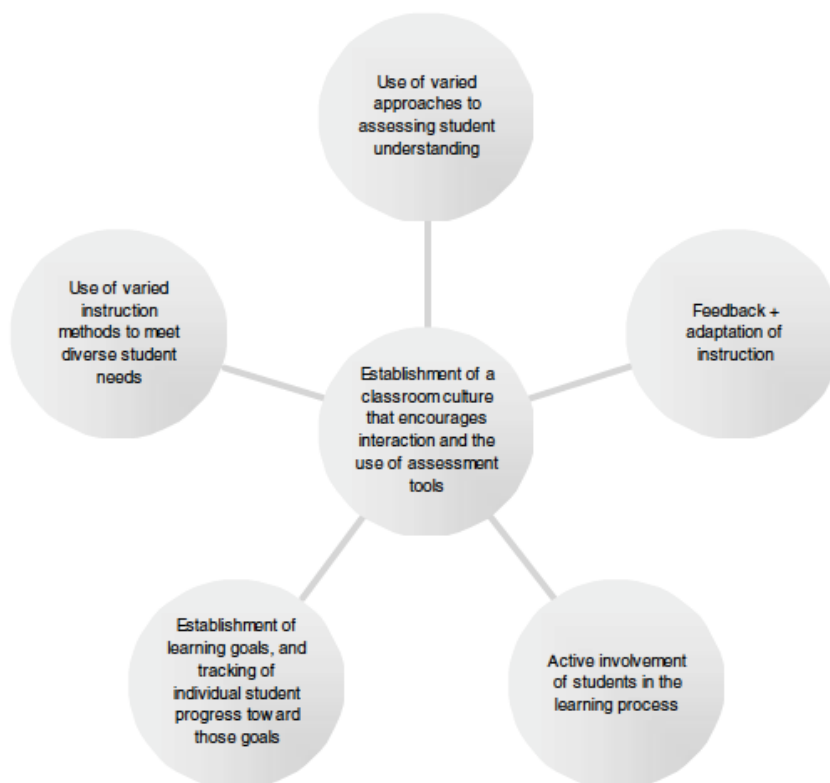
Source: OECD (2005), p. 46

More recently, several authors have argued for further theoretical development of formative assessment. Croussard and Pryor (2012) argue for a more radical approach to formative assessment to allow for more exploratory approaches to learning where learning outcomes are not already defined, and which provides room for 'contingencies' and meaning-making in classrooms, as they describe, to be 'taken up more openly and dialogically with students, as opposed to formative assessment sitting in a instrumental relationship to a given curriculum' (p. 251).

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Echoing Croussard and Pryor's concerns that assessment is often placed in an instrumental relationship with curriculum, James (2014) has noted that much of the research on formative assessment has focused on the 'technical perspective' and on fairness, transparency, and efficiency. Timmis et al. (2016), in their review of 'technology enhanced assessment' argue that the aims and methods of assessment therefore should be evaluated in order to develop '…assessment that is more meaningful and more educationally and culturally relevant for learners and teachers' (p. 457). New assessment approaches will be needed to measure new curricular priorities to develop students' competences for creativity, problem solving, adaptability, and so on (Timmis et al., 2016; Pepper, 2013).

Black and Wiliam (2018) have highlighted that any 'theory of formative assessment' needs to '… be embedded within a wider theoretical field, specifically, within a theory of pedagogy' (p. 551). They propose a model for the design of educational activities influenced by theories of pedagogy, instruction and learning and by subject disciplines (and theories of learning need also to redress the neglect of assessment). They note that subject learning, requires the development of 'disciplinary habits of mind' (i.e. epistemologies) (see also Yorke, 2003).

The model proposed by Black and Wiliam is centred on planning and design structured first around learning and content aims, which are then used to guide the sequencing of specific activities, with successive activities stimulating learning from previous work. Tasks need to be designed to engage learners so as to elicit evidence of their understanding. The teacher may then infer appropriate next steps in instruction. They note that dialogue is important not only to assess student understanding, but also to develop the '…sociocultural aspects of learning, the habits of collaboration and of working in and through a community' (p. 556). Effective dialogue needs link to earlier learning and to open to broader perspectives. Students are given the opportunity develop their thinking with longer answers (other than single-word responses).

Figure 3.2: Model for assessment in relation to pedagogy
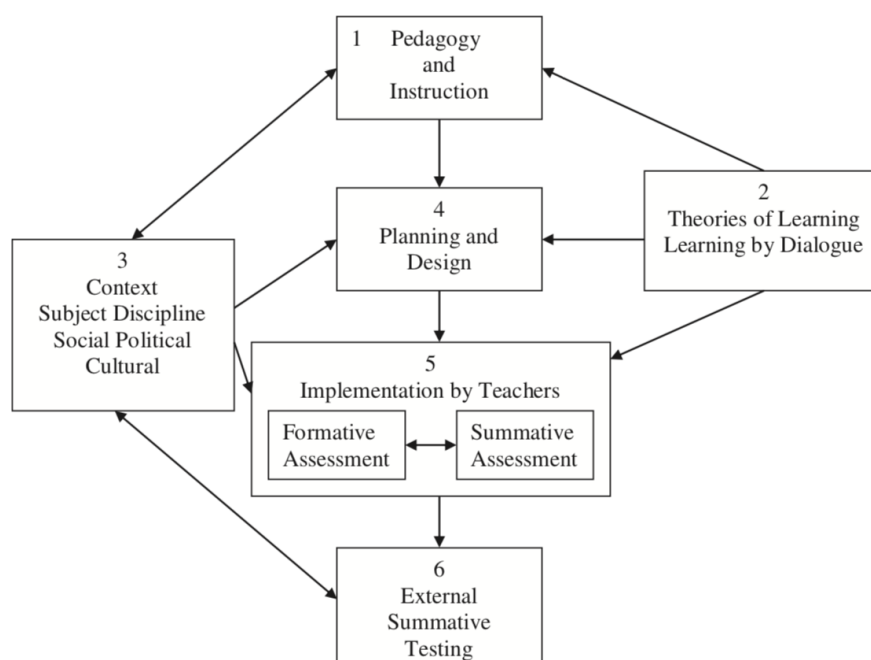
Source: Black and Wiliam (2018), p. 556

4. Digital formative assessment

While teachers' skills to use formative assessment are absolutely vital, digital tools create possibilities for deepening formative assessment practice within and beyond the classroom. Based on the literature identified for this review, we may summarise advantages of different digital learning environments including:

- rapid (real-time) feedback and scaffolding of next steps for learning at an appropriate level of difficulty.

- support for learners' choices (to personalise learning and support intrinsic motivation)

- immersive learning environments to support situated learning

- mobile tools to support assessment of 'anytime, anywhere' learning

- set up of complex ill-defined problems that challenge learners and support collective engagement in problem solving in small groups or in massive multiplayer online platforms

- opportunities for self- and peer-assessment

- access to resources and online exemplars

- Collection (or 'mining') of educational data to better understand learning processes and contexts, and in turn, use these data to generate learning analytics to predict student progress and adapt learning

- the potential for a more seamless integration of formative and summative assessments

- opportunities for learners to design their own learning goals and strategies.

This last point is of particular importance for the Assess@Learning policy experimentation, which will include country dialogue labs not only with teachers, but also with students in order to learn more about how they experience DFA and the extent to which DFA tools enable them to direct their own learning.

This approach to student involvement in the policy experimentation reflects growing recognition that student engagement in decision making supports is both a good practice and a legal obligation in most countries under the UNCRC (UN Convention on the Rights of the Child) (Elwood, 2012; Lundy, 2007). Research on DFA should focus not only on actively involving students in the assessment of their own learning, but also soliciting their input on their experience of DFA and their involvement in development of DFA strategies. Moreover, children's participation in education and in assessment, must be inclusive, and '…encourage opportunities for marginalized children to be involved ... it needs to provide equality of opportunity for all, without discrimination on any grounds' (UN Committee 2009, 30, cited in Elwood and Lundy, 2010).

The proposed working definition of DFA is based on Black and Wiliam's 2010 definition of formative assessment, modified to reflect digital contexts (Box 4.1). This definition recognises that formative assessment may be wholly designed to be carried out digitally or may include activities that blend digital and non-digital tools and activities (e.g. the use of tools such as rubrics (including paper-based) to evaluate digital learning. The definition is also intentionally broad – referring to all features of the learning environment that support assessment --- in order to encompass the very broad range of approaches, tools and strategies. This working definition may be further modified to reflect what is learned during the project period.

Box 4.1: Working definition for digital formative assessment

Digital formative assessment includes all features of the digital learning environment that support assessment of student progress and which provide information to be used as feedback to modify the teaching and learning activities in which students are engaged. Assessment becomes 'formative' when evidence of learning is actually used by teachers and learners to adapt next steps in the learning process.

Source: Assess@Learning Partners, 2019; Black and Wiliam, 2010

Box 4.2	Definitions uses in within partner countries
Mapping definitions	

The EU Network of Excellence defines technology enhanced learning as the use of digital technologies to support new ways of learning in all education sectors. It focuses on lifelong learning that is part of daily activity and that involves collaborative knowledge sharing and building (Gillet, Scott and Sutherland, 2015). Timmis et al. (2016) adopt the term 'technology enhanced assessment' to complement technology enhanced learning, defining it as 'any use of digital technologies for the purposes of enhancing formal or informal educational assessment for both formative and summative purposes.'

Countries participating in the Assess@Learning policy experimentation:

Box 4.2	Definitions uses in within partner countries
Estonia	Digital formative assessment has no separate definition and is considered as one tool to conduct formative assessment. Formative assessment is a collection of pedagogical practices taking place during studies, in the course of which a pupil's knowledge, skills, attitudes, values and behavior are analyzed. It is important for the pupil to be aware of the assessment model which is being used and understand expectations placed on him or her. Feedback is provided on the pupil's previous results and shortcomings, the pupil is encouraged and guided in further studies and the future objectives and routes of studying are planned. Emphasis is also put on peer assessment as a tool to learn self-assessment skills.
Finland	In Finland, formative assessment is intended to guide and encourage student learning. There is significant emphasis on self- and peer- assessment. Digital formative assessment tools are used to support student self- assessment, including assessment of the learning process (and not just the outcomes).
Greece	Greece has developed programmes to support remote learning, but currently does not have a national strategy to support digital formative assessment.
Portugal	In Portugal, the main purposes of formative assessment include: - *Improvement of teaching and learning* based on a continuous process of pedagogical intervention, in which the learning objectives, the expected learning outcomes and the assessment procedures serve as reference - *Diversity* of procedures, techniques and tools for collecting information on student performance - *Adequacy* of procedures, i.e., the quality that we always pursue in the information we collect means that the procedures are consistent with the nature of the task / activity being evaluated - *Feedback*, i.e., formative assessment is continuous, systematic and comprehensive.

Box 4.2	Definitions uses in within partner countries
	Digital formative assessment has been introduced as a regulatory measure and is the main method for assessment. It has also integrated in the curricular aims.
Spain	In Spain, the Education Law highlights that assessment is to be continuous, formative and integrating. Teachers are to assess students' learning as well as their teaching processes and practices, for which they are to establish indicators of achievement. When student progress is not adequate, educational reinforcement measures are to be established during the course. Students' acquisition of key competences and learning objectives are part of the assessment criteria and standards listed in the Law. This definition applies to the use of digital formative assessment, as well.

The proposed typology (Figure 4.3) is intended to guide selection of cases and support analysis for the Assess@Learning policy experimentation. A range of tools and platforms that support digital formative assessment are set out in the vertical axis of the typology, while different modes for formative assessment are set out in its horizontal axis.

The categories for the horizontal axis, in particular, require further explanation:

- **The digital learning environment** – This column draws Black and Wiliam's (2018) proposed model for assessment in relation to pedagogy. The term 'learning environment' within the typology thus refers to the use of digital platforms and tools to structure learning and content aims, to guide and sequence activities, and to elicit evidence of understanding. It may involve a combination of technologies as well as face-to-face interactions. The specific approach will vary by subject area and learning aims, but needs to be grounded in theories of learning and to support learning through interaction (whether with fellow learners, the teacher, or with learning objects in the digital environment).

- **Student-centred learning and assessment** – This column emphasizes the importance of student agency, including student-centred learning and assessment to identify and adapt learning. For example, a variety of Web 2.0 tools may embed assessment (e.g. through quizzes embedded in e-textbooks) or students may use platforms to design their own multi-modal projects. Assessment may draw on non-digital tools such as rubrics that set out standards and criteria by which to measure quality of their own work. E-coaches and other digital monitoring tools may help students to track their progress toward learning goals, provide automated feedback and/or scaffold activities for learning based on prior responses.

- **Student collaborative learning and assessment** - This column emphasizes the importance of student collaboration and collective engagement in learning and assessment. For example, students may benefit from online peer feedback (e.g. through online discussion platforms). Multi-player online games designed for educational purposes provide opportunities of students to address complex, ill-defined problems. In these environments, assessment is grounded in the problem-solving activity itself. While games may scaffold levels of challenge, learners participating in the process may also play an active role in assessing the effectiveness of different problem-solving approaches and may contribute new ways to refine and improve them.

Put differently, the first column highlights teacher decisions on how to use different digital tools and platforms to support student learning, to track student progress and identify learning needs, to provide varied instruction methods, and to encourage student interaction and the use of assessment tools in digital environments.

The second column highlights the use of digital tools and platforms to support each student's active involvement his/her own learning, scaffolding of learning to meet specific learning needs (with as little or as much feedback is appropriate), student choice and ability to focus on areas that are most motivating, and the use of assessment tools to track progress and adjust learning strategies.

The third column highlights the importance of classroom cultures that encourage interaction and the use of assessment tools. Students interact with each other, provide peer assessment and feedback, and interact with specific problems or learning challenges.

Together, the three columns set out in the typology correspond to the elements of formative assessment identified in the OECD (2005) international study referenced above and illustrated in Figure 3.1.

The typology is also intended to highlight the affordances and limitations of different digital tools and platforms (as set out in the cells of the table). For example, Web 2.0 platforms provide opportunities for students to engage in self-directed learning and to interact with each other. Formative assessment may still be based on teacher feedback or student self- or peer-assessment, or students may access online quizzes or materials to support further learning. Other online platforms, such as digital games, may provide automated feedback and scaffolding. These may be used to support broader teaching goals – helping teachers to identify student performance levels, or to reinforce recent learning. Multi-player online games focus students in collective problem solving – with assessment focused on progress toward solving the problem rather than on each student's specific approach.

The studies identified for this review highlight diverse ways in which teachers have integrated digital learning and formative assessment within their courses. Several of the studies feature digital tools and platforms developed by the authors in partnership with teachers. Others describe the use of Commercial-off-the-Shelf (COTS) programmes that have been adapted to support specific learning goals, or programmes that provide students with opportunities to practice skills (e.g. an online platform to provide students with opportunities to practice mathematical problem solving).

For the majority of these studies, teachers do not need to have an in-depth understanding of technologies, but they do need to understand the affordances and limitations of the different tools and platforms in order to integrate them in lesson designs.

Figure 4.3

Draft Typology	The digital learning environment	Student-centred learning and assessment	Student collaborative learning and assessment
Personalised learning platforms			
e-portfolios/digital diaries	Students' personal learning environments, use of multi-modal materials/tools	Student-directed, reflection, self-assessment.	Peer assessment, collaborative projects, etc.
Digital storytelling	Students' personal learning environments, use of multi-modal materials/tools	Student-directed, reflection, self-assessment	Peer assessment, collaborative storytelling, etc.
Social media (blogs, wikis)	Students/teachers identify areas for online discussion. Integrated with other tools (e-textbooks, mobile learning, etc.)	Peer feedback	Discussion boards, Facebook, blogs and wikis, text messages and other social media to support peer collaboration and assessment
Online resources	Internet-based resources to support student research	Teacher scaffolding to develop student research skills.	Peer assessment, collaborative research project,
E- textbooks	Multi-modal materials/tools to demonstrate and model content/interactivity	Student self-pacing; Automatically differentiated (adaptive) or differentiated by teacher (non-adaptive)	Discussion boards, Facebook, blogs and wikis, text messages and other social media to support peer collaboration and assessment

Mobile learning	Situated learning, immersive and interactive	Automatically differentiated (adaptive)	Text messages, social media to support collaborative learning and assessment
Classroom polling/interactive white boards	Classroom polling to check student understanding, guide and adapt classroom discussions according to student understanding	Contingent teaching (non-adaptive: teachers adapt/differentiate content according to identified needs)	Opportunities to support peer learning; opportunities for collective and contingent decision-making
Rubrics	Teachers may develop or identify existing scoring rubrics setting out standards and criteria to identify student progress and learning needs. Rubrics may be analog or developed with online tools. Analog rubrics may be used to assess digital learning products	Students may use scoring rubrics to identify their own progress and adjust learning strategies.	Students may use scoring rubrics for peer assessment or to assess the quality of their collaborative work
Dash boards and monitoring tools	Analysis of students' learning trends and patterns to identify learning needs	Contingent teaching (non-adaptive: teachers/students adapt according to identified needs)	NA
Digital games (individual or multi-player educational games)	Collective engagement to address complex/ill-defined problems (e.g. in a game format/network learning).	Automatically differentiated (adaptive)	Designed to support collaborative problem-solving or competitive play
Integrated formative and summative assessment	Can be multi-modal, based on interactive content – or traditional	Automatically differentiated	May include collaborative problem-solving elements

	online tests and quizzes	(adaptive) (e.g. CATS)	
- On-demand assessments - Research and development	Ongoing research and development to support integration of the design, content and formative assessment and instruction.	'On-demand' assessments that support student choice on assessment methods, timing of assessment	

5. Findings from the literature

This section sets out findings from empirical studies on the use and impact different technologies to support digital formative assessment. It begins with a brief overview of measurement technologies that support digital formative assessment. These include research using evidence-centred design to support automated feedback, scaffolding of next steps, and better integration of formative and summative assessments, and rubrics to support teacher and learner self- and peer- assessment in web 2.0 environments.

This is followed by a discussion of research on how the different tools are used to support learning and assessment, and evidence of impact on student learning. As noted above, the design of learning and assessment need to be structured differently in order to take into account how knowledge is structured in different domains. Therefore, studies on the use of digital tools to support learning and assessment in different disciplinary areas are highlighted:

- Personalised learning platforms

  - e-portfolios/digital diaries

  - social media (blogs, wikis, etc.)

  - digital storytelling

- E-textbooks

- Mobile learning

- Classroom polling

- Dashboards and monitoring tools

- Digital games

- Integration of formative and summative assessment ('on-demand' assessments, ongoing research and development).

It should be noted that these tools are not mutually exclusive of each other. For example, classroom polling, dashboards and digital games may be part of an integrated platform. Teachers may also design lessons drawing a range of digital tools. Indeed, researchers point to a future where different tools and platforms are connected to each other and track student learning so support a more seamless learning experience.

As teachers plan to integrate these different tools and platforms, they need to take their different affordances and limitations into account. For example, many Web 2.0 tools provide a platform students' self-directed learning, and access to a range of resources, social media and opportunities online peer- and self-assessment. Assessment and decisions on next steps for learning are done by teachers and students, rather than via an automated system. On the other hand, digital games, mobile learning programmes, online quizzes, and other tools may feature automated feedback and scaffolding of learning so that next steps better match the learners' needs or provide opportunities for collaborative problem solving among players.

Classroom polling provides teachers with information on how well students understand elements of a discussion, but teachers must use their own expertise as they decide how to guide the subsequent discussion. Some digital games may feature complex, ill-structured problems that challenge students to develop their problem- solving skills and in the case of multi-player games, to collaborate with other players.

5.1 Measurement technologies and tools to support digital formative assessment

This section sets out a brief background of some of the different measurement technologies and tools that shape approaches to digital formative assessment. This is relevant for automated

learning programmes that scaffold next steps in the learning process (e.g. digital games). The section begins with a discussion of evidence-centred design, an approach to designing assessments of complex competences. It then turns to a discussion of the emerging fields of learning analytics and educational data mining. These different methods underpin a range of innovations in digital formative assessment. A brief discussion of scoring rubrics follows. Rubrics are a more traditional tool for assessment of student progress toward learning objectives and may be used in analog or digital environments.

Evidence-centred design

Many innovations in digital assessments are supported by 'evidence-centred design' (ECD), an approach developed by Mislevy, Almond and Lukas in 2003. Designers of assessments decide first on the complex skills, knowledge or other attributes that are to be measured, and then the tasks or situations that will provide evidence of student proficiency. Thus, the link between the evidence to be derived from the assessment and the claims about student proficiency are made explicit (Mislevy and Haertel, 2006 in Ganes et al.). The nature of the construct guides selection or development of relevant tasks and the construct-based scoring criteria and rubrics (Messick, 1994). This approach has been considered as revolutionary, particularly because traditional assessment methodologies used for large-scale assessments treat learning tasks as discrete items, and they cannot easily capture complex performances and processes (Chudowsky and Pellegrino, 2003). A long-term goal for research and development is to develop a more seamless integration of digital formative and summative assessment.

Gane et al. (2018) point out that as cognitive models of domain proficiency become increasingly complex, more complex, multi-faceted arguments regarding what students know and are able to do are needed. The underlying framework for assessment thus needs to set out the 'layers' of development for proficiency in a given domain to guide the design of tasks. Moreover, when designing with technology, one needs to ensure that measurements are focused on the intended construct, without measuring irrelevant constructs. This supports the validity of measurements (i.e., the assessment measures what it is intended to measure).

Learning analytics and educational data mining

Learning analytics and educational data mining are emerging and related fields for analysis of data collected in online learning platforms. Learning analytics is defined as 'the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environment in which it occurs (Long and Siemens, 2011).' Learning analytics may be used to predict learner performance, to recognise patterns that support suggestions for learning resources relevant to leaners' needs, and to support more personalised learning environments (Siemens, 2012; Verbert et al., 2012).

Reyes (2015) notes that learning analytics may support teachers' analysis of student performance and identify learning needs, to enhance social learning, or to detect online behaviours that may indicate frustration, confusion or boredom. The data themselves are often difficult to decode, however. Moreover, these data provide little insight on the quality of learner engagement. Additional data are needed to identify effective steps for learning (Van Horne, Russell and Schuh, 2015).

Box 5.1	Examples of technologies used to support digital formative assessment
Bhagat and Spector (2017) describe a range of current technologies to support digital formative assessment:	

- **HIMATT** (Highly Integrated Model Assessment Technology and Tools) combines the features of DEEP (Dynamic Enhanced Evaluation of Problem Solving), Text-MITOCAR and SMD (Structure, Matching, Deep Structure) (Pirnay-Dummer, Ifenthaler, and Spector, 2010).

- **AKOVIA** (Automated Knowledge Visualization and Assessment) is based on HIMATT. It is applicable for the semantic analysis of natural language (e.g., discussion forums, essay writing) and graphical knowledge representations. Automated feedback is one of the key features of AKOVIA, which can help the

Box 5.1	Examples of technologies used to support digital formative assessment

learners to understand their writing and improve it accordingly in an effective way (Ifenthaler, 2014).

- **AssiStudy** is based on Service-Oriented Architectures (SOA). It creates personalised training exams based on students' questions from the past exams stored in the repository. These training exams provide immediate feedback explaining the mistakes. This system used various Natural Language Processing (NLP) techniques to match reference answers (RA) with student answers (SA). After the training exams, teachers use students' performance information to develop evaluation exams. Three main types of exams can be created: enumeration, specific knowledge and essay (Rodrigues and Oliveira, 2014).

- **iSMILE** Identification of Students' Misconceptions in Individualized Learning Environment (iSMILE) System is developed to provide feedback based on misconceptions in understanding a particular concept. This system is based on Model View Controller (MVC) architecture. Assessment procedure has two levels. Firstly, student needs to answer a root question. In the next step, a linked question is provided based on the answer for the root question to evaluate the deeper understanding of the concept. After finishing both levels, students are provided elaborated feedback about their misconceptions if they make any mistakes. (Bhagat, Subheesh, Bhattacharya and Chang, 2017),

- **Formative Assessment-Based Mobile Learning (FAML)** is used to provide only hints, when the students failed to find correct answers and motivated the learners to find the answers by their own. The results showed higher learning performance, learning attitude, and learning motivation by using FAML (Hwang and Chang, 2011)

- An online game-based formative assessment named **tic-tac-toe quiz for single-player (TRIS-Q-SP)**. It is also integrated an Intelligent Tutoring System (ITS) to teach computer programming. It includes three types of feedback (delayed

Box 5.1	Examples of technologies used to support digital formative assessment

feedback, knowledge result and elaborated feedback). TRIS-Q-SP improved experimental group's problem-solving skills, which resulted in better learning achievement. Immediate elaborated feedback was one of the reasons for better learning performance. Hooshyar et al. (2016).

- A web-based assessment tool called **Siette** developed for university botany course. Siette provided elaborated immediate feedback, with detailed explanation for the wrong answers. Students who used Siette, performed better than the students who underwent traditional formative assessment (Conejo, Garcia-Viñas, Gastón, and Barros, 2016)

Source: Bhagat and Spector, 2017

Educational Data Mining (EDM) is closely related to learning analytics, but is more concerned with research on learning processes and patterns in very large collections of educational data (Romero and Ventura, 2013) and may be used to improve digital learning platforms (and thus the quality of automated feedback or scaffolding of next steps provided to learners). Data gathered through online learning analytics may, in turn, nourish education data mining, which requires large and detailed data sets.

Learning analytics and educational data mining are thus the foundation for a variety of digital tools. For example, data on student learning (e.g. gathered through clicker data, online behaviours) may support visualisations of learner progress (e.g. in a dashboard format), thus allowing teachers make decisions on whether to move on to next steps, or to further explore possible learner misconceptions, for example, through classroom dialogue and questioning (this is somewhat akin to the 'stoplight' exercise, in which students indicate their level of understanding with green, amber or red signals) . These tools may also support students to track and reflect their own progress. 'E-coaches' may also provide students with 'actionable information' and guide them toward effective learning strategies (explored in more detail in the section on tracking tools).

Learning analytics are also embedded in digital game-based 'stealth' assessments. A model proposed by Shute and Ventura (2013) tracks gameplay behaviours that can act as evidence of a claim (specified through evidence-centred design) and links these to claims about competences and estimates of competency levels (Shute and Ventura, 2013; Shute, Ventura, et al., 2009). These are used diagnostically and formatively to adapt game levels, provide targeted feedback and other forms of learning support as students continue game play. The evidentiary models of evidence-centred design ensure the validity of the assessments (see Groff, 2018).

Methods developed for educational data mining, in the meantime, draw on evidence of how users interact with online tools (e.g. adoption of bookmarks, highlights, notes, etc.) in order to better understand how different types of learners' progress and the kinds of interventions that are most likely to help them close learning gaps (Van Horne, Russell and Schuh, 2016). Over time, these data may be used to improve tools for feedback and personalisation of online learning.

Rubrics

A rubric is a tool for assessment of learning. Clearly defined expectations and criteria to assess performance levels for each criterion support consistency of assessment. They may also support students to reflect on and assess the quality of their own and of others' work. Rubrics are particularly useful for assessment of complex, contextualized problems (Company et al., 2017).

Rubrics may be used to assess the quality of work in digital learning environments. They may be used formatively (to identify student progress and learning needs) or summatively (to assign marks). Criteria for assessment are adapted to the subject matter and learning goals.

One example of a rubric used in a digital environment is proposed by Hung, Chiu and Yeh (2013). They describe 'theory-driven design rubric' to assess students' multimodal texts (e.g. web-pages, e-portfolios, digital storytelling). The rubric sets out criteria using a multi-literacies perspective, with criteria for linguistic, visual, auditory, gestural and spatial elements performances based on a 5-point scale (with 5 indicating 'excellent cohesion' and 1 indicating 'poor cohesion'). Cohesion in this study refers to '…. 'the way in which the various elements of the text are drawn together to achieve unity.' (Levy and Kimber, 2009, p. 493).

Figure 5.1: The five dimensions of the design rubric illustrated in a radar chart
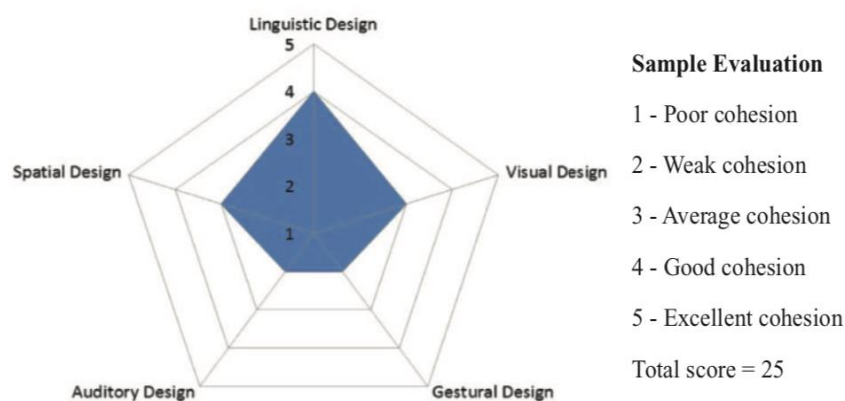

Figure 1: The five dimensions of the design rubric illustrated in a radar chart

Source: Hung et al., 2013, p. 403

In a pilot study, teachers used the rubric to provide feedback to students, and to also facilitate student self- and peer-assessment. They found that that the rubric supported scaffolding of student learning, and that students improved their awareness and understanding of multimodal presentation.

A second example features a generic web-based system for 'adaptable rubrics' (Company et al, 2017). While existing platforms do support 'static rubrics', they do not have the functionality to support adaptable rubrics with additional levels of detail to improve student understanding, or to scaffold learning for next steps.

The main features of the adaptable 'rubrics platform' featured in this study are:

- Feedback (with detailed scores and levels of performance, on request)

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- Adaptability to different learning needs (for example, students may access more or less detail, as desired)

- Collection of metadata to support adaptive behaviour in the future

- Automated management of weights among scoring criteria during rubric creation;

Company et al. (2017) describe implementation of their rubric design in a Mechanical Computer Aided Design training course (tertiary level), noting that the tool proved to be effective in supporting formative assessment to support development of complex skills. The main advantage of the tool was that users were able to access multiple levels of detail for each quality criterion.

The study also found that the tool was effective in collecting user interaction metadata (i.e., educational data mining), which can be used to develop further improvements in teaching strategies, although further research is needed in this area. The authors conclude that the platform provides a good foundation for a future 'intelligent tutoring system based on adaptable rubrics...' that will also automatically activate subsequent tasks adapted to learning needs (Company et al., 2017).

The remainder of this section presents findings from studies on the design and implementation of DFA to support student learning. It is organised to present research for each of the tools included in the typology. For each tool, we have included studies on how teachers working in different subject areas have used DFA to support students to develop 'disciplinary habits of mind'. Our aim is to explore evidence on effective practices and to inspire reflection on how different tools and approaches may be adapted in different contexts.

5.2 Personalised learning platforms

Web 2.0 tools and technologies are seen as a means to support student-directed learning, for example, with personalised learning platforms (Alexander, 2006; Dabbagh and Kitsantas, 2012; McLoughlin and Lee, 2010). Students have access to a wide range of teaching and learning activities, as well as platforms that support the development of creative products (individual and collective). Web 2.0 supports user-generated content, social networking, participatory cultures and virtual communities. In educational contexts, Web 2.0 may support team projects, online

research, student-directed learning (e-portfolios/digital diaries, wikis, and blogs and other social media platforms such as Twitter, Facebook). Students can interact with each other and with other experts in online 'activity spaces' (Attwell, 2007). A range of tools and services (e.g. the cloud, Dropbox, Google Docs, social media platforms) allow students to share resources and to generate knowledge. Multi-modal tools (video, audio, access to online texts) may be used to support learning (e.g. instructional videos, online research) and/or provide new opportunities for students to create their own media-based products.

Some researchers have suggested, however, that current educational uses of Web 2.0 technologies fall short of their potential. For example, Liu, Lu, Wu and Tsai (2016) observe that Web 2.0 learning activities '… may be perfunctory and may lack critical construction of knowledge (Tess, 2013)' and that assessments, which are often conducted within a specific framework, may be inconsistent with open and creative dimension of Web 2.0 learning. Kop and Hill (2008) note that teachers themselves may not have a solid foundation on how to use Web 2.0 technologies to support diverse student needs or to support student control or to improve the quality of learning.

Rahimi, van den Berg and Veen (2015) argue that teachers need a more robust 'learning model' to effectively increase student control in personal learning environments. They propose a 4-stage process model to guide design of student-centred instructional approaches that engage students in complex problems (e.g. project-based learning, problem-based learning, inquiry-based learning):

1. **forethought (providing choices)** – Teachers set the general assignment, suggest learning resources, group work structure and Web 2.0 tools (e.g. digital mind mapping, brain storming, blogging, co-authoring and storytelling. Twitter and blogs may support communication between students and the teacher and students). To support students to develop their autonomy and metacognitive skills through knowledge management, evaluating the quality of content, and planning and monitoring their progress. Students then decide on their learning goals (based on intrinsic interest), the outcomes they expect to achieve, and their learning strategy.
2. **performing (scaffolding)** – Students carry out their learning plans in this phase. The pedagogical design of scaffolding of learning activities supports learners to develop their learning. Learners produce and co-author content, communicate and collaborate with peers, connect with relevant people, add learning resources to their personal learning environment.

3. **reflecting (assessing)** – This phase is seen as essential to effective learning, metacognition, learning to learn and self-regulation. Students evaluate their learning strategy and outcomes and consider how to improve it in the future. Teachers should provide triggers for reflection and involve students in a dialogue about his or her learning practice. Rahimi et al. (2015) emphasise that process-based assessments are needed to track cognitive, social and personal development. This may be augmented by learning analytics (discussed below).

4. **feeding back (applying)** – students should be encouraged to actively participate in constructing and re-shaping the learning environment. A two-part feedback mechanism, first asking students to evaluate the choices offered, the Web 2.0 learning resources to be used by other students and the teacher, and second, by analysing students' technological and learning preferences, and through analysis of their interaction with the personal learning environment and learning resources. This feedback to teaches can support learning and improvement in teaching with new technologies

Rahimi, van den Berg and Veen (2015)

The task for teachers is to scaffold learning so that students are able to develop competences and assume control of their learning and to provide students with opportunities to develop their own learning environments (Rahimi et al., 2015).

Peer assessment in personal learning environments

Research highlights both positive and negative impacts of peer review on student learning. Some studies have found that student creativity may be hampered by peer comments, while other have shown that the quality of work is enhanced (Hurlburt, 2008; Laru, Näÿkki and Järvelä, 2012; Sluijsmans, Brand-Gruwel and Merriënboer, 2002; Tsai and Liang, 2009). Tseng and Tsai (2007), in a study of peer assessment in a high school science course, found that student learning outcomes were significantly improved at each step. However, Hou and Cheng (2012) suggest that teachers need to intervene in peer assessment in a timely fashion to promote positive interactions for knowledge construction. An international study by the OECD (2005) on classroom-based formative assessment underscores the importance of teaching students' competences for self- and peer-assessment.

Students need guidance and tools to support constructive feedback and to engage in in-depth reflection. Tools, such as rubrics setting out performance criteria, need to be flexible enough to

accommodate the development of creative products, and structured enough to ensure comments support and improve learning. The effectiveness of rubrics may be gauged by correlation between the peer and teacher ratings (Lu-Ho Hsia, Iwen Huang and Gwo-Jen Hwang, 2015).

Eyal (2012) suggests Web 2.0, when appropriately supported, provides learners with opportunities to produce information, and to adopt or develop their own criteria for self- and peer assessment. This approach, Eyal argues, '…is particularly suited to the information age, characterized by scepticism about knowledge: Is there an agreed-upon truth, which can be the basis for a unified program of study? Is it clear how learning occurs and how teaching promotes it? Is there a theory of learning and teaching that is better than others and accepted by all?' (p. 44).

Other authors have observed that learners' epistemological beliefs are associated with their preferred learning strategies, reasoning and knowledge acquisition (Hofer and Pintrich, 1997; Liu, Lin and Tsai, 2011; Tsai, 1998). Tsai (2012), in line with Eyal (2012), in a study online peer assessment, interviewed 40 higher education students to gather insight on the impact of anonymised peer assessment. The study found that students generally benefited from the diverse knowledge perspectives (epistemic relativism) on their work, but that careful judgement of the validity of peer comments was essential. The study participants also indicated that they learned to view peer opinions and preferences as subjective (social relativism). Students with higher self-efficacy in their use of the Internet gained more from the online peer assessment.

The need for more structured approaches to guiding peer assessment are also suggested. For example, peer assessment of blogs may focus on criteria related to content, the quality of writing, relevance of resources included, use of sources, independent analysis, and the organisation and look and feel of the blog (Eyal, 2012). Sample (2009, cited in Eyal) suggests a five-level scale on the quality of arguments made in the blog. These types of assessment tools are ostensibly also relevant to assessment of the content of wikis, which are collaborative websites where users may modify content and structure (https://en.wikipedia.org/wiki/Wiki). In addition, wikis provide opportunities to track student cooperation (via online data on contributions to each page).

5.3   E-textbooks

E-textbooks offer new opportunities for teaching and learning with diverse media formats. Different types of e-textbooks include:

- Digital versions of traditional print textbooks. While these technologies do not require new approaches to teaching and learning, they provide ready access to quality-assured, standardised materials and are cost effective.

- 'Reflowable' digital textbooks that may be adjusted for mobile devices, and which allow content creators to embed multi-modal objects within the text. They also offer advantages of accessibility for users with disabilities.

- Media rich, integrative, interactive textbooks that offer more interactivity and more embedded media (e.g. video and links to external platforms). The most advanced versions may include image galleries, 3D models, scrolling sidebars to support interest-driven interaction (Chesser, 2011; Jimenez and Moorhead, 2017).

- Texts with web portals offering interactive features (quizzes) and adaptable learning paths based on student performance and preferences (Chesser, 2011).

- Open, or 'wiki' textbooks – teachers and other colleagues may create their own version of course support content and share documents on an open platform. Others may use the content as is, or further adapt and change it. Under the Creative Commons licensing rules, the only intellectual property requirement is that any derivative works should also be open and freely available. Open Courseware projects at MIT and Harvard follow this model. (Chesser, 2011). Since a publisher is not coordinating content development, peer review is done through the active monitoring and updates of the authority community (as is the case for Wikipedia).

Open Access platforms provide teachers with the opportunity to design their own texts and digital formative assessments (Morris-Babb and Henderson, 2012). For example, Hooley and Thorpe (2017) describe a computer-based text and assessment to support high school students in

developing discipline-area reading and comprehension skills (American Government) as an example of instructor-created content (noting that textbook publishers had not developed suitable tools). The feedback was developed by four content experts, two upper secondary civics teachers, a reading specialist and a university professor specialized in adolescent literacy. Questions derived from chapter reading were uploaded to a community website. Students were able to select responses once they had finished chapter reading. Based on their responses, students were guided to areas of the text where they might find the relevant information. On average, scores of pre- and post-tests improved by 5 to 7 points. Students in the 'treatment group' also showed significant gains in chapter content knowledge. The authors note that while the multiple-choice format used is not appropriate for all students, the embedded reading instruction and feedback can support struggling readers (Hooley and Thorpe, 2017).

In another example, Jiminez and Moorhead (2017) describe a project to support 10th year history students to create their own multi-modal textbooks using open education resources alongside textbook authoring software. A main aim of the project was to help students develop their capacity to understand and reconcile differing viewpoints, and to also critically assess the potential value of digital sources. In other words, students developed historical thinking capacity its '…value for different interpretive purposes' (p. 568). Students were encouraged to choose their own topics of interest, primary sources and narrative structures. Each student developed a research question and selected two relevant primary resources (students were free to decide on the topic of interest so long as it mapped to one of the California State Standards and did not overlap with any of their classmates' questions).

- The course designers collaborated with local archivists who provided guidance on use of digitized artefacts, on copyright and use of primary sources, as well as how these sources can be used to explore a different perspective of historical events.

- The research team curated a digital library using sources from across the Internet, using Google Docs to organise it. It provided more than 300 links to source material. Students identified sources from among these different databases.

- A curriculum module with mini-lessons to support learning of data collection instruments and technologies to support their work. Students worked in groups to develop chapters for inclusion in a digital history textbook.

- Students worked with technologies to develop interactive images, galleries with collections of relevant images, scrolling sidebars with historical documents and textual analysis, pop-overs for new windows with additional contextual data, video and audio embedded in pages, and interactive 3D images. The aim was to use these features to draw readers' attention to different perspectives, to develop meaningful narratives.

Throughout the project, students critiqued existing digital texts and also reviewed each other's work – referring to principles of good design. Students also made suggestions for improvement. At the end of this learning unit, each student presented his or her contribution to the textbook (their chapter), and how the different perspectives included. The students also evaluate the team's work at the end of the unit, based on a rubric that had been developed by the research team and cooperating teacher.

The authors note that while the project was successful, with 78% of students successfully emphasising multiple perspectives of historical events, the time required to develop 'thick narratives' was difficult within limits of the school timetable and curriculum. In addition, some students did not have the necessary software or computers at home. The authors also note that capacity to support constructivist pedagogies and to integrate formative assessment was also vital to the success of the project (Jimenez and Moorhead, 2017).

Digital storytelling

Digital stories, as defined by Sylvester and Greenidge (2009), are 'anything that employs digital technology to construct narrative.' (p. 290). Digital storytelling may support learning in a range of subjects, including literacy (including digital literacy), sciences, mathematics, and so on (Park and Baek, 2011; Starčic et al., 2016).

For students who are learning to write, the process of creating a digital story provides an opportunity to develop awareness of audience, as well as how to clarify the purpose and form. It may feature still images, narrated soundtracks, video clips, and so on, all of which help to make a story more vivid. Sylvester and Greenidge (2009) note that use of digital tools can support students who are less capable writers, allowing them to discover the enjoyment of creating stories using multiple media, and to build their confidence and self-efficacy.

For students studying the sciences or engaged in mathematical problem solving, digital story telling supports 'narrative' (i.e. the sequences of events that define the experience) and 'agency' (i.e., the power to choose what happens next) (Lindgren and Schwartz, 2009). Digital storytelling provides a structure for students to collect information, test new ideas, and organize what they have learned in a more understandable way (Hung et al, 2012). For students learning in a virtual learning environment (e.g. Second life), spatial and interactive features may support learning of difficult concepts. Learners can visualize and contextualize learning objects, interact (e.g. avatar-to-avatar or avatar-to-object).

Studies identified in this review did not explicitly focus on formative assessment within the context of digital storytelling. Nevertheless, the storyboarding process, which helps students to introduce events in a logical way and illuminate any gaps in narrative (Sylvester and Greenidge, 2009), is an opportunity for formative assessment. The process of editing a digital may also provide more opportunities for self- and peer- assessment of narrative. Rubrics to support digital formative assessment, and of digital storytelling within e-portfolios, also provide relevant insights.

5.4   Mobile learning

Mobile learning includes some features of Web 2.0 (smartphone and tablet access to Internet) as well as texting features, and tools to take pictures, make audio recordings to support multi-media assessment. Mobile learning, by definition, opens possibilities for learning 'anytime, anywhere'. This may involve opportunities for situated learning, or to have ready access to study tools and opportunities to engage with peers and/or to received automated feedback.

The latter approach is illustrated by the Maths4Mobile site developed by researchers at the Institute for Alternatives in Education at the University of Haifa has five free applications for

download on mobile phones[2]. They applications, which support different levels of learning in geometry, algebra and pre-calculus, are:

- **Graph2Go** is a special-purpose graphing calculator developed to support conceptual understanding of functions, school algebra and real analysis

- **Solve2Go** supports solving equations and inequalities by means of conjectures based on visual thinking. Learners may refute or support by examples provided by the tool.

- **Quad2Go** is designed for lower secondary students learning geometry. It supports learning about quadrilaterals by generating of randomly constructed quads. Each example can be changed by dragging either its vertices or sides Students may learn about critical and non-critical attributes

- **Sketch2Go** is a qualitative graphing tool. Students may bypass the use of algebraic symbols to experiment with concepts in visual form.

- **Fit2Go** is a linear and quadratic function graphing tool and curve fitter. Students can view a phenomenon, identify variables, conduct experiments and take measurements in order to construct models of the phenomena.

Students may explore concepts and test their understanding with teacher-developed quizzes that are storied on the site. The mobile environment also allows students to exchange text messages regarding their learning, to send the diagrams they have developed.

A 2010 evaluation by Daher found that groups of eighth year students were successfully in using the tools on this site on their mobile phones collaborate to solve maths problems and to advance their knowledge. (This is the most up-to-date evaluation of the programme identified.)

Other applications to support learning anytime, anywhere may include teacher-developed podcasts of lectures, supplemental video materials, classroom discussions, demonstrations, and

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[2] Math4Mobile website: http://www.math4mobile.com/development#educational

so on. They may be used to differentiate instruction to address varied student needs (Thomas and McGee, 2012).

Other research on mobile learning identified for this review refers to formative assessment in situated learning contexts. To be effective, however, pedagogical plans need to incorporate learning and assessment objects and that activities and the kinds of interactions learners will perform are planned effectively. Digital scaffolding mechanisms can support learners to self-assess as they interact with physical objects and physical locations as well as with digital information and other learners (Santos, Cook and Hernández-Leo, 2015).

Natural sciences

To illustrate how these features can support situated learning, Santos, Cook and Hernández-Leo (2015) describe a scenario where students in a natural sciences class on bird identification could use a programme with simulation soft, as well as audio of birds singing. Learners could log success when they have identified a bird and share their location. Their behaviour and interaction could also be logged, and learners could later reflect on their performance.

In another example of mobile technologies to support situated learning, Shih, Chu, Hwang and Kinshuk (2011) describe a programme to support learning of botany. Teachers, including one who had created the campus plant encyclopedia, another with expertise in information technology and the class teacher cooperated in the design learning content by using the 'repertory grid method' to classify the characteristics of the campus plants and context-aware technology). Students were able to access to compare predesigned learning materials on their mobile devices with features of real plants. The programme tracked individual learning behaviours and offered personalized support. Students noted that they enjoyed the experience, felt less pressured when the teacher was not present, and appreciated the opportunity to learn at their own pace. They also interacted frequently with classmates to complete learning goals. The authors also note that in their analysis of results, they found no significant differences in performance between high- and low-achieving students (Shih, Chu, Hwang and Kinshuk, 2011)

Culture and history

Mobile learning may also reinforce students' learning during field trips to explore cultural or historical sites. For example, Hwang and Chang (2011) developed a 'Formative Assessment-based Learning guiding Mechanism (FAML)' to explore the Chin-An temple in southern Taiwan. Prior to the visit, students were introduced to the history of the site in a classroom-based lesson. During their visit, students had the opportunity to apply what they had learnt in the actual location, by interacting with questions on their mobile devices. The programme included a scaffolding strategy with hints and additional multimedia content. Students who did not provide correct answers were provided with additional hints. This encouraged further interaction with the environment. Hwang and Chang (2011) found that students using FAML demonstrated better learning performance, and better motivation.

Language learning

Kukulska-Hulme and Viberg (2018) review studies conducted between 2010 and 2016 on how mobile learning has been used to support collaborative learning of foreign and second languages. Teachers may design tasks or situated learning to encourage using mobile devices, blending spoken, written and text chat to support collaborative earning (Andujar, 2016). Examples of tasks include use of tables for online reading programmes, with learners deciding on the content and pace (Lin 2014), use of mobile devices to create personal learning environments where learners may regulate their own learning and interact with peers (Pellerin, 2014). Troussas et al. (2014) used a problem-solving approach encouraging learners to work at first individually and then collaboratively. Kirsch (2016) encourages collaborative digital story telling combined with exploratory discussions and dialogic teaching.

Digital games - for example games that facilitate listening and speaking skills (Berns et al., 2016; Hwang et al., 2016) - may be played on mobile devices may also support 'anytime, anywhere' learning. Access to popular media may also provide new ways for students to learn language.

Kukulska-Hulme and Viberg (2018) note that more research is needed on the process and steps for mobile learning design particularly in regard to collaborative learning. Learning analytics may

provide data on how learners communicate and interact with each other with mobile devices outside of education contexts and may then be taken into account in the development of learning plans.

5.5   Classroom polling

Classroom polling technologies use student response systems (e.g. clickers or students' cell phones) for rapid assessment of student understanding and to guide next steps in classroom discussions. Teachers may create multiple choice assessments or more open responses based on text messages. (Thomas and McGee, 2012).

The effectiveness of classroom polling technologies is linked to teachers' formative assessment competences. Yarnall et al. (2006), in a project implemented in primary and lower secondary school science classrooms in a California school district (2001 – 2004) found that the polling technologies tended to reinforce teachers' existing approaches to assessment. Teachers who had 'thinking-focused' goals (e.g. assessing students' approaches to problem solving, understanding of new concepts, and so on) were more likely to use the new technologies to deepen their assessment practices, to focus student reflection on critical elements of learning science and to foster student skills for self-assessment. Some of the 'thinking-focused' teachers used the polling tools to engage students in improving their own questioning skills. In one example, the teacher involved students in judging the quality of questions – i.e. questions that required more thought vs. those that required only a simple answer. In another example, teachers used software to gather data on students' thinking during hands-on activities, such as laboratory exercises, and then analysed the results with students. Teachers who began the study with stronger 'thinking-focused' approaches also tended already to have stronger skills for classroom management and more experience in structuring and scaffolding science inquiry.

A second study, the Technology-Enhanced Formative Assessment (TEFA) project, focused on building teachers' formative assessment skills, with use of technology. The 'question cycle' was used as prototype for using LRSs to enhance formative assessment. During the question cycle, the teacher presents a question or problem to the class. Students are given time to reflect on the question, either individually or in small groups. The students enter their responses through the

LRSs, and the teacher shares the results with the class and then guides a whole-class discussion, exploring the different responses. The teacher concludes the discussion with a micro-lecture or by highlighting major points (Beatty et al., 2008). Other uses included use of student response systems to assess prior knowledge, to survey student learning preferences, to elicit misconceptions and to challenge students' ideas. The authors of the study found that student response systems strengthened formative assessment practice by providing student anonymity and allowing teachers to organise discussions to respond to whole class needs. Teachers who were the most self-reflective were the most likely to improve (Beatty and Gerace, 2009).

5.6   Digital games

Digital games provide immersive learning experiences in a situated context. As has been mentioned, learners may benefit from real-time and integrated formative feedback Learning may be scaffolded, with increasing levels of complexity introduced as learners advance through the game (Milrad, Spector and Davidsen, 2003). Bhagat and Spector highlight emerging technologies, including 'stealth' assessments (e.g. the learner is unaware that he/she is being assessed), automated concept map-based assessments that gather evidence as to how learners are thinking about a problem, visualisations that support learner self- assessment and self-regulation, and tools to support learner collaboration and social networking.

Different studies have found that games increase motivation, support collaboration, help to develop digital literacy skills, increase attention and retention of learning, provide opportunities for self-regulated learning (Annetta et al, 2009; Buckley and Anderson, 2006; Gunter and Kenny, 2008; Ke, 2008; Sheehy et al, 2008). As Gee (2003) observes, games, in and of themselves, are essentially assessments.

Digital learning games have a variety of aims and formats. They include:

- Targeted games (e.g. an individual app to develop a specific skill)
- Games which include a storyline and series of puzzles to explore a concept (e.g. mathematical thinking)

- Open-ended sandbox games, which offer tools and contexts to construct an item or to reach specific outcomes

- Simulations that set out series of problems, with features that allow the learner to compare their own approach to that of experts

- Virtual worlds to engage players in problem-based quests and that require the learner to draw on their knowledge of a specific subject area or areas. These may feature complex, ill-defined problems to be defined individually or collectively. Formative assessment providing corrective feedback may be provided to correct misconceptions (and, as emphasized by Bhagat and Spector, such feedback needs to be provided early in the process so that learners do not develop misconceptions that are difficult to address later in the process)

- Commercial Off-the-Shelf (COTS) games, which may be adapted for instructional purposes (e.g. SimCity and Newton's Playground)

(Bhagat and Spector, 2017; Groff, 2018).

Below are brief accounts of digital games that have been designed to support learning and assessment in history, mathematics, and the sciences are set out to illustrate how they can be used to support learning. While these games share common elements (narrative structure, role play, a mission or problem to be solved, etc.), each if the uses described below has been developed to support domain-specific learning objectives as well as transversal skills such as critical thinking, collaboration, and so on. Formative assessment may be embedded through scaffolding of the game, tools that support learner reflection, or dialogue and reflection

History

A first example highlights 'teaching in the gamic mode' to allow learners to interact with scholarly arguments in history.' As described by the authors, '[t]e basic idea to use game-based learning to teach history is to apply procedural rhetoric to construct scholarly historical arguments as games. Games may be used to create a 'limited reality'. The rules of play require internal consistency and the ability to understand and predict what will happen in the game environment.

The game can thus be used to carry an argument (Juul, 2005). Assessment is thus built into the game through repeated testing of an argument. Learners interact with content and thus develop an understanding of evidential relationships and interpretation to develop an effective historical argument. This approach can be applied to any discipline. Teachers need to be aware of the philosophy of their academic discipline and how the discipline creates knowledge.

Clyde and Wilkinson (2012) first tested this approach in a workshop at the Library Orientation Exchange (LOEX) of the West 2010 at Mount Royal University, Calgary, where participants took on the role of students and designed their own games to support historical arguments. The approach was again used with a group of students in grades 7 to 9, who were completing a two-week summer camp in comparative world mythology. With these students, the main aim was to have learners to demonstrate content knowledge, rather than to develop a complex argument. The students used map editors and scripting tools of an off-the-shelf game (Age of Mythology) to develop their projects. In addition, they modified an off the shelf puzzle game (Half-Life) to manipulate objects representing facts and interpretation, and to create 'evidence objects' (Clyde and Wilkinson, 2012)

Clyde and Wilkinson (2012) note that within the context of a history course, it is important to introduce the approach and address any misconceptions (e.g., students may see the game as a decision-making tool or vehicle for factual content). Students need to understand that the aim is to create a single, well-supported argument. A scaffolded approach to introducing the approach, with three fifty-minute classes and assignments is recommended: the first class is focused on rhetoric, procedural rhetoric and how games can carry arguments; the second class is focused on procedures for designing a board game (Hex48) and an at-home assignment to play The History Game and participate in an online discussion to reflect on experiences with peers. The third class may be used to introduce 'the epistemological and disciplinary norms in history for creating reasonably justified truths about the past'. Following this, students are given a small-group assignment to develop rules for a gamic version of a course reading or lecture. At this point, students have the foundation to develop a project outline and annotated bibliography which may then be used to present arguments as a game using procedural rhetoric with a short essay or an

essay with a set of game rules. 'Both the game and essay express the argument presented in the outline, allowing students to see how different modes can carry the same argument.

Mathematics

Panoutsopoulos and Sampson (2012) explore the use of a commercial, off-the shelf game (Sims 2-Open for Business) to support lower secondary students' mathematics learning. They argue that the game-based approach is useful for providing concrete learning experiences, thus supporting learners to draw links between abstract theories and real-world situations. The Open for Business simulation engages students in data monitoring, strategic thinking, decision making and planning and performing actions to manage a business. Students et product prices, hire employees and manage employees. The game graphics support interactivity and the learners' sense of control. Teachers designed worksheets to support student reflection on their activities. Results of the study were that students participating in the game activities: achieved the same results as those in the control group; had better achievement of general educational objectives related to student capacity for analysis, synthesis and evaluation; and, did not change their attitudes towards mathematics teaching and learning, but students did report positive effects on their understanding of the application of mathematics in real-world situations.

In a second example, Denham (2018) studied game-based learning of algebraic concepts in lower secondary settings, focusing on how teachers can most effectively integrate games in classroom teaching to support learning. The study was particularly interested in whether game play should take place before instruction, after instruction, or should be integrated throughout the teaching unit. The study found that while all students participating in the game showed learning improvement, those who played the game prior to instruction showed the most significant improvement. In this sense, the game was used as a tool to bridge students' prior knowledge with what they were about to learn (a fundamental element in formative assessment). As noted by Denham, the study supported the hypothesis that 'advance organizers' can help students to increase knowledge retention, skills and conceptual understanding and connection between concepts.

Sciences

Suseata et al. (2010) developed a classroom multi-player role-playing game to support ecology learning within the framework of Chile's 6th year curriculum. The game sets out a virtual world projected on the walls of the classroom. All student play at the same time, interacting with their individual input devices (e.g. the computer mouse). The game itself is based on a narrative, or background story with mini-narratives, or 'quests'. Players interact with the quest, taking on a specific role and mission within the narrative. Players are exposed to information, tools and objects that are used to advance the game. They also collaborate with other plyers to develop a strategy.

The game features a number of different Quests to ensure equilibrium of the ecosystem, with each one emphasizing a key teaching objective (the order of play is determined by the curriculum structure). The objectives of the game are:

- Quest 1: A foreign predator species is introduced to the eco-system, upsetting its equilibrium. Players work in groups of three in the three virtual zones defined in the game, to help frighten off or eradicate a predator species that has been introduced to ecosystem. Player awareness of the problem, of their own role and willingness to work collaborative to achieve the goal are emphasised.
- Quest 2: An epidemic spreads across the animal population. Players work in groups of two, one taking the role of a Hunter to immobilize animals that have been infected by a parasite. A second student takes the role of the Shaman to cure the animal. The aim is to stop expansion of the epidemic. – Player awareness of his/her role, use of information to make choices on actions, and dialogue between are emphasised.
- Quest 3: Deer reproduction rises to plague proportions. Players are distributed over the three different spaces of the virtual environment to manage the entire ecosystem. Player understanding of the problem, personal autonomy and responsibility in upholding the group agreement in support of the goal are emphasised.

The Quests integrate 'triggers' – that is events or conditions such as an event or action that arise during an activity and which change the conditions of play. The game enabled visualisation of the food change and concepts of ecological equilibrium, an understanding of the consequences of human actions in different scenarios. AT the end of each Quest, teachers guided student reflection to ensure that students were assimilating the main concepts. The evaluation of the pilot found that it would be important to increase the complexity of each Quest and to clearly define the teachers' role in the deliberation of the learning content.

5.7 Tracking tools: Dashboards and E-coaches

As highlighted above, learning analytics gather data based on student interactions with different learning environment. These include click stream data, log ins, times spent on specific web pages (referred to as 'event data'), course grades, course completion rates, etc. (performance data).

Data gathered with learning analytics tools are useful to track and predict student performance and retention. Teachers and other school staff can develop strategies to prevent student failure or early school leaving (these fall within the category of medium-, or long-term formative assessment). In addition, tools such as dashboards, have been designed to help teachers to visualise and interact with data for course planning.

As an example, classroom polling tools (sometimes referred to as 'learner response systems, or LRSs), allow teachers to conduct on-the-spot surveys. Polling devices communicate with software on the teacher's computer. Students use the LRS devices to respond to questions posed by the teacher, and responses are aggregated and displayed on the teachers' computer in the form of bar charts or graphs. The devices allow students to respond to yes/no or multiple-choice questions. Some devices also accept free text or numeric answers. Using these polling devices, teachers are able engage all students, including those who are less likely to speak up during class, in active classroom discussions (Looney, 2012).

Yarnall et al. (2006) found that the effectiveness of LRSs depended on teachers' approach. For example, they found that teachers who had been more focused on 'accountability' goals for assessment (e.g. keeping students on task), tended to use the new technologies to reinforce these narrower approaches. Teachers who had 'thinking-focused' goals for assessment (e.g. assessing students' approaches to problems solving, understanding of new concepts, and so on) were more likely to use the new technologies to deepen their assessment practices, to focus student reflection on critical elements of learning science and to foster student skills for self-assessment.

In other research, Dyckhoff et al. (2012) describe their efforts to develop a learning analytics toolkit, 'eLat', to help teachers sort through large sets of data. They note that indicators used for Dashboard visualisations need to be carefully designed, and that teachers also need instructions

for interpretation. To be effective, learning analytics tools such as dashboards need to be evaluated for their:

- *Usability and usefulness* – tools should be accessible for novice users as well as experienced users who may want to make deeper analyses. Dyckhoff et al. call for research on types of indicators that are most useful in different learning scenarios.

- *Interoperability, extensibility and re-usability* – Dyckhoff et al. (2012) note that Learning Analytics tools such as dashboards cannot be easily adapted for different virtual learning environments. Ideally, an interoperable Learning Anlaytics tool will be able to collect and analyse data from different learning platforms (mobile tools, games, and so on).

- *Real-time operation* – tools should provide current and comprehensive data analysis capabilities, including interactive analysis and visualization features.

- *Data privacy*

They also note ongoing challenges in identifying those variables that provide 'pedagogically meaningful' data, and that more research and development is needed. Indeed, Scheffel et al. (2014) note that there is little empirical research on the impact of different learning analytics tools on learning.

In a more recent study, Thille and Zimarro (2017) attempt to tackle the challenge of 'meaningful pedagogical data' through the development of an integrated learning analytics system that captures data on how students interact with a task or assessment when solving a problem (which they refer to as 'learning process data'). They describe the development of effective learning and assessment opportunities that will generate meaningful data and that can successfully explain and predict student progress toward learning objectives. They also note the need to create feedback tools that will support them in improving pedagogical approaches. Ongoing research focuses on how teachers interpret existing dashboards and whether and how these support pedagogical decisions. Dashboard that help students not only monitor their learning, but also to identify more effective learning strategies area also needed (Thille and Zimarro, 2107).

E-coaches

Students may also use digital tools to track their own learning progress. For example, e-coaches use data gathered with learning analytics and educational data mining, may provide students with data on their performance and suggest appropriate next steps. The Khan Academy[3] – an online learning platform with high international visibility – which has a learning analytics dashboard, helping learners to follow their progress, and offers personalized feedback and assessment for learners who are using the online lessons.

In another example, the E2 coach was developed using data from more than 49,000 physics students at the University of Michigan, including extensive information on learner background and preparation with and details of their progress throughout the course and final outcome. These data were used to construct models predicting learner performance and were refined based on structured interviews with a range of students on strategies that led to success. The E2 Coach provides 'actionable information' for students, guiding them toward strategies that will support their learning. Evaluations on outcomes for students using E2 Coach are planned.[4]

5.8   Toward integration of formative and summative assessment

Digital technologies may potentially support integration of formative and summative assessments. In other words, data from large-scale external assessments, which used for monitoring of students across the education system, may also be used to shape teaching and learning in classrooms. In turn, classroom-based assessments will be able to provide valuable data for decision makers at school and system levels.

Currently, however, there are important technical barriers to seamless integration of classroom-based formative assessment and large-scale summative assessments:

- There are challenges related to creating reliable measures of higher-order skills, such as problem solving and collaboration in the context of large-scale assessments (Chudowsky

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[3] Khan Academy, https://www.khanacademy.org/

[4] E2 Coach, https://er.educause.edu/articles/2013/12/e2coach-tailoring-support-for-students-in-introductory-stem-courses

and Pellegrino, 2001; Gipps, 1996; in, 1993; Pellegrino, Baxter and Glaser, 1999). The strongest critiques of large-scale assessments are usually directed at standardised tests that rely upon multiple-choice, close-ended question formats. Standardisation of assessments supports reliability of results (i.e., the results are consistent across student populations). Multiple-choice assessments treat cognitive tasks as discrete items. However, this methodology is at odds with research emphasising learning as the 'continuous acquisition and restructuring of domain-based knowledge'.

- Typically, data gathered in large-scale assessments are not at the level of detail needed to diagnose individual student needs for formative purposes. Most education systems have defined standards for learning – or intended learning outcomes. Assessments are thus designed to measure student performance relative to the learning targets (in other words, assessments are 'criterion-referenced). Student scores are converted into a scale, which are then tied to broad proficiency categories, such as: below basic, basic, proficient, advanced (McGehee and Griffith, 2001). But several measurement experts argue that these categories are too broad to provide any kind of diagnostic information necessary for profiling individual student needs (Rupp and Lesaux, 2006; Buly and Valencia, 2002). (See also Looney, 2011.)

While digital technologies create the potential for more seamless integration of formative and summative assessment, research and development is still in the early stages. Bennett (2015) identifies three stages of integration of digital assessment technology. Stage 1 introduced the delivery of traditional assessments via computer. In stage 2 (the current state-of-the-art), incremental changes such as the introduction of new soring formats, automation of different processes and improvements in measurement constructs have been introduced. Indeed, there are examples of innovative computer-based assessments that score student performances on complex cognitive tasks, such as how students go about problem solving, or open-ended performances such as written essays, or student collaboration on constructed response format. Some ICT-based assessments may incorporate simulation activities or allow students to interact and collaborate on constructed response formats. These kinds of assessments are relatively new and limited in number (Looney, 2011). Moreover, as highlighted by O'Leary et al. (2018), current technologies for measuring skills as collaborative problem solving tend to neglect complex competences or measure them '…in ways that may not correspond to situations' (p. 167).

Bennett suggests that in the future (stage 3) assessment and instruction will be fully integrated. At this stage, the design, content and format of assessment and instruction and assessment will be grounded in the learning sciences and are capable of measuring complex performances

situated in realistic contexts (following the principles of evidence-centred designs and competence models). At the third-stage, assessments are more integrated with instruction and performances are sampled repeatedly over time (Bennet, 2015). Assessments may thus sample a wider range of learning priorities and use a variety of measures and performances for a deeper view of student learning.

As research and development in the fields of learning analytics and educational data mining progress, it may be possible to develop learning environments where data are gathered from different platforms in an ongoing fashion, and support both formative and summative assessments (Groff, 2018).

Online access to curriculum-embedded, or on-demand assessments (test banks)

Curriculum-embedded assessments are, by definition, aligned with instruction and provide information that may be used to modify teaching and learning. These assessments are typically available 'on demand'. In other words, teachers and/or students decide when they are ready to take a test in a particular subject or skill area and select a test from an online central bank of assessment tasks. This control over timing of the test means that teachers are able to use results to provide feedback to students when it is most relevant to their learning. In Scotland, the assessments may draw on a central set of tasks that are mapped to standards and critical skills, topics and concepts in the curriculum. Teachers may use these tools to design and administer tests locally, following central guidelines and criteria. They may also access centrally-designed assessments. The on-demand assessments comprise up to 50% of the final examination scores (Darling-Hammond and McCloskey, 2008). Potentially, on-demand assessments may be used for both formative and summative purposes. In Australia, for example, the IMPROVE initiative is an online interactive tool that provides teachers with access to numeracy, literacy and science test times, which are linked to more than 12,000 digital curriculum resources and activities. The tool incorporates diagnostic elements to help teachers to identify students' strengths and weaknesses.

The assessment items are also mapped to the Australian National Assessment Program – Literacy and Numeracy (NAPLAN) and National Assessment Program – Science Literacy[5].

On-demand assessments provide an effective approach to aligning tests with curriculum and may potentially be used for both summative and formative purposes. Nevertheless, on-demand assessments are confronted with the same technical limits as large-scale assessments. As noted by O'Leary et al (2018), digital technologies to measure higher-order skills '...are still quite structured and rigid, with complex forms of learning either being neglected or measured in ways that may not correspond to real-life situations' (p. 455).

5.9   Designing learning with digital formative assessment

Digital formative assessment will only be effective to the extent that teachers have developed capacity to integrate assessment in classroom-based teaching and learning – that is, with or without digital tools (Beatty et al., 2008; Yarnall et al., 2006). A range of surveys and evaluations have found that a majority of teachers tend to use new technologies to reinforce traditional approaches to learning and assessment. For example, teachers may develop superficial questions that fail to elicit student understanding or possible misconceptions (Langworthy et al, 2010; Selwyn, 2010; Voogt, 2009).

The guidelines to be produced through the Assess@Learning policy experimentation can support teachers to strengthen their formative assessment competences. Indeed, there is some evidence that as teachers embed new technologies in their pedagogy and gain confidence, their goals for teaching and assessment begin to shift. Teachers who are already engaged in innovative approaches to classroom assessment may deepen practice with new technologies (Somekh et al., 2007; Yarnall et al., 2006).

Teachers will also need to extend their 'assessment literacy' to include digital tools, and to take full advantage of their capacities. Eyal (2012) proposes that a 'definition of digital assessment literacy' would tailor Stiggins (2002) definition of an 'assessment literate teacher' – i.e., as a

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[5] See also http://www.improve.edu.au/

teacher who knows what assessment methods to use to collect information on the students' achievements, conducts a dialogue about effective assessment results, using the ranking scores, reports, and portfolio, and understands how to use assessment to increase the motivation of learners and include them in the learning process' -- and tailor this to the digital environment. Moreover, Eyal proposes that teachers' should also know when to hand over assessment responsibilities to students in order so that they may develop their capacities for self-directed learning, and for reflection and development (Eyal, 2012).

Decisions on how to integrate digital formative assessment are related to the design of the learning environment, opportunities for students' self-directed learning and assessment, and opportunities for collaborative learning (as highlighted in the typology). Both the digital and face-to-face interaction need to be considered as part of a blended approach.

- **The design of the learning environment** includes attention to the overall classroom culture, the manner in which students and teacher interact and the quality of their relationships, and the way teachers organize to the educational setting to facilitate learning[6].

Decisions on how to integrate digital technologies need to be based on the different affordances and limits of technologies (e.g., mobile learning programmes that may support plant identification in the field, digital storytelling to encourage the use of narrative and logical thinking in learning mathematics or sciences, the use of games to reinforce skills for argumentation in a story, and so on). Pedagogical decisions on when and how to use digital learning activities within a specific lesson are also important (e.g. before a lesson in order to assess prior learning and engage students in the new content, or during a lesson to reinforce learning).

- Personal online learning environments, as has been emphasised, with opportunities for **student centred-learning and assessment**, may provide more opportunities for student self-directed learning. Digital games with automated feedback and scaffolding of learning may also provide opportunities for students to learn

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[6] The Glossary of Education Reform, https://www.edglossary.org/learning-environment/

independently. Teachers will need to provide guidance, particularly for younger learners, to ensure they are able to choose appropriate activities (the right level and that will hold their interest). They will also need support as they develop skills for self-assessment and taking decisions on next steps for learning.

- **Student collaborative learning and assessment**, including discussions in the classroom and online, provide opportunities to elicit evidence of student understanding, to explore possible misconceptions. The Black and Wiliam (2018) model for assessment in relation to pedagogy, above, highlights the importance of learning through dialogue. While Black and Wiliam highlight the importance of classroom dialogue, their model can easily extend to different digital formative assessment modes. For example, Web 2.0 platforms and mobile learning, and other digital technologies provide opportunities for online interaction and discussion, and support a-synchronous learning (i.e., not during class hours). Classroom polling technologies (for synchronous learning) may provide ways for students who are less likely to actively engage in dialogue to register their understanding of issues and concerns.

Salend (2009) proposes that teachers should consider a variety of factors when deciding whether and how to integrate digital formative assessment, including whether the assessment technique will:

- allow the teacher and students to measure meaningful skills and instructional outcomes in a direct and complete way

- be appropriate for the class (their age, developmental, academic, cognitive, language, social, behavioural, and technological levels)

- accommodate students' individual differences (e.g., disability, cultural and linguistic background, and socioeconomic status)

- help the teacher to plan, deliver, evaluate, and revise instruction to enhance student learning

- facilitate the sharing of relevant information with other professionals and students' families.

Baya'a, Shehade and Baya'a (2009) propose a framework for evaluating web-based learning environments, including criteria related to usability, content and educational value. Usability refers to the clarity of the purpose and added value of the web-based learning environment, navigability, readability and relevance of various features. Content criteria refers to the quality of resources and references, relevance to learning needs, sufficiency of information (i.e not an excessive amount), and appropriateness of method and level of difficulty. Educational value refers to the specific learning activities, monitoring of learning and opportunities for feedback and scaffolding of learning.

Nokelainen (2006) suggests that when deciding how to use DFA, teachers need to consider criteria for their 'pedagogical usability' to address the question, 'Does the system, and/or learning material it contains, make it possible for the student and the teacher to achieve their goals ?' (p. 189).

The criteria proposed in this study build on criteria commonly proposed to evaluate learning materials, including "….'learner control', 'possibility for cooperative or collaborative learning activities', 'explicit learning goals', 'authenticity of learning material; and 'learner support (scaffolding)'." (p. 181). Additional criteria proposed take into account elements that are important for evaluating digital learning environments. The full set of 10 criteria proposed include:

- learner control

- learner activity

- cooperative/collaborative learning

- goal orientation

- applicability

- added value

- motivation

- valuation of previous knowledge

- flexibility, and

- feedback

Nokelainen suggests that "… in practice the role of the criteria is to give the learner a chance to choose the most suitable learning material possible for any learning situation." The need for further research to test the generalizability of these criteria for different age groups and different domains is also noted.

6. Directions for policy

This section sets out an initial set of policy concerns for strengthening digital formative assessment in schools across Europe. The case studies and country dialogue labs (engaging a range of stakeholders, including students) that are part of the Assess@Learning policy experimentation will provide further insight.

As illustrated by the research highlighted in this review, digital formative assessment has the potential to enhance learning – providing more opportunities for self-directed learning, for interaction with peers, and new ways to engage with complex problems. New assessment technologies may, over the long term, support a more seamless integration of formative and summative assessment. To realise the potential for digital formative assessment, further thought at the policy level will need to be given to:

- **Teacher development** – Teachers' skills to integrate effective formative assessment in their lessons plans, to respond to evidence of student learning and needs, to provide opportunities for students to direct their own learning, are fundamental. Greater attention to teachers' assessment competences in both initial teacher education and continuing professional development is needed. Teachers will also need to develop their technological literacy. This includes a basic understanding of the potentials and limits of different digital tools.

Where possible, cooperative work between subject teachers and teachers with specific programming skills (as illustrated in a number of the studies reviewed in this paper) may open new doors to designing programmes to support specific pedagogical goals.

- **Ensuring coherence of digital formative assessment with other educational priorities** – New priorities for teaching and learning are frequently introduced in a piecemeal fashion, with little attention to how different priorities relate to one another. Efforts to introduce digital formative assessment are likely to fare better if it is clear how they may reinforce new curricular priorities (e.g. competence-based curricula, personalised learning, and so on). Guidelines on how to integrate formative assessment will support teachers to address everyday challenges of introducing new practices.

- **Accessibility of digital tools and programmes and implications for equity** – While access to computers from home has grown significantly in recent years, it is not universal. In Greece, for example, home access to computers has grown from 36.7% in 2006 to 70.5% in 2017. This represents significant progress, but also highlights that 30% of homes do not have a computer. Moreover, some learning programmes and tools require increasingly sophisticated hardware and connectivity, requiring regular upgrades. Policies to support digital learning will need to address issues related to access.

- **Encouraging investments in research and development** – Digital tools to support assessment and learning are still in the early stages of development. Greater cooperation between educators and programmers may lead to the development of more effective tools for learning. Investments in adaptive learning analytics may lead tools to track meaningful data and better meet individual learner needs.

Investments in technologies to create a more seamless integration of formative and summative assessment are also needed. These technologies have the potential to radically change education – with the design, content and formative of assessment and instruction grounded in learning sciences, and capable of measuring complex performances in realistic contexts.

While beyond the scope of this specific review, which has focused on pedagogical dimensions of digital formative assessment tools, it is also important to note the need for research related to the broader implications of digital learning and assessment – including risks of social exclusion (e.g. through interactions in social media that reinforce social divisions, or through uneven student participation in online platforms). Educational data mining may also lead to a loss of student privacy and raise ethical concerns (Timmis et al., 2015).

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