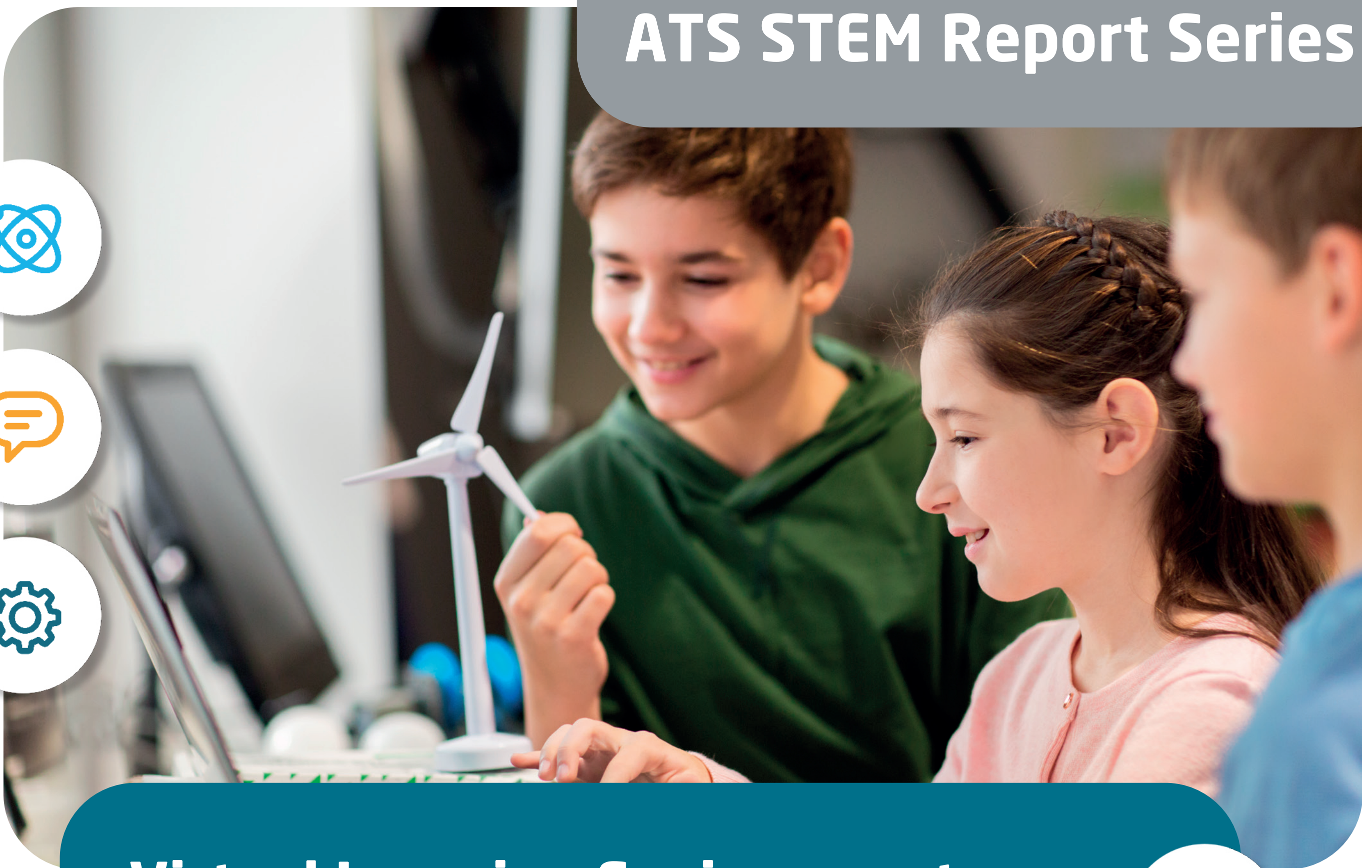
ATS STEM

Report #4 of
ATS STEM Report Series



Virtual Learning Environments and Digital Tools for Implementing Formative Assessment of Transversal Skills in STEM

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This is Report #4 of #5 in the ATS STEM Report Series. All reports in the series are available from the project website: **http://www.atsstem.eu/ireland/reports/**

- Report #1: STEM Education in Schools: What Can We Learn from the Research?
- Report #2: Government Responses to the Challenge of STEM Education: Case Studies from Europe
- Report #3: Digital Formative Assessment of Transversal Skills in STEM: A Review of Underlying Principles and Best Practice
- Report #4: Virtual Learning Environments and Digital Tools for Implementing Formative Assessment of Transversal Skills in STEM
- Report #5: Towards the ATS STEM Conceptual Framework

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FOREWORD

Assessment of Transversal Skills in STEM (ATS STEM) is an innovative policy experimentation project being conducted across eight European Union countries through a partnership of 12 educational institutions **(www.atsstem.eu)**. The project is funded by Erasmus+ (Call reference: EACEA/28/2017 - European policy experimentations in the fields of Education and Training, and Youth led by high-level public authorities). The project aims to enhance formative digital assessment of students' transversal skills in STEM (Science, Technology, Engineering and Mathematics). ATS STEM is co-financed by the ERASMUS+ Programme (Key Action 3 – Policy Experimentation). The project partnership comprises ministries of education, national and regional education agencies; researchers and pilot schools.

The countries and regions in which the digital assessment for STEM skills is being piloted are **Austria, Belgium/Flanders, Cyprus, Finland, Ireland, Slovenia, Spain/Galicia** and **Sweden** as per below:

- Dublin City University, Ireland
- H2 Learning, Ireland
- Kildare Education Centre, Ireland
- Danube University Krems, Austria
- Go! Het Gemeenschapsonderwijs, Belgium
- Cyprus Pedagogical Institute, Cyprus
- University of Tampere, Finland
- Ministry of Education, Science and Sport, Slovenia
- National Education Institute Slovenia
- University of Santiago De Compostela, Spain
- Consejería De Educación, Universidad Y Fp (Xunta De Galicia), Spain
- Haninge Kommun, Sweden

Dublin City University (DCU) is the project coordinator. A core element of DCU's vision is to be a globally-significant university that is renowned for its discovery and translation of knowledge to advance society. DCU has an interdepartmental team of experts from three different research centres bringing their combined expertise to bear to help lead and deliver the project goals. These centres have expertise in digital learning, STEM education and assessment, and are respectively the National Institute for Digital Learning (NIDL), the Centre for the Advancement of STEM Teaching and Learning (CASTeL) and the Centre for Assessment Research, Policy and Practice in Education (CARPE).

NIDL
National Institute for Digital Learning

The National Institute for Digital Learning (NIDL) aims to be a world leader at the forefront of designing, implementing and researching new blended, on-line and digital (BOLD) models of education **(https://www.dcu.ie/nidl/index.shtml).** The NIDL'S mission is to design, implement and research distinctive and transformative models of BOLD education which help to transform lives and societies by providing strategic leadership, enabling and contributing to world-class scholarship, and promoting academic and operational excellence.

CASTeL
Centre for the Advancement of STEM Teaching and Learning

The Centre for the Advancement of STEM Teaching and Learning (CASTeL) is Ireland's largest research centre in STEM education **(http://castel.ie/).** CASTeL's mission is to support the development of STEM learners from an early age, and so enhance the scientific, mathematical and technological capacity of society. CASTeL encompasses research expertise from across the Faculty of Science and Health and the DCU Institute of Education, one of Europe's largest educational faculties.

CARPE
Centre for Assessment Research, Policy and Practice in Education

The Centre for Assessment Research, Policy and Practice in Education (CARPE) is supported by a grant from Prometric to Dublin City University **(https://www.dcu.ie/carpe/index.shtml).** The centre was established to enhance the practice of assessment across all levels of the educational system, from early childhood to fourth level and beyond.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This report was written as part of a research project entitled, *Assessment of Transversal Skills in STEM (ATS STEM).* The project is funded by Erasmus+ (Call reference: EACEA/28/2017 - European policy experimentations in the fields of Education and Training, and Youth led by high-level public authorities). The report is based on two tasks from the project's Work Package 2 as outlined in Appendix A – namely, *Formative assessment design (WP2.1)* and *Architectural Implementation of the Tool Platform for Formative Assessment of Key STEM (WP2.2).*

This report is the fourth in a series of five based on deliverables related to the ATS STEM project. Reports #1, #2 and #3 are concerned with the research pertaining to STEM education in schools, with national policies for STEM in various European countries and with principles underlying digital formative assessment, respectively. Drawing on the first four reports, the fifth report presents an integrated conceptual framework for the assessment of transversal skills in STEM.

This report foregrounds the discussion in a number of seminal frameworks for technology-enhanced learning and then outlines the potential of nine digital architectures to be used for formative assessment. It categorises these nine architectures into Virtual Learning Environments and Digital Assessment Tools.

Virtual Learning Environments (VLEs) are online platforms that facilitate different kinds of interactions between students and teachers. Six VLEs are discussed:

1. **Content Management Systems (CMS):** virtual environments that allow for the storage and access of files. These files can be uploaded and downloaded by both students and teachers. CMS can be used for formative assessment through the administration of simple quizzes.
2. **Learning Management Systems (LMS):** platforms that allow for instructors to post course materials, interact with students, set assignments and return work to students. LMS are distinct from CMS in that the primary focus is on the instructor providing content and managing the course. LMS provide for the use of quizzes which can be used for formative feedback purposes.
3. **ePortfolios:** defined by Kingmore (1993, p.2) as "systematic collections of student work selected to provide information about students' attitudes and motivation, level of development and growth over time". ePortfolio systems afford high levels of control to students, who can curate their own work and determine who is allowed to access it. ePortfolios have strong potential to be used for formative assessment as they allow for instructors to assess a student's work in the context of their development over time, and offer informed critiques.
4. **Learning Analytics/Data Dashboards:** Learning Analytics refers to the collection of information about learners, which can then be presented in illustrative ways. Data Dashboards are the architecture through which this information is relayed. Because learning analytic systems amass a range of information about learners, including areas where their learning is unsatisfactory, they have strong formative assessment potential.
5. **Adaptive Learning Systems/Intelligent Tutoring Systems:** provide "tailored learning materials or activities to cater for personalised learning needs" (Xie et al., 2019, p.2). One type of architecture through which this provision takes place is Intelligent Tutoring Systems (ITS). ITS increasingly use AI technology to develop targeted lessons that adapt to the needs of each learner. ITS encompass a wide range of environments, but can be adapted for formative assessment purposes, for example through the provision of targeted quizzes or games.
6. **Games:** there are many different ways that games can be used for formative assessment, and a large industry has developed around the production of educational games. It is argued in this report that while games do have formative assessment potential, it is important for educators to think critically about the potential exaggeration of the educational possibilities of games, and ensure they are always used in line with up-to-date pedagogical strategies. Similarly, important is the issue of transfer: ensuring that skills learnt through a game can be utilised outside it.

Digital Assessment Tools are specifically designed for assessment purposes. Three are discussed:

1. **E-items:** test items which are adapted from traditional pencil and paper assessments and specifically designed for administration through technological means. Technology allows for the development of item types that are not possible in written format, such as drag and drop questions or graphing items.
2. **Computer Adaptive Testing (CAT):** this allows for an assessment to be altered based on a student's ability level or learning needs. An obvious example of CAT is a multiple-choice quiz that gives more difficult questions to a student who gets a lot of correct answers early on.
3. **Classroom Response Systems (CRS):** platforms designed for the provision of immediate classroom feedback. CRS usually take the form of devices which are distributed to all students in a class. Students use these devices to answer questions given to them by the instructor. While CRS do not intrinsically entail formative assessment, they can be used as such with effective pedagogy.

It is recognised that the architectures discussed, while conceptually distinct, are often used in tandem with each other or together as part of larger systems. Drawing on the concept of affordances, it is argued that while many digital technologies have the potential to be used for formative assessment, there are various mitigating factors that affect whether this happens in practice. The use of technology for formative assessment purposes is possible only when effective pedagogical strategies are deployed by educators.

INTRODUCTION

The purpose of this report (#4) is to provide guidance for the use of digital tools and associated architectures that can be implemented or adapted to support formative assessment of Science, Technology, Engineering, and Mathematics (STEM) transversal skills. A recent report from the Department of Education and Skills on digital learning in Irish schools noted a persistent lack of effective technology use in the creation of new knowledge and educational content (DES, 2020). Formative assessment is defined by Black and Wiliam (1998) as teachers and/or students using evidence to adapt teaching and/or learning to meet immediate educational needs. While some commentators make a distinction between the terms *formative assessment* and *assessment for learning*, they will be used interchangeably throughout this report. It is important to note at this juncture that, as Torres et al. (2018) highlight, there is no universally agreed upon definition of transversal skills and what they encompass. That said, transversal skills in STEM are considered by many commentators to be applicable across all four STEM domains and not bound to a particular subject. According to Torres et al. (2018), STEM skills categorized in the literature as transversal include those pertaining to cognitive processing (e.g., analytical and conceptual thinking) and achievement (e.g., efficiency, proactivity, organization, autonomy, and accuracy). These skills are particularly relevant in the context of problem-based learning, research-based learning, and/or enquiry-based learning.

The term *architecture* also requires explanation. For the purposes of this report, it refers to the design of an environment in which digital tools and software may be intentionally housed or used for specific purposes. Each type of architecture can encompass tools or software with similar features such as those pertaining to data collection/analysis and/or user interactions and the challenge is to select the best architecture for the intended outcome. The concept of *affordances* will also be relevant to several aspects of this report. Affordances refer to the different "action possibilities" (Gibson, 1977) that are latent in a piece of technology. These possibilities exist irrespective of whether they are used - therefore when discussing the uses of specific digital tools, it is important to understand the educational context in which they are situated, as this will affect how they are actually utilised in practice (Brown, Conole, & Beblavỳ, 2019) In all, nine different categories of architectures are featured here with the potential of each for formative assessment purposes within the STEM content domains outlined and evaluated.

ARCHITECTURE CATEGORISATION

At the most general level, architectures can be categorized in two ways: Virtual Learning Environments (VLEs) and Digital Assessment Tools (DATs). In thinking about the architecture of VLEs and DATs, the following framework originally proposed by Crook (1994) is useful as it places the focus not on the affordances of technology itself, but rather on the dimensions of interaction between digital tools, students and the teacher. In this respect, the framework helps to avoid techno-centric thinking as the design architecture and technology affordances need to be understood in the wider context of classroom instruction. There are four dimensions of collaborative interaction described within this framework: (i) interactions with computers, (ii) interactions in relation to computers, (iii) interactions at the computer, and, (iv) interactions around and through computers (Crook, 1994).

Collaborative interactions around and through computers refer to circumstances where engagement may be dislocated in time and space—that is, students are not using the VLE and digital tools together at the same moment or in the same geographical location. The emphasis is on the level of collaboration that can arise when learning activities, including assessment, are extended beyond standalone classroom computers and digital tools. Thus, this fourth category of interaction involves digital tools and more recently networked mobile devices that enable teaching, learning and assessment to take place beyond the physical walls of the traditional classroom (Crook, 1994).

Extending this fourth category, Anderson (2003) notes three main types of interactions that take place in distance learning: student-student, student-teacher and student-content. His theory of *interaction equivalency* states that a well-designed remote learning experience should allow for the substitution of one interaction for another without compromising learning. Another seminal framework for thinking about the different types of interactions in online distance learning environments is the Community of Inquiry (CoI) Framework (Garrison, Anderson, & Archer, 2000). This framework is a "collaborative-constructivist process model" that determines "the essential elements of a successful online higher education learning experience" (Castellanos-Reyes, 2020, p.557). There are three components of the model:

1. Cognitive presence: a focus on developing critical thinking.
2. Social presence: the development and maintenance of online relationships between learners and encouragement of collaboration.
3. Teaching presence: a leadership role directing learning to facilitate the cognitive and social presences. (Castellanos-Reyes, 2020).

Understanding these three presences can help both researchers and teachers to develop and implement effective online teaching courses. For the purpose of this report, the model provides a means by which different online architectures can be evaluated as part of an overall online learning system. The reader is referred to a publication from The Quality Assurance Agency for Higher Education (QAA, 2020) entitled, *Building a taxonomy for digital learning*, for another approach to conceptualizing how learners engage with technology.

VLEs are designed to allow learning or assessment processes to occur through the use of platforms that facilitate these interactions and different conceptions of presence to varying degrees. The Joint Information Systems Committee defines VLEs as "'online' interactions of various kinds that take place between learners and tutors" (JISC, 2002). Sneha and Nagaraja (2014) define VLEs as "the components in which learners and tutors participate in online interactions of several kinds, comprising online learning" (p. 1705). They are the basis of web-based learning and offer platforms for communication between students and instructors. In short, VLEs serve as places, spaces and online environments for management, interaction, and learning using technology solutions within a wider digital ecology. Although the terms VLE and Learning Management System (LMS) are often used interchangeably, it is important to note that VLEs are much wider in their conception than LMS. As such, in this report LMS will be discussed as a type of VLE.

DATs are explicitly designed for assessment purposes and include applications such as technology-enabled items, displays of student data and adaptive testing. Conejo, Garcia Vinas, Gaston and Barros, (2016), for example, developed a DAT called *Siette*, where tests are generated according to teachers' specifications and are adaptive in that questions are selected intelligently to fit the student's level of knowledge. Such examples fall under Crook's (1994) original conception of interactions *with* computers but now extend to VLEs. The capability of delivering feedback in a more timely manner (or immediately in some applications) is one of the key advantages of DATs.

Figure 1 presents a visual map of relationships between various architectures discussed in this report. Given that the goals of learning and assessment are not always independent, it is not surprising to find that some types of architecture can fall under both VLEs and DATs. The figure is designed to highlight the fact that architectures cannot always be neatly categorized as separate entities. For example, an architecture such as *Data Dashboards* is often embedded into *Learning Management Systems, Intelligent Tutoring Systems,* and Games.

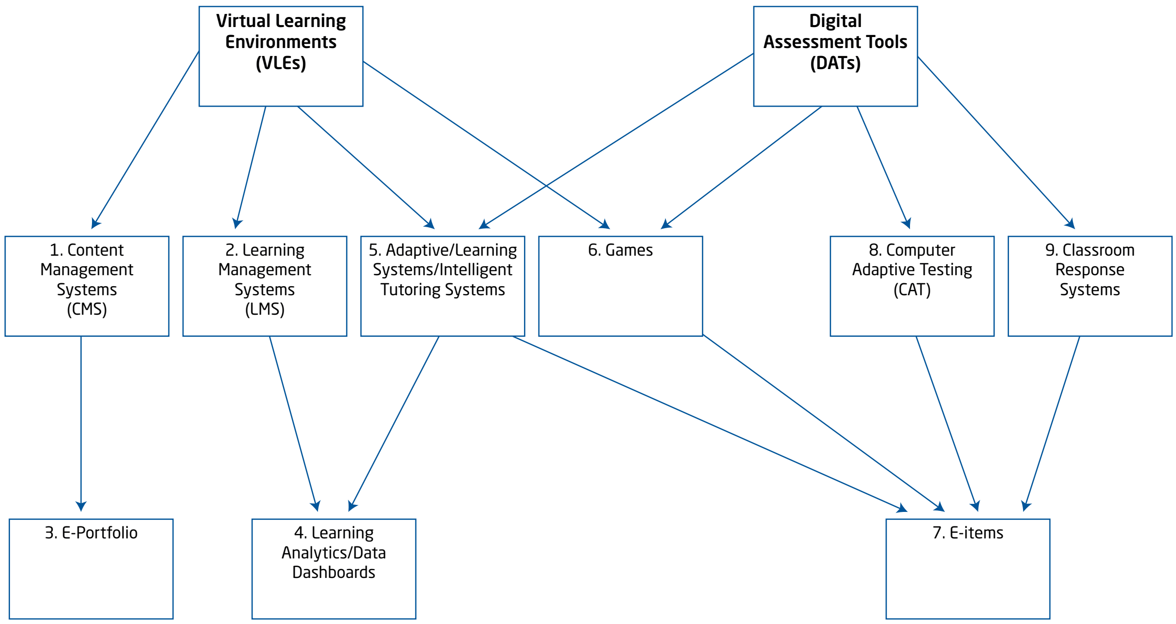

Figure 1: A Categorization of Architectures for Digital Tools

The research literature makes it clear that feedback can be considered formative only when it is used to improve teaching and learning. It follows then, that an architecture's capacity to support feedback opportunities (how often, what type, to whom, and how used) must be paramount when considering its worth. This is where the concept of affordances is illuminating - Brown, Conole & Beblavỳ (2019) note that affordances always exist "in relation to individuals and their capabilities" (p.18). Just because an architecture can support formative assessment, it does not necessarily mean this will happen in every case, and understanding the broader educational context in which an architecture is utilised is key to determining whether it will be used to provide formative feedback.

In Report #3, a technology enhanced formative assessment framework originally proposed within the context of the *Formative Assessment in Science and Mathematics Education* (FaSMEd) project was presented. The FaSMEd framework proposes the following technological functions for enhancing formative assessment: 1) Sending and Displaying, 2) Processing and Analyzing, and 3) Providing an Interactive Environment. These three functions will frame the evaluation of each architecture's capacity for enhancing the formative assessment of STEM transversal skills.

This paper presents a discussion of each type of architecture, beginning with those corresponding to VLEs (*Content Management Systems, ePortfolios, Learning Management Systems, Data Dashboards, Intelligent Tutoring Systems, and Games*). Following that, the discussion turns to DATs and related architectures (*E-items, Computer Adaptive Testing, and Classroom Response Systems*). The publication of the QAA (2020) contains a very useful glossary of terms associated with digital learning and assessment (see, pp.13-16). Some of the software associated with the different architecture types is also highlighted in the main text of this report, while the reader is referred to Appendix A for more detailed information pertaining to this and other software currently available for assessment purposes.

VIRTUAL LEARNING ENVIRONMENTS (VLES)

1. Content Management Systems

Content Management Systems (CMS) are online structures that store and display content such as text, files, or images. Ghoneim et al. (2017) explain that this architecture, as a piece of organizational software, allows content to be created and managed collaboratively (p. 16). CMS operate under the premise of a shared platform, and both users - student and teacher - have the same level of access to content. The user is able to post content and control who views and/or interacts with it. One of the key features of CMS is communication between users. In education literature and practice, CMS are often seen in the form of portfolios in which users compile educational content in a way that allows for feedback from instructors or other learners.

The Jupyter Notebook provides an example of an innovative platform that can be used as a CMS. Jupyter Notebooks allow for teachers to present complex computational data to learners in varied ways that promote engagement. While the architecture offers multiple affordances beyond simply the presentation and organisation of information, this is its basic function. A key advantage of the architecture is that it is open source and adaptable (as detailed in an open textbook by Barba et al., (2019). Users therefore can tailor it to specific needs, such as the administration of simple quizzes or a "ticket to leave" system whereby students need to demonstrate they have achieved (Wakeford, n.d.). As such, it has strong potential to be used for formative assessment.

2. Learning Management Systems

Learning Management Systems (LMS) are management platforms that allow instructors to post course materials and for students, interact with learners and submit completed assignments. They are different from CMS because their emphasis is on giving organizational and interactive tools to the instructor rather than content control to students. These platforms, which have been used in education for over 20-years (Weller, 2020), are adaptable to include relevant sections such as assignments, discussions, and presentation materials, and once set up can be carried over from year to year (Ghoneim et al., 2017). Importantly, even though the term LMS is often used interchangeably with VLE and is more common in North America and Australia than Europe, the latter term reflects a much wider conception of the digital learning ecology. A key advantage of LMS is that they are often integrated with various other digital technologies such as student management systems. Weller (2020) notes that the LMS is "the dominant and arguably the most successful education technology" (p.63) and that for many in educational technology, the LMS "is at the centre of their work" (p.67). He writes that LMS often "doesn't get the credit it deserves" (p.67) for being such an important piece of technology.

Commonly used LMS include Moodle, Canvas, and Blackboard. LMS features such as discussion boards or quiz modules can be adapted for formative assessment when combined with an instructor's feedback-focused pedagogy. For example, an instructor could use the quiz module to administer practice quizzes for a year end exam. In this scenario, the instructor might set up the quizzes to provide immediate feedback upon completion, such as a summary of incorrect multiple-choice items with relevant information the student could use to understand the correct solution.

3. ePortfolios

ePortfolios, an online version of educational portfolios, are a specific form of content management system (Himpsl & Baumgartner, 2009). Educational portfolios are defined by Kingmore (1993) as "systematic collections of student work selected to provide information about students' attitudes and motivation, level of development and growth over time" (p. 2). Technology-enhanced features of ePortfolios allow for greater functionality due to ease of uploading work as it is completed, direct control over who views material, and increased interaction between the student and teacher. Defined by Brazdeikis and Valineviciene (2015) for the EUfolio project, ePortfolios "are (student-owned) dynamic digital workspaces [in which] students can capture their learning, their ideas, access their collections of work, reflect on their learning, share it, set goals, seek feedback and showcase their learning and achievements," (p. 3).

ePortfolios can be independent web-based tools, or embedded into existing management platforms. Most uses can be classified under the FaSMEd framework as "Providing an Interactive Environment", due to their emphasis on instructor-student feedback, peer feedback, and self-assessment. Mahara (Catalyst IT, 2018) is one example of a free and open-source web-based electronic portfolio management system. Using this tool, students are able to upload blog posts, projects, presentations, and other demonstrations of learning as well as interact with other users on the site.

In the UK, the Joint Information Systems Committee (JISC) (2008) recommends the use of ePortfolios as tools for formative assessment because of their capacity to capture educational advancement as students develop through their coursework. Other commentators (e.g., Radhakrishnan, Hendrix, Mark, Taylor & Veras, 2018.) have pointed to the fact that their use helps students make connections across different areas of learning – a potentially significant feature when considering the assessment of transversal skills in STEM.

Examples of positive outcomes from the use of ePortfolios include those reported by Deeley (2018) who noted that students who uploaded their work onto Mahara receive timely feedback to incorporate into their final term paper and by Hooker (2017) who reported deeper and more reflective thinking by students. On the other hand, it has been noted that the development and implementation of ePortfolios requires a significant amount of time (Smart, Sim, & Finger, 2015) and the tool is "rooted in a complex pedagogy" with recurring tensions arising between the process and product conceptualizations of it (Scully, O'Leary, & Brown, 2018, p. ii).

4. Learning Analytics/Data Dashboards

Learning analytics refers to the collection and measurement of data about learners, which can then be relayed back to learners (Ferguson et al., 2016). When data is presented to learners in a clear and instructive way, learning analytics allows for formative assessment to take place, as learners can see through visual tools such as graphs what areas they need to focus their learning on (Schwendimann et al., 2016). The architectures that present the collected data to learners are known as data dashboards.

One example of this type of architecture is the Digital Dashboard for Learning (DDL), which is a "tool that provides visibility into key indicators of student learning through simple visual graphics such as gauges, charts and tables within a web browser" (Bajzek et al., 2007, p.2). Data Dashboards can present information in an assortment of formats, such as quiz modules, games, and discussion boards. These formats are appealing for learners because they allow high level information to be presented in a visually appealing way (Bajzek et al., 2007). Research is still ongoing on the use of technology to collect data and use visualization as a means of helping learners (Nyland, 2018; Bhagat & Spector, 2017). Therefore, discussion regarding the most effective visualizations for formative purposes is still developing in the field. It is important to note as discussed by Selwyn (2019) that learning analytics (like much data science) is usually driven by companies seeking to mine data. As such, tools such as data dashboards can be conceptualised as merely a small facet in a larger project of learning analytics and data extraction.

Data dashboards are considered part of the "Processing and Analyzing" dimension of the FaSMEd framework. Data Dashboards can provide information without interfering with the learning experience, otherwise known as "stealth" assessment (Bhagat & Spector, 2017) - although occasionally the dashboard data is shared with learners to allow them to direct their study. These tools often use learning analytics, data mining, or artificial intelligence procedures to gather, synthesize, and analyze information. An example would be a data dashboard embedded into a learning management system. Discussion board posts can be text mined according to predetermined rules based on grading criteria. One such rule might be that a student has to explicitly state a hypothesis. The text mining analysis and/or associated scores would be presented in the form of a data dashboard. Text mining and other similar procedures are time consuming to develop and validate, but once set up can produce quick feedback for the user.

Best practice in formative assessment calls for timely feedback, which is an emphasis of Data Dashboards. Nyland (2018) argues that Data Dashboards used for formative assessment have the “explicit purpose of providing feedback to students or instructors based on data collected in the course” (Nyland 2018, p. 507). Nyland (2018) highlights that not all Data Dashboards are designed specifically for formative assessment. However, dashboards designed with other intentions (such as research) can be used for formative assessment as well because of the feedback they provide. Two examples of specific tools are presented to highlight the benefits of Data Dashboards for formative assessment.

Automated Knowledge Visualization and Assessment (AKOVIA) was designed for the automatic analysis of written language (e.g., written essays, discussion forum posts) (Ifenthaler, 2014). AKOVIA can be used for a variety of purposes, such as the “investigation of learning processes, distinguishing features of, subject domains, cross-curricular, non-routine, dynamic, and complex skills, or the convergence of team-based knowledge” (Ifenthaler, 2014, p. 241-242). While originally developed for research on learning and education, AKOVIA has applications in formative assessment because it is able to provide quick feedback (Spector et al., 2016). Bhagat and Spector (2017) highlight the automated feedback as “one of the key features of AKOVIA, which can help the learners to understand their writing and improve it accordingly in an effective way” (p. 314).

Eduminer, explicitly designed for formative assessment, automatically collects information (mainly from students’ discussion board posts) to analyze both individual and collective (class-wide) knowledge. Eduminer classifies students into cognition levels based on their posts (see Appendix D) through text mining techniques. The cognition level of the student’s response is compared to the intended cognition level of the discussion. This information is then displayed using the visualization of a cognitive circle (see Appendix E). The instructor can use that information to help guide students. Hsu et al. (2011) evaluated the use of Eduminer in a graduate level human resource management course. While comparing students using Eduminer with a control group, Hsu et al. (2011) found Eduminer students reached quantitatively higher cognition levels than the control group. Results from a survey and qualitative feedback showed that students also had favorable opinions of the individual cognition circle in helping their own learning (Hsu et al., 2011).

Specific technologies such as Eduminer and AKOVIA demonstrate the potential that Data Dashboards have for enhancing the learning process. This architecture can prove useful for formative assessment of transversal skills in STEM because of its quick and transparent feedback. For example, students could be instructed to complete discussion board posts related to transversal skill competencies such as inquiry or critical thinking. Text mining could analyze the competencies students reach and provide appropriate visualization. This would allow for much quicker feedback than an instructor could provide. In addition, the instructor would be able to use this fast feedback to adjust their teaching and student support. However, it is important to note that just because data dashboards allow for the provision of formative feedback, it is not the case that such feedback will be provided in every case. The concept of affordances emphasises that contextual factors affect how digital tools are utilised (Brown, Conole, & Beblavỳ, 2019). As such, to determine the extent to which data dashboards lead to formative feedback, it would be necessary to understand the specifics of how instructors use them - it is entirely possible that they would use the dashboard to monitor student progress without providing any feedback.

5. Adaptive Learning Systems/Intelligent Tutoring Systems

Adaptive Learning Systems are those that “provide tailored learning materials or activities to cater to personalised learning needs” (Xie et al., 2019, p.2). Intelligent tutoring systems (ITS) are an important platform through which adaptive learning takes place (Xie et al., 2019). ITS provide technology-generated tutoring that mimics interaction with an actual human tutor (Anderson et al., 1985). ITS engage students in “sustained reasoning activity and [interact] with the student based on a deep understanding of the student’s behavior.” (Corbett, Koedinger, & Anderson, 1997, p. 850). Although ITS have been available for several decades, as Crook (1994) identifies in the aforementioned framework, increasingly the architecture uses “artificial intelligence techniques to understand what students are doing with a piece of educational software so that advice and feedback can be provided to them to assist with their learning and understanding” (Kennedy et al., 2013, p. 171). ITS are used in many different applications, ranging from virtual simulations to online quizzes. ITS applications most often take the form of “Providing an Interactive Environment” within the FaSMEd framework. Fishtree is an example of such an application, which “aligns content to learning objectives” and “adapts to the learning profile and knowledge gaps of every learner”. Commonly used in the USA, such applications ostensibly allow instructors to devote more time to teaching rather than having to tailor individual assessment plans for each student.

ITS architecture has a history of engaging in STEM formative assessment. Feedback is often given after a problem is completed or a skill is demonstrated, but this varies from software to software. Examples of STEM-oriented ITS include: problem solving in mathematics (Koedinger & Corbett, 2006; Razzaq et al., 2005), physics (Gertner & VanLehn, 2000), genetics (Corbett, Kaufmann, MacLaren, Wagner, & Jones, 2010), and computer programming tasks (Corbett & Anderson, 1995; Kasurinen & Nikula, 2009).

Recently, ITS has been used for more complex applications in STEM. This often involves combing through log data and using machine-learning and/or data mining techniques. Kennedy et al. (2013) developed ITS to be embedded into surgical simulations to provide real time feedback to students. Another piece of software developed for STEM application is Inq-ITS, a web-based intelligent system designed for automatic assessment of physics, life science, and earth science in simulation environments. Gobert et al. (2013) conclude that Inq-ITS establishes that with an appropriately guided data-mining system, it is possible to produce a rich description about students' learning to be used during tutoring. Azevedo et al (2009) developed a virtual environment, MetaTutor, specifically to help students develop self-regulatory learning habits within the science curriculum. MetaTutor uses "pedagogical agents as external regulatory agents used to detect, trace, model, and foster students' self-regulatory processes during learning about complex science topics" (p. 17). Current research in Sweden is expanding upon digital avatar paradigms to explore the use of social robots. Furhat robots are being explored to determine the learning benefits they can bring - they are currently being trialed assisting students in learning math, artificial intelligence, machine learning, and sustainable energy (Moubayed & Taylor, 2019).

The works cited demonstrate the prevalence of ITS for STEM formative assessment. There is wide variation in the environments using ITS, ranging from individual multiple choice E-items all the way to simulations or games. There are applications ranging from low level skills, such as answering correct/incorrect questions, to more transversal constructs such as inquiry. Overall, ITS demonstrates clear potential for use in formative assessment in STEM.

6. Games

Games are recognized as having potential for learning and assessment (e.g., Baker & Delacruz, 2008; Mislevy et al., 2012; Shute et al., 2009). This paper uses the word "game" to refer to a large variety of activities from quiz-like games to video-game environments under the broader conception of Gamification. Gamification is defined by Dichev and Dicheva (2017) as "the introduction of game design elements and gameful experiences in the design of the learning process" (p.2). The game architecture can be classified as "Providing an Interactive Environment," but many also include "Processing and Analyzing." Although published work on the educational benefit of games has become frequent in the last decade, it is important to note that possible educational advantages of games are dependent on many factors (Dichev & Dicheva, 2017). In a meta-analysis of studies evaluating the benefits of educational games, Clark et al. (2015) conclude that research suggests that games can aid learning, but only when carefully designed and with a sound pedagogical foundation: "...games as a medium definitely provide new and powerful affordances, but it is the design within the medium to leverage those affordances that will determine the efficacy of a learning environment" (p.116).

Similar to ITS, there have been many examples of games used for formative assessment purposes in STEM. One of these is Physics Playground, a game designed to assess students' understanding of physical principals (Shute, Ventura & Kim, 2013). Kim and Shute (2015) evaluated the game in a classroom setting and reported that measures of performance in the game correlated with traditional paper-based measures of physics knowledge. Student performance on the paper-based measures of physics knowledge increased from pre to post tests after playing the game. This suggests that not only is the game able to assess learning, but learning increases as a result of engaging in the game (Kim & Shute, 2015). The increase of learning is likely due to the fact that students were aware of their performance within the context of the game - they would only pass the level if they could apply the proper physics skills/phenomena. This could be seen as a form of feedback.

Lot and Salleh (2016) investigated game-based learning for formative assessment using the platform Zondle, a tool for teachers and/or students to create learning games. They found that game-based learning was effective in increasing learning, engagement, and performance on subject knowledge. Lot and Salleh (2016) recommend that game-based assessments include competencies and skills that are designed and customized to match competencies and skills in non-game environments. To be most useful for learning, the criteria for high performance should also be communicated to students.

Tris-Q-SP is a computer-programming formative assessment software using playful elements of game-based architecture. Students play tic-tac-toe against a computer opponent. When they attempt to place their marker on the board, a multiple-choice question pops up. If the student answers the item correctly, their token is placed in the designated spot. If not, their opponent's token is placed there. Students receive immediate correct/incorrect feedback and also have a dashboard color coded to represent content they have learned and will learn (Hooshyar et al., 2016). Hooshyar et al. (2016) describe the color coding scheme: "yellow represents 'already know the concept', red represents 'the concept is unknown and not ready to learn', and green represents 'unknown concept but ready to learn', showing the knowledge level of each user on that particular concept" (p. 27). Tris-Q-SP, with its form of feedback, is considered both a game and an expansion of ITS (Hooshyar et al., 2016). Results showed that, in relation to a control group, those who used the software showed greater learning of computer programming constructs. Students playing Tris-Q-SP also had increased positive attitudes towards learning computer programming.

It is critical to examine the exaggerated selling points companies may make about their games. Before purchasing a game for educational use, stakeholders should consider where the research regarding the game is coming from. Like many products, sources of data regarding games are often solely from the company selling the game. Linderoth (2018) warns against the influence of commercial interests on education. Linderoth (2014) explains that constructing games is a complex process which "demands several competencies at once", such as "being knowledgeable about learning, education and game design." Additionally, while results from studies testing the educational benefit of games are promising, it is crucial to note the issue of transfer, which refers to "being able to take what you have learned in one context and apply it to solve problems or learn in a new context (Mayer, 2019, p.533). Games are ultimately only useful in education to the extent that they allow students to develop skills that can be applied outside the context of the game. Mayer notes that "the best chance for positive cognitive consequences of game playing occurs when the cognitive test evaluated outside the game playing environment taps a skill that was repeatedly exercised within the game" (2019, p.541).

Two conflicting goals must be managed in game-based assessment: "in games, the situation must be at the leading edge of what they can do to provide engagement and enjoyment, whereas in assessment, students' responses to these situations must provide evidence of their general proficiencies" (Kim & Shute, 2015, p. 341). Some games may be designed for learning purposes and do not assess general proficiencies, while others are designed specifically for summative assessment purposes with learning as an afterthought. Teachers have specific working conditions and needs—and it is important that their voice is integrated into game design and development. As Linderoth (2018) explains, when the teacher's voice is considered in development, there is a greater possibility that the game solves the didactic problems that teachers encounter. Additionally, even if games are designed with input from teachers, there is no guarantee they will be utilised in the classroom in the best possible way. Sanchez-Mena and Marti-Parreno (2017) conducted a literature review of 11 studies on the topic of teacher acceptance of digital games, and found a number of factors that affect whether games get used, such as teacher training levels and personality factors. As such, just because games offer certain affordances (Brown, Conole, & Beblavỳ, 2019), various factors influence whether they are utilised.

To maximize benefits related to the goals of this project, game architecture should include teachers as a stakeholder in development and be intentionally geared towards the formative assessment of STEM transversal skills. While research indicates that games can aid learning, this is only possible when they are designed carefully and with transfer of skills in mind.

DIGITAL ASSESSMENT TOOLS (DATS)

Digital assessment tools are specifically designed for the assessment process. Ideally, these tools should be able to support the entire cycle of assessment (Conejo et al., 2016). Because of their specific assessment purpose, these tools offer the unique capabilities of "greater student access, flexibility, ease of constructing the assessment tools, and immediate formative feedback" (Cassady & Gridley, 2005, p.24). Much of the previously explained software has variations that can be considered as digital assessment tools. For example, many ITS systems are developed with formative assessment goals in mind. Although not representative of the full range of available solutions, three types of architecture fall neatly into the digital assessment tools category: E-items, Computer Adaptive Testing and Classroom Response Systems. Several examples of Classroom Response Systems and E-item tools are available - more examples of digital assessment are given in Appendix F.

7. E-items

Technology has allowed innovations in assessment items. Because of the resources required to build them, E-items are typically used in large-scale summative assessments such as e-TIMSS or NAEP (National Assessment of Educational Progress, [USA]). Items in e-assessments can be classified as being a) "modeled on those used in paper-and-pencil testing" b) "creatively presented in the context of real- life situations to help enhance the fidelity of the measurement with the construct being assessed" and c) "entirely unique and only logistically feasible through technology" (Sircei & Zinisky, 2006, p. 332). Digital technology can allow simple changes to enhance items, such as a drag and drop feature (Sircei & Zinisky, 2006). More complex items can take the form of graphical modeling where examinees model data through a graph, shade a geometric shape, or draw trend lines (Bennett, Morley, & Quardt, 2000). Computer-based testing using E-items has been validated in different forms and is increasingly preferred over pencil-and-paper (Sircei & Zinisky, 2006).

One example of software that supports the E-item architecture is TAO. This platform is open source and allows users to build, deliver, and share assessments online (Ghoneim et al., 2017). The platform enables both E-items and adaptive testing. Researchers at the University of Massachusetts (UMASS) Amherst have used TAO for reading and math tests and created engaging items based on pencil-and-paper assessments. They found that the application of E-items allows measurement to occur in a more authentic way (Open Assessment Technologies, 2017). The authenticity refers to an item's ability to appear more natural to the learner than a traditional multiple choice item. While this study used TAO as a summative assessment application, its open source capabilities provide an environment that has the potential to be used for formative assessment as well.

8. Computer Adaptive Testing

Computer Adaptive Testing (CAT) allows for items to be adapted on the basis of a student's ability. CAT often involves multiple choice items. The score a student earns on the first item or set of items will determine the next item or set of items a student receives. For example, if a student answers most items correctly, they may receive a set of more complicated items. This allows learning to be on target with the student's ability level (Oppl et al., 2017). Therefore, as Louhab et al., (2018) explain, the overall purpose of CAT is to generate the optimal test for each student.

MISTRAL eLearning Platform uses CAT components for formative assessment in order to determine optimal learning content for students (Oppl et al., 2017). The software has a module which uses traditional IRT-based scoring and item selection procedures and also has an option for manually grading constructed response items. The module for adaptive testing aims to evaluate where a student is on their learning. By using adaptive testing, the program is able to diagnose which of the course objectives the student has reached or mastered (Salcedo et al., 2005).

Another form of computer adaptive testing is Siette (Oppl et al., 2017; Gouli et al., 2002). This software was used in a plant identification course. Using location information, questions are catered to specific plants near the student's location. Therefore, items are adaptive to the current stimuli that a student might be encountering (Conejo et al., 2016). This is adaptive in a different sense than traditional CAT frameworks since it is not based on ability level, but on location. In addition to being a CAT software, it employs ITS techniques. Students are able to receive immediate feedback on the questions with reference material (Conejo et al., 2016). "Students who used Siette performed better than the students who underwent traditional methods for formative assessment. More interestingly, immediate feedback helped the students attain better performance, which is not possible without the use of technology." (Conejo et al., 2016, p. 315). Siette is an excellent example of how software types can be combined for specific STEM formative assessment purposes.

9. Classroom Response System

Classroom Response Systems (CRS) are an architecture for the provision of immediate classroom feedback. The basic structure of this takes the following form: when asked by the teacher, students press a key on a mobile-sized device to indicate their response. Responses are then transmitted to a computer and analysed to provide a visualization. This can be used for teachers to check in with students' understanding of a concept, or to poll students on a topic (Farrell & Rushby, 2016; Beatty & Gerace, 2009). Recognising the interactions between teachers, learners and computers as outlined by Crook (1994), CRS can be best understood as a tool that exists as part of a wider digital ecology.

Socrative is one classroom response system that has numerous applications. Socrative is a form of smart phone response system that can be used in the classroom. Instructors design questions and control the flow, timing, and other administrative aspects of implementation. Students are able to log into their device to interact in real-time with the questions. Their responses are displayed visually for instructors as bar charts as well as in the format of Excel data (Coca & Slisko, 2013).

CRS are common in higher education and are becoming more common in K-12 classrooms. CRS can be applied to STEM content areas because the items are controlled by the instructor. An important consideration of this architecture is the capabilities of multiple choice items to assess the intended transversal skills. Beatty and Gerace (2009) argue that CRS have a specific place within K-12 STEM education because they are able to "clarify thought through the process of articulation and externalization; to expose students to different points of view and lines of thinking; to promote analysis and resolution of disagreements; to supply stimuli, context, and tools for individual sense-making; and to provide practice speaking the social language of science" (p. 154-155). These systems can allow for a student centered classroom. Students receive immediate feedback on their responses and instructors can use information collected from CRS to cater instruction.

Aljaloud et al. (2015) conducted a literature review on current research trends in the field of CRS (referred to, in this case, as Student Response Systems). They found that research demonstrated "encouraging possibilities in the areas of interactivity, academic performance and learning, and student engagement" (p.323). However, they also noted several potential limitations, in particular academic inefficiency (there is no guarantee that students who select the correct answer actually understand the material). While promising, their conclusion is that further research is necessary to utilise CRS to the maximum level.

CRS usage is not inherently considered formative assessment. Beatty and Gerace (2009) argue that the pedagogy applied to the CRS is what creates formative assessment practice. Using CRS during class is not enough for formative assessment. An instructor needs to use CRS and provide feedback to students or to use responses to inform their teaching.

CLASSROOM IMPLEMENTATION AND FORMATIVE ASSESSMENT

The architectures presented here all have benefits that are supported by empirical research, although it is noted in some cases that the evidence of such benefits is at an early stage. Some were specifically designed for formative assessment. Others were not but can still be used for this purpose. The main considerations in choosing the best architecture will depend on priorities within the formative assessment program, as well as the resources available. For example, if the priority is for a personalized formative assessment environment, then any architecture selection must be centered around the student's own learning, allow them to have immediate feedback, and be adaptable based on student need. However, if it is to be centered on the instructor, then feedback needs to be suitable for use by teachers to adjust instruction. Additionally, for the affordance of formative assessment to be realised, there needs to be an understanding of the contextual factors that determine how the architecture is used - there would be limited benefit in introducing a powerful LMS if educators were not trained in using it for formative assessment purposes.

It is important to consider if just one version of the architecture will be used, or if it will be used on different interfaces across schools. For example, a tool designed for learning management systems may see implementation in different forms such as Canvas or Moodle. If there is no specific tool that the content is applied to, it will be important to consider how content will be shared between platforms (such as txt files). For items across different platforms, the Accessible Portable Item Protocol (APIP) could serve as a resource in combating this challenge (Russell et al., 2011).

In report #3, the importance of self-regulatory and process-oriented feedback toward formative assessment is discussed (see, Reynolds et al., 2019). Azevedo et al. (2009) explain that "regulating one's learning involves analyzing the learning context, setting and managing meaningful learning goals, determining which learning strategies to use, assessing whether the strategies are effective in meeting the learning goals, evaluating emerging understanding of the topic, and determining whether there are aspects of the learning context which could be used to facilitate learning (p.14)." Therefore, as Hattie and Timperley (2007) contend, feedback related to self-regulation focuses on developing skills in self-assessment, or confidence to engage further in a task. Pinger et al. (2018) describe process-oriented feedback as informing the learner about their strengths and weaknesses, and providing them with strategies to close the gap between the learning goal(s) and their current level of understanding. Each architecture, depending on application, can produce both self-regulatory and process-oriented feedback. As a tool is selected and/or designed, its capacity to support process-oriented and self-regulatory feedback should be considered, in addition to whether the contextual factors of the classroom indicate it is likely the architecture will be used for effective formative assessment.

Resources are another important consideration. Certain architectures require more resources upfront, specifically those which use machine learning models. It is also important to remember that investment in resources may not always lighten the implementation burden for instructors. For example, while platforms such as Mahara are relatively straightforward to implement, instructors must invest a significant amount of their time in helping students to develop ePortfolios and in providing them with feedback they can use. Ultimately, however, the argument made in Report #3 must be reiterated: digital resources for formative assessment are a means to an end only. The value of any virtual learning environments and digital tools selected will depend on whether they are functional, flexible, practical and above all, useful in ensuring that formative assessment leads to improvements in learning.

CONCLUSION

In this report, nine different architectural categories of learning technology systems and solutions were presented and discussed in terms of their educational affordances. While the nine categories are not fully representative of the available technology solutions or discrete, as many are embedded within and/or interact with each other, classifying them in this way allows for insight into the key benefits each can offer for formative assessment. However, one of the key takeaways from this report is that determining how these architectures can be used for formative assessment does not necessarily mean that they will be used for this purpose in every case. Understanding the affordances, dimensions, and presences offered by digital tools is important, however there are several contextual factors that affect how such tools are actually used. For the formative assessment potential of digital tools to be realised, they have to be implemented in accordance with contemporary theories of learning and be backed up with sound empirical research (which, for many of the types of architecture discussed, is at an early stage).

Each system was examined for its capacity to provide formative assessment in STEM environments. A detailed breakdown of all specifically mentioned systems, solutions and/or software solutions in terms of type, subject area, age, purpose, formative assessment potential, limitations, and availability/source is contained in Appendix A. In essence, the report was written to guide decision-making around the choice and design of formative assessment software in STEM contexts, as per the intention specified for Work Package 2 in the original ATS STEM proposal document.

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APPENDIX A

Assessment of Transversal Skills in STEM (ATS STEM)

Erasmus+ Call reference: EACEA/28/2017

Terms of Reference for Work Package 2, Task 1c and Task 2

Excerpts from the Original Proposal (See pages 61-65)

WP 2 – STEM Formative Digital Assessment Approach
Work package (WP2) is focused on digital assessment and provides an evidence-based platform for the formative assessment of STEM learning tasks. It will result in a carefully selected STEM formative assessment digital tool package that fits the development and assessment of transversal skills as agreed upon in WP1. The outcomes of the comparison or adaptability of tools for STEM formative assessment will raise awareness of the didactic implications of formative assessment in the teaching and learning process. The development and/or adaptation of a tool package will be carried out basing on careful review of existing solutions and in close cooperation with key users in order to suit the needs of the piloting partner's schools and support the didactic purpose of the chosen assessment as well as suit considerations regarding storage of evidence and quality assurance of the assessment operation and outcome.

Task 1: Formative Assessment Design: Building Critical Skills in STEM: How Digital Assessment Can Give Learners Feedback 30/09/2019

The initial task will involve:

- (c) Identification of an appropriate tool or tools that have demonstrated successful outcomes in formative assessment of STEM. Such a tool or tools will be determined by the review, but examples may include e-portfolios or adaptive learning environments.

Output: A recommendation for a key tool or platform for the project.

Task 2: Architectural Implementation of the Tool Platform for Formative Assessment of Key STEM Skills 30/11/2019

The initial task will involve:

- (a) This task will involve the design of an architecture using the digital tool identified for formative assessment concentrated on how that tool may be adapted for assessment of STEM transversal skills.
- (b) This adaptation will involve the development or repurposing of the identified tool to suit local contexts and cultural conditions. It will highlight the key potential affordances for learners of the tool.

Output: Architectural design and implementation of tools adapted for assessment of STEM transversal skills that demonstrates the key potential affordances for learners of the tool.

APPENDIX B

Summary Features of Software Presented in this Paper

Part 1: Basic Information

Software	Architecture Type	Subject Area	Age	Purpose
Mahara	Content Management System: ePortfolio	Any content of work can be uploaded. Often writing-based.	K-12/Higher Ed	Students are able to upload blog posts, projects, presentations, and other displays of learning. This web-based platform enables interaction with other users on the site. Mahara allows for students to upload work over time to have a multi-year collection of their learning.
e-scape	Content Management System: ePortfolio	Design/ Technology, Science and Geography	K-12	Automatically add classroom data (through the use of PDAs) into an e-Portfolio.
Moodle	Learning Management System	N/A	K-12/Higher Ed	Learning management system for course management.
Canvas	Learning Management System	N/A	K-12/Higher Ed	Learning management system for course management.
Blackboard	Learning Management System	N/A	K-12/Higher Ed	Learning management system for course management.
Digital Dashboard for Learning (DDL)	Data Dashboard	Online courses	Higher Ed	Provides visuals of student learning on an online dashboard. It was designed specifically to support online courses.
AKOVIA	Data Dashboard	Written Language	K-12/Higher Ed	Designed for the automatic analysis of written language (e.g., written essays, discussion forum posts), it can be used for a variety of purposes such as "investigation of learning processes, distinguishing features of, subject domains, cross-curricular, non-routine, dynamic, and complex skills, or the convergence of team-based knowledge" (Ifenthaler, 2014 , p. 241-242).

Software	Architecture Type	Subject Area	Age	Purpose
Eduminer	Data Dashboard	Human Resource Management	Higher Ed	Text-mines discussion board posts to provide data regarding student learning. It analyzes where a students reached cognitively compared to corresponding cognition level for the prompt.
INQ-ITS	Intelligence Tutoring System	Inquiry in Science	K-12	A web-based intelligent system designed for automatic assessment of physics, life science, and earth science in simulation environments.
MetaTutor	Intelligence Tutoring System	Science Curriculum	K-12	Provides assistance of student developing self-regulatory learning habits within science curriculum. It uses "pedagogical agents as external regulatory agents used to detect, trace, model, and foster students' self-regulatory processes during learning about complex science topics" (p. 17).
Furhat Robots	Intelligence Tutoring System	Math, artificial intelligence, machine learning, and sustainable energy	K-12	Use of social robots in the classroom to assist students with learning course material.
Physics Playground	Game	Physics	K-12	A game where students digitally sketch elements to complete a given task. For example a weight may need to be drawn into the interface to allow an obstacle to move, which demonstrates a student's knowledge of gravity.
Zondle	Game	N/A	K-12	A tool for teachers and/or students to create learning games.

Software	Architecture Type	Subject Area	Age	Purpose
Tri-Q-SP	Game & Intelligence Tutoring System	Computer-programming	K-12	Students play tic-tac-toe against a computer opponent. When they attempt to place their marker on the board, a multiple choice question pops up. If the student answers the item correctly, their token is placed in the designated spot. If not, their opponent's token is placed there. Students receive immediate correct/incorrect feedback and also have a dashboard color coded to represent content they have learned and will learn.
Socrative	Classroom Response System	N/A	K-12/Higher Ed	Smart phone response system that can be used in the classroom. Instructors design questions and control the flow, timing, and other administrative aspects of implementation. Students are able to log into their device to interact in real-time with the questions. Their responses are displayed visually for instructors as bar charts as well as data in excel format.
Mistral	Computer Adaptive Testing	N/A	K-12/Higher Ed	An eLearning Platform that uses CAT components for formative assessment in order to determine optimal learning content for students. Uses adaptive testing to diagnose the course objectives a student has met.
Siette	Computer Adaptive Testing & Intelligence Tutoring System	Plant Identification	Higher Ed	This software was used in a plant identification course. Using location information, questions are catered to specific plants near the student's location. Therefore, items are adaptive to the current stimuli that a student might be encountering.
TAO	E-items	N/A	K-12/Higher Ed	This platform is open source and allows users to build, deliver, and share assessments online. This platform enables both e-item and adaptive testing functionalities.

Part 2: Formative Assessment Potential of Software Presented in this Paper

Software	Formative Assessment Potential	Limitations	Availability	Sources
Mahara	Can be used for formative by teacher adding feedback directly to student entries as the student progresses through coursework	Feedback is dependent on instructor adding it. Therefore, the instructor's pedagogy, feedback type, and frequency of feedback are variable.	Open-Source	(Deeley, 2017; Ghoneim et al., 2017; https://mahara.org/)
e-scape	Intended for formative assessment, students are able to automatically incorporate their work in real-time to their portfolio	Teacher training processes have proved difficulty and still need refining. This is because teachers have a hard time changing their pedagogy.	Restricted Access	(Kimbell 2012; Stables & Lawler; 2011)
Moodle	N/A	Not specifically built for formative assessment, it is up to the instructor use elements of the LMS for formative purposes.	Open-Source	(Deeley 2017; Ghoneim, 2017; https://moodle.org/)
Canvas	N/A	Not specifically built for formative assessment, it is up to the instructor use elements of the LMS for formative purposes.	Associated Costs	https://www.instructure.com/canvas/en-gb
Blackboard	N/A	Not specifically built for formative assessment, it is up to the instructor use elements of the LMS for formative purposes.	Associated Costs	https://www.blackboard.com/blackboard-learn/index.html
Digital Dashboard for Learning (DDL)	Designed for formative assessment	Designed for a specific institutions usage.	Available to Carnegie Melon students, faculty, & staff	(Bajzek et al., 2007)
AKOVIA	Emphasis on feedback in the software can enable formative assessment applications	Software was not designed specifically for formative assessment	Associated Costs	(Ifenthaler, 2014; Bhagat and Spector, 2017; Spector et al., 2016)

Software	Formative Assessment Potential	Limitations	Availability	Sources
Eduminer	Designed for formative assessment	Students reported confusion over collective cognition circles. Further research needs to be done on understanding best-practice in visualization.	Associated Costs	(Hsu et al., 2011)
INQ-ITS	Designed for formative assessment	Text-replay tagging of log data and educational data-mining takes significant time and resources.	Associated Costs	(Gobert, Sao Pedro, Raziuddin, & Baker, 2013)
MetaTutor	Designed for formative assessment of self-regulatory feedback	So far, research has shown promising results of scaffolding some aspects of SRL, but not all.	Restricted Access	(Azavedo et al, 2009)
Furhat Robots	Designed for formative assessment	No empirical results yet	Associated Costs	(Moubayed & Taylor, 2019)
Physics Playground	Designed for formative assessment applications	Research is still ongoing regarding physics playground, it is currently funded by NSF and IES grants.	Restricted Access	(Shute, Ventura, & Kim, 2013; Kim & Shute, 2015).
Zondle	Can be used for formative purposes	Website is currently down.	Open Source	(Lot & Salleh, 2016)
Tri-Q-SP	Designed for formative assessment	Currently limited to computer programming knowledge assessment.	Restricted Access	(Hooshyar et al., 2016)
Socrative	Can be used for formative purposes	Requires a feedback-centered pedagogy for formative assessment to occur.	Open Source	(Coca & Slisko, 2013)
Mistral	Designed for formative assessment	Teachers must input grades for constructed response items, delaying feedback.	Restricted Access	(Oppl et al., 2017; Salcedo et al., 2005)
Siette	Designed for formative assessment	Location information of device is needed, which can incur privacy issues.	Restricted Access	(Conejo et al., 2016)
TAO	Can be used for formative purposes	Software development skills may be needed to customize the platform.	Open-Source	(Open Assessment Technologies, 2017; https://www.taotesting.com/)

APPENDIX C.

Assessment of Transversal Skills Using ePortfolios

	21st Century skills (ATCS)	Description - Indicators
Ways of thinking	Creativity / Innovation	• To be able to create new and worthwhile ideas
		• To be able to work creatively with other
		• To be able to implement innovations
		• To be able to elaborate, refine and analyze one's own ideas
	Critical thinking / Problem solving / Decision making	• To express thoughts and ideas effectively, using any type of communications (oral, written, artifact, technology etc.) in several contexts and for a range of purposes
		• To be able to listen to other's thoughts and ideas
		• To share opinions and provide feedback
	Learning to Lean / Metacognition	• To use several types of reasoning in appropriate situations
		• To use systematic thinking by considering the interaction of the small parts of the whole problem in order to solve it
		• To make decisions and judgements
		• To critically evaluate online and other resources using
Ways of working	Collaboration	• To interact effectively with others
		• To work effectively in diverse teams
		• To manage group projects
		• To guide and lead others (having a respectful behaviour
	Communications	• To be able to communicate in oral or written form in their mother tongue and additional language
		• To be able to read and understand different texts
		• To be able to formulate arguments in a convincing matter
		• To develop skills to use aids (such as notes, schemes, maps etc.)

	21st Century skills (ATCS)	Description - Indicators
Tools for working	ICT / Digital literacy	• To access and evaluate information and communication technology (ICT)
		• To use and manage information online
		• To create media products (i.e. video, audio etc.)
		• To apply technology effectively
	Information literacy	• To access and evaluate information
		• To use and manage information
		• To be able to search, collect, organise and process information
		• To be able to use technology as a tool to research, organise and collect information
Living in the world	Citizen ship	• To participate in community/neighbourhood activities
		• To be able to display solidarity on issues affecting the local or wider community
	Life and Career	• To adapt to change
		• To be flexible
		• To manage goals and time
		• To work independently
		• To interact effectively with others
		• To work effectively in diverse teams
		• To manage projects
		• To guide and lead others
	Personal and Social responsibility	• To be able to communicate
		• To be able to express one's frustration in a constructive way
		• To be able to maintain a degree of separation between professional and personal life
		• To be able to view and understand different viewpoints
		• To be able to negotiate

(Project EUfolio 2015, p. 16-17)

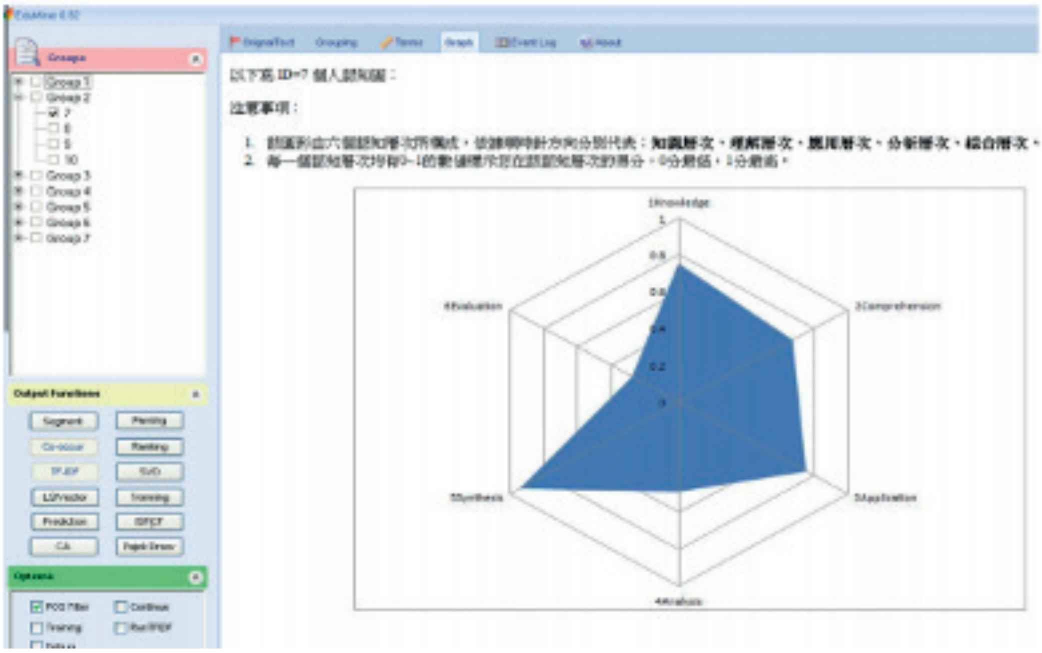
APPENDIX D.

Cognition levels in Eduminer

Cognitions	Definitions	Instances
Knowledge	Basic knowledge mentioned in class	Source of laws and rules
Comprehension	Ability to explain the reason why we need the knowledge	Why laws and rules related to salary are needed?
Application	Ability to apply existing knowledge on specific or new conditions	Able to use the reason of stipulating laws and rules to explain relevant opinion on secret-keeping of salary
Analysis	Ability to classify issues, explain each classification one by one and organise them in a systematic method	Discuss topic of secret-keeping of salary from different aspects
Synthesis	Ability to synthesize different knowledge in organisational way	Conclude a solution for secret-keeping of salary
Evaluation	Ability to propose evaluation and criticism on ideas, answers or methods with personal or existing criteria	Propose reasons to judge the agreement/disagreement of secret-keeping of salary

(Hsu, Chou, & Chang 2011, p. 3434).

APPENDIX E.



(Hsu, Chou, & Chang 2011, p. 3436)

APPENDIX F.

List of Digital Assessment Tools

Animoto	An application which allows students to make videos, either individually or collaboratively, which can then be viewed by the class and the teacher.
Answer Garden	A tool for online brainstorming or polling, educators can use this real time tool to see student feedback on questions.
Ask3	This app for the iPad allows students and teachers to collaborate on lessons both in and outside of the classroom. Questions can be posted to specific classrooms set up in the app, and students can add their thoughts, answers, and thinking to the whiteboard.
AudioNote	A combination of a voice recorder and notepad that captures both audio and notes for student collaboration.
Backchannel Chat	A platform that allows students to discuss what they are learning with each other, in a Twitter-like forum that is moderated and monitored by the teacher.
Biblionasium	A platform which allows teachers to monitor what books students are reading, and to set them reading challenges. Students can also recommend books to each other.
BubbleSheet	An app that allows students to complete assignments and common assessments using an iPhone or iPad Quizzes up to 10 questions are free.
Buncee	A tool for students and teachers to create interactive presentations, shared with the whole class. Teachers can use the presentations to determine a student's content mastery.
Chatzy	A chatroom forum where teachers can monitor students' conversations and guide discussion towards learning outcomes.
ClassFlow	A forum which allows teachers to deliver interactive lessons to students on their devices, and to send customised quizzes to track their progress.
ClassKick	An app which allows teachers to set customised activities for students to complete, which are then uploaded so that feedback can be provided by both the teacher and the other students.
Coggle	A mind mapping tool designed to understand student thinking.
Conceptboard	This software facilitates team collaboration in a visual format – similar to mind mapping, but using visual and textual inputs. Compatible on tablets and PCs, Conceptboard can work from multiple devices.
Crowd Signal	A tool for teachers to create polls and surveys.
Dot Storming	This app is an online interactive whiteboard, where students can add virtual sticky notes to displays, and vote on what they think are the best ideas. Very good for allowing collaborative and consensus-based work.
EdPuzzle	Allows teachers to create custom videos for students to watch, or to add annotations/notes to existing videos. Tracks which students are watching and how many times they watch.
Edulastic	An app for teachers to create quizzes with technology-enhanced items (eg: drag and drop, audio-visual content). Also provides a platform to track student progress and identify areas in which students are lacking.

Five Card Flickr	Designed to foster visual thinking, this tool uses the tag feature from photos in Flickr.
FlipGrid	Teachers provide information/a lesson and students can record brief response videos in order to demonstrate what they have learnt and provide feedback.
ForAllRubrics	This software is free for all teachers and allows you to import, create and score rubrics on your iPad, tablet or smartphone. You can collect data offline with no internet access, compute scores automatically and print or save the rubrics as a PDF or spreadsheet.
Formative Feedback for Learning	An iPad app that is designed to foster and encourage communication between students and teachers. Through a conference setting it uses icons to prompt discussions. Dylan Wiliam, our resident formative assessment expert, says, "Formative Feedback for Learning looks very useful. I can see myself recommending it to others."
GimKit	A tool that allows teachers to administer quizzes to students, who answer in real time on their devices. Students can earn in-app currency in order to "level up" their playing experience.
Google Forms	A Google Drive app that allows you to create documents that students can collaborate on in real time using smartphones, tablets and laptops.
GoSoapBox	A student response system that allows teachers to track responses. Includes a "confusion meter" that students can use to indicate anonymously that they do not understand a topic.
iBrainstorm	An iPad app that allows students to collaborate on projects using a stylus or their finger on screen.
I>Clicker	A device that helps facilitate all student response to polls, questions and other teacher-led discussions.
iLeap Pick a Student	Helps the teacher pick a student from the class, and uses turn-based selection so every student is selected before a student is picked again. Supports multiple classes and has a number of selection options.
InfuseLearning	A platform by which teachers can engage all students on any device, getting valuable formative feedback along the way.
iThoughts	This mind mapping app for Apple's iFamily® is a great visual tool to help you brainstorm ideas, plan projects and themes, and set goals. As students discuss ideas and possible answers to discussions, educators can visually see the path that their thinking takes, helping to understand how students are learning.
Kahoot	A game-based platform that allows teachers to create and administer quizzes that students answer in real time on a mobile device.
Lesson Up	Allows teachers to easily design interactive online lessons, and also to administer quizzes.
Lino	A virtual corkboard of sticky-notes so students can provide questions or comments on their learning. These can be used like exit tickets or during the course of a lesson.
Mentimeter	Allows you to use mobile phones or tablets to vote on any question a teacher asks, increasing student engagement.

Micropoll	A simple tool for designing short polls. Polls can be easily embedded into a website.
Microsoft Teams	An online forum that allows students to work collaboratively on group assignments. Especially useful when students want to work but cannot be physically in the same space, as there is support for video chatting.
Naiku	A tool for teachers to create and administer quizzes. Provides real time updates on student progress.
NearPod	Allows teachers to create their own custom interactive lessons. Teachers can also choose from over 7,000 existing lessons that have been developed by content experts.
Padlet	Provides an essentially blank canvas for students to create and design collaborative projects. Great for brainstorming.
Pear Deck	An app that allows teachers to create slideshows, with interactive elements that students can engage with on their own devices. Also available as a plug in for Google Slides.
Peergrade	The teacher sets up an assignment and a rubric. Students upload their own work and are then given a classmate's work (anonymised) to critique.
Piazza	An online forum where students can ask questions related to the curriculum and other students can provide answers and incite discussion. Teachers can also guide the direction of learning with prompts. This program is designed to mimic the style of teaching in third level institutions.
Pick Me!	An easy to use app for the iPod, iPad and iPhone that facilitates random student selection. Can be organized by class for convenience.
PlayPosit	An interactive video platform that allows teachers to add assessment features to ensure students are actively engaging with content.
Plickers	This allows teachers to administer a quiz with only one device. Students are given printed "Plickers" which have a unique QR code on them. Students use these Plickers to select their answers, which are read by the teacher's device.
Poll Daddy	Quick and easy way to create online polls, quizzes and questions. Students can use smartphones, tablets, and computers to provide their answers and information can be culled for reports.
Poll Everywhere	Teachers can create a feedback poll or ask questions. Students respond in various ways and teachers see the results in real-time. As Steven indicates, with open-ended questions you can capture data and spin up tag clouds to aggregate response. You should note that Poll Everywhere has a limit to the number of users. Mentimeter (listed above) does not which makes it a little more functional.
Poll Maker	A simple online tool for creating polls. This platform allows for questions with more than one answer.
ProProfs	A piece of software that allows teachers to create and administer quizzes and games, and gives students a platform to work collaboratively on projects.

Rabble Browser	An iPad app that allows a leader to facilitate a collaborative browsing experience.
Quia	Allows teachers to create and administer their own quizzes, games and surveys, as well as giving access to open source quizzes from other users.
QuickVoice Recorder	Another free voice recording app for the iPhone or iPad that allows you to record classes, discussions or other project audio files. You can sync your recordings to your computer easily for use in presentations.
Quizalize	Allows teachers to create quizzes and games which are visually appealing to students, and also provides information as to the areas where students are underperforming. The app then allows further quizzes to be targeted based on ability level/previous performance.
Quizizz	Similar to other apps, this allows teachers to administer quizzes to students, which can be completed either in class or at home. Teachers receive detailed feedback on student performance. Teachers can make their own quizzes or choose from those already on the platform.
Quizlet	Teachers can use this platform to crat flashcards to aid student learning, and also administer quizzes to students.
Random Name/ Wordpicker	This tool allows the teacher to input a class list and facilitates random name picking. You can also add a list of keywords and use the tool to have the class prompt a student to guess the word by providing definitions.
SeeSaw	Students use the app to create digital portfolios of what they have learnt, while can be in the form of text/videos etc. Parents can also be granted access to these portfolios to gain a better understanding of their child's academic progress.
Slido	A slideshow tool where students can ask questions, which get voted on by others so that the teacher knows which questions most students are thinking of. Also allows teachers to administer quizzes.
SmartResponse VE (for SMARTboards)	A cloud-based software that enables students to respond to planned and spontaneous questions and take quizzes using any of their favorite Internet-enabled devices, from anywhere.
Socrative	Engaging exercises and games that engage students using smartphones, laptops and tablets.
Spiral	A wide-ranging app that allows teachers to set assignments, track student progress, and allows students to work collaboratively on projects using a range of stimuli, eg text, video, audio. Also allows students to build up an educational portfolio.
Tagxedo	A tag cloud generator that allows you to examine student consensus and facilitate dialogue.
The Answer Pad	Provides electronic answer sheets to quizzes so that students can take them on their own devices. Provides instant feedback on student performance to the teacher.
The Queue	A chat app that allows teachers to incite and moderate discussion, and also to set assignments which students can post text or videos responses to.

ThinkBinder	A collaboration tool that allows students to ask questions and discuss topics in a group, share, create and work together on almost any project.
TodaysMeet	This online collaboration tool allows educators to create a "room" in which students can share ideas, answers and thoughts to lectures and lessons. Educators can view student responses in real time for evidence of learning.
Triventy	A quiz platform that allows teachers to administer quizzes, which students use their own devices to answer. Results are displayed on the classroom computer.
Typeform	An app that allows teachers to administer polls to students.
Verso	A platform that allows teachers to set assignments and give lessons to students, which provides teachers with detailed feedback to structure subsequent learning.
VoiceThread	Allows you to create and share conversations on documents, diagrams, videos, pictures or almost anything. This facilitates collaborative student discussion and work.
Vocaroo	A free service that allows users to create audio recordings without the need for software. You can easily embed the recording into slide shows, presentations, or websites. Great for collaborative group work and presentations.
Voxer	A voice recording app. Students can use this app to record ideas or complete assignments verbally. Recordings can be shared with the teacher, parents or other students.
Wordable	A vocab game in which students are given verbal clues to a particular topic and have to guess the topic.
Wordle	Generates tag clouds from any entered text to help aggregate responses and facilitate discussion.
XMind	A mind mapping software for use on computers and laptops.
Yacapaca	An app for marking assignments where student answers are judged by an artificial intelligence system which gives immediate feedback to learners. Teachers can set their own quizzes or access those already in the app.
Yo Teach!	Another app for creating a classroom backchannel so that students can communicate with each other, and with the teacher.
Zoho Survey	A website that allows teachers to administer polls and surveys to students.

(Source: Dyer 2014, 2019; Common Sense Education 2019)

NOTES

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