Analyzing Interactions in Automatic Formative Assessment Activities for Mathematics in Digital Learning Environments

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Abstract: This paper discusses the theme of the analysis of the interactions in a Digital Learning Environment (DLE) to study formative assessment processes. We propose a definition for a Digital Learning Environment based on the concept of a learning ecosystem, and we provide a model to analyze the interactions occurring among the components of a DLE during automatic formative assessment activities for Mathematics. Using the model, we qualitatively analyze two different activities of symbolic computations, carried out by 396 students of grade 8 in different contexts, to identify the interactions through which formative assessment strategies are developed. In the conclusions, we suggest ways to adopt this model for learning analytics, to analyze the interactions in large online courses.

1 INTRODUCTION

According to Wilson (1995), a learning environment is "*a place where learning is fostered and supported*". It includes at least two elements: the learner, and a "*setting or space wherein the learner acts, using tools and devices, collecting and interpreting information, interacting perhaps with others, etc*." (Wilson, 1995). The traditional learning environment that everyone knows is the classroom, where the teacher teaches, students learn, individually or with their peers, using tools such as paper, pen, and a blackboard. The diffusion of technology transformed this traditional learning environment by adding digital tools, as tablets or computers, and the IWB (Interactive White Board). Besides equipping physical places with technologies, the technological revolution brought to the creation of a new learning environment, situated in a non-physical dimension: that of the Internet, accessible from everywhere via computers, tablets, or even smartphones. This is the essence of the "Digital Learning Environment" (DLE); besides the learner and a setting, which can be virtual, a device is needed to access the activities.

Today, due to the COVID-19 pandemic, online platforms have known increasing popularity, supporting smart-schooling, and class attendance from home (Giovannella et al., 2020). They have been invaluable to permit students from all social and cultural backgrounds to carry on their education. The interest in DLEs in the research has increased accordingly, making different theories and models come to life (Fissore et al., 2020).

This paper intends to contribute to the discussion about the essence of DLEs providing a definition and a model for analyzing learning interactions in a DLE. The theoretical framework includes a review of various studies on DLEs and a proposal of definition. Particular characteristics of DLEs for Mathematics are considered, based on theories on formative assessment and Automatic Formative Assessment (AFA). Then, a model for the interactions among the members of a DLE is proposed, to highlight the interactions during AFA activities. In the following sections, an AFA activity for grade 8 Mathematics in a classroom context is presented. Some episodes involving students working on this activity are analyzed using our models, to show what kinds of interactions can support formative assessment strategies. The conclusions suggest how these findings could be used in learning analytics research.

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2 THEORETICAL FRAMEWORK

2.1 Definition of Digital Learning Environment

The concept of "Digital Learning Environment" has a long history, and it has known several developments and many different names over the years: Virtual Learning Environments (Wilson, 1996), Online Learning Environments (Khan, 1997), Computerized Learning Environments (Abdelraheem, 2003), and Digital Learning Environments (Suhonen, 2005). The common factor among all these definitions is the use of the Internet and its tools to provide an environment where learning is supported, generally represented by a Learning Management System (LMS). An LMS, according to Watson and Watson (2007), is "*the infrastructure that delivers and manages instructional content, identifies and assesses individual and organizational learning or training goals, tracks the progress towards meeting those goals, and collects and presents data for supervising the learning process of an organization as a whole*." While similar environments are mainly used to support online educational processes, we are convinced and have proof of the fact that web-based platforms can also be successfully adopted in classroom-based settings: in our conception, DLEs should not only be confined to distance education (Barana, Marchisio, & Miori, 2019; Barana & Marchisio, 2020; Borba et al., 2018).

More recently, many authors have developed an interest in conceptualizing digital learning environments as ecosystems, borrowing the term from ecology (García-Holgado & García-Peñalvo, 2018; Giovannella et al., 2020; Guetl & Chang, 2008; Uden et al., 2007; Väljataga et al., 2020). According to Encyclopaedia Britannica (www.britannica.com), an ecosystem is *"a complex of living organisms, their physical environment, and all their interrelationships in a particular unit of space."* The natural ecosystem, constituted by a biological community in a physical environment, is the fundamental example; however, this definition can be applied to any domain, even artificial environments, by specifying the living community, environment, and space unit.

There are several models of learning or e-learning ecosystems in the literature, which vary for the components included based on the theoretical assumptions considered. In general, they contemplate individuals, computer-based agents, communities, and organizations in a network of relations and exchanges of data that supports the co-evolutions and adaptations of the components themselves (Guetl & Chang, 2008). Following this trend, in this thesis, we chose to use the term "Digital Learning Environment" to indicate a learning ecosystem in which teaching, learning, and the development of competence are fostered in classroom-based, online or blended settings. It is composed of a human component, a technological component, and the interrelations between the two. The human component consists of one or more learning communities whose members can be: teachers or tutors, students or learners, and their peers, the administrators of the online environment. The technological component includes:

- A Learning Management System, together with software, other tools, and integrations which accomplish specific purposes of learning (such as web-conference tools, assessment tools, sector-specific software, and many others);
- Activities and resources, static or interactive, which can be used in synchronous or asynchronous modality;
- Technological devices through which the learning community has access to the online environment (such as smartphones, computers, tablets, IWB);
- Systems and tools for collecting and recording data and tracking the community's activities related to learning (such as sensors, eye-trackers, video cameras.

The interrelations between the two components can include the interactions and learning processes activated within the community and through the use of the technologies as well as pedagogies and methodologies through which the learning environment is designed.

Independently of the fact that the DLSs are based on a web-based platform, teaching and learning can occur in one of the following modalities:

- Face to face, in the classroom or a computer lab, with students working autonomously or in groups through digital devices, or solving tasks displayed on the Interactive White Board with paper and pen or other tools;
- Entirely online, using the DLE as the only learning environment in online courses or MOOCs;
- In a blended approach, using online activities to integrate classroom work, such as asking students to complete them as homework.

These three modalities can be adapted to different situations, grades, aims, and needs. For example, the face-to-face modality can be suitable with students of the lowest grades and in scholastic situations where the classroom work is predominant. The blended approach can offer useful support to the face-to-face lessons at secondary school or university (Marchisio et al., 2020). Online courses are generally used for training and professional courses, university courses, or learning in sparse communities, where face-to-face meetings are difficult to organize (Abdelraheem, 2003; Marchisio et al., 2020).

In this conceptualization, the DLE is not limited to technological artifacts, even if they play a crucial role. The learning community takes a prominent place: it can include, according to the kind of DLE, students and peers, teachers and tutors (who are facilitators of learning activities), designers of educational materials, and administrators of the digital environment. The use of these technologies, such as web-based platforms, assessment tools, and other systems such as sensors or eye-trackers, allows for collecting, recording, and using learning data. These data can be elaborated within the DLE to provide information useful to make decisions and take action. In the following paragraphs, we will explain how these data can be used to improve learning, teaching, and the development of competences.

2.2 Formative Assessment

Formative assessment is one of the key principles which, according to the majority of scholars, should be included in the design of a learning environment, being it physical or virtual (Barana & Marchisio, 2016, Barana, Fissore, & Marchisio, 2020; Gagatsis et al., 2019). In this study, we refer to Black and Wiliam's definition and framework of formative assessment (Black & Wiliam, 2009). According to them, "*a practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited*". They identified three agents that are principally activated during formative practices: the teacher, the student, and peers. Moreover, they theorized five key strategies enacted by the three agents during the three different processes of instruction:

- KS1: clarifying and sharing learning intentions and criteria for success;
- KS2: engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding;
- KS3: providing feedback that moves learners forward;
- KS4: activating students as instructional resources; and
- KS5: activating students as the owners of their own learning.

2.3 DLEs for Mathematics

In this paper, we consider particular DLEs for working with Mathematics through suitable technologies and methodologies. The LMS that we use is based on a Moodle platform and it is integrated with an Advanced Computing Environment (ACE), which is a system for doing Mathematics through symbolic computations, geometric visualization, and embedding of interactive components (Barana, Brancaccio, Conte, et al., 2019), and with an Automatic Assessment System based on the ACE engine. In particular, we chose Maple ACE and Moebius AAS. Through this system, we create interactive activities for Mathematics based on problem solving and Automatic Formative Assessment (AFA), which are the main methodologies used in the DLE, and that we have better defined and characterized in previous works (Barana, Conte, et al., 2018; Fissore et al., 2020). In detail, the characteristics of the Mathematics activities that we propose are the following:

- Availability of the activities for a self-paced use, allowing multiple attempts;
- Algorithm-based questions and answers, so that at each attempt different numbers, formulas, graphs, and texts are displayed, computed on the base of random parameters;
- Open mathematical answers, accepted for its Mathematical equivalence to the correct one;
- Immediate feedback, returned when the student is still focused on the task;
- Interactive feedback, which provides a sample of a correct solving process for the task, which students can follow step-by-step;
- Contextualization in real-life or other relevant contexts.

2.4 Modelling Interactions in a Digital Learning Environment

The technological apparatus of a DLE, particularly when the LMS is integrated with tools for automatic assessment, has a mediating role in the learning processes. We can identify the following functions through which it can support the learning activities (Barana, Conte, Fissore, et al., 2019):

- **Creating and Managing:** supporting the design, creation, editing, and managing of resources (e.g., interactive files, theoretical lessons, glossaries, videos), activities (e.g., tests, chats for synchronous discussions, forums for asynchronous discussions, questionnaires, submission of tasks) and more generally of the learning environment by teachers, but also by students or peers;
- **Delivering and Displaying:** making the materials and activities available to the users;
- **Collecting:** collecting all the quantitative and qualitative data concerning the actions of the students (such as movements and dialogues), the use of the materials (for example, if a resource has been viewed or not, how many times and how long), and the participation in the activities (such as given answers, forum interventions, number of tasks delivered, number of times a test has been performed, evaluations achieved);
- **Analyzing and Elaborating:** analyzing and elaborating all the data collected through the technologies related to teaching, learning, and the development of competences;
- **Providing Feedback:** giving the students feedback on the activity carried out and providing teachers, as well as students, with the elaboration of learning data.

To schematize these functions, we propose the diagram shown in Figure 1. The external cycle represents the five functions; the black dashed arrows represent how data are exchanged within the DLE through automatic processes. The technologies of a DLE, to accomplish one function, uses the data or the outputs resulting from the previous one: the learning materials, created through the LMS or other sector-specific software through the "creating and managing function", are displayed via devices through the "delivering and displaying function". Information about the students' activities is collected by the LMS, other software, or tools through the "collecting function" and it is analyzed by these systems, which may use mathematical engines, learning analytics techniques, algorithms of machine learning, or artificial intelligence, through the "analyzing and elaborating" function. The results of the analysis are feedback in the sense of Hattie's definition (i.e., *information provided by an agent regarding aspects of one's performance or understanding*) (Hattie & Timperley, 2007). They can be returned to students and teachers through the "providing feedback" function, and they can be used to create new activities or edit the existing ones. This circle represents a perfect adaptive system from the technological perspective (Di Caro et al., 2018).

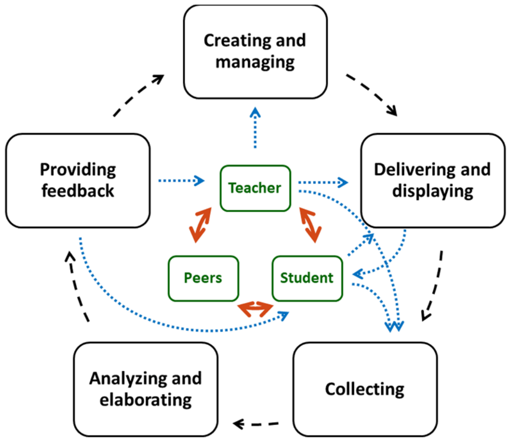

Figure 1: Diagram of the interactions among the components of a DLE through the functions of the technology.

In a human-centered approach, at the center of the DLE, there is the learning community, composed of students, teachers, and peers (who are the agents in the Black and Wiliam's theory of formative assessment): they can interact with the DLE through its functions receiving and sending information. The blue dotted arrows represent the interactions between the community and the digital systems that occur through human actions, such as reading, receiving, inserting, providing, digiting. For example, the teacher, or designer, or tutor can create the digital activities through the "creating and managing" functions of the DLE; tasks are displayed ("delivering and displaying" function) and received, seen, or read by the students through some device. The students, individually or with their peers, can insert their answers or work. The technology collects them through the "collecting" function. The system analyzes the students' answers and provides feedback ("providing feedback" function) returned to the student. Simultaneously, the information about the students' activity is returned to the teacher through the "providing feedback" function; the teacher can use it to edit the existing task or create new ones. The continuous double-ended orange arrows represent the interactions among students, teachers, and peers, which in classroom-based settings can be verbal while in online settings can be mediated by the technology. This model allows us to identify some outcomes that the adoption of a similar DLE with AFA, through the functions previously shown, makes it possible to achieve:

- **To Create an Interactive Learning Environment:** all the materials for learning and assessment can be collected in a single environment and be accessible at any time. They can activate the students who can be engaged in the navigation of the learning path, solve the tasks and receive feedback;
- **To Support Collaborative Learning**, through specific activities, delivered to groups of students, which enhance the communication and sharing of materials, ideas, understanding;
- **To Promote Formative Assessment**, by offering immediate feedback to students about their results, their knowledge and skills acquired, and their learning level. Feedback can also be returned to the teachers on the students' results and their activities, supporting decision-making.

The identification and classification of a DLE's functions can allow us to identify the interactions in a DLE, to analyze their nature and the contribution of technology that mediates them. In this sense, the diagram in Figure 1 is a proposal of schematization of the interactions among the components of a DLE. It helps us understand how data are shared among the components of a DLE, elaborated, and used. The information gained is useful from a learning analytics perspective since it allows us to identify the role of data during the learning processes. Moreover, this model helps us identify and separate the functions and outcomes of technology in learning processes, which is necessary to have a clear frame and find causal connections, especially when analyzing large data quantities.

3 METHODOLOGY

In this study, we aim at showing how the diagram of the interactions among the components of a DLE can be used to model learning processes, and in particular to understand how formative assessment can be enacted in a DLE for Mathematics. To this purpose, we analyzed an AFA activity concerning symbolic computations for students of grade 8, experimented in a classroom-based context. The task (Figure 2) asks students to formulate, represent, and compare different formulas derived from a geometrical shape. The shape is non-standard and students are asked to find as many formulas as they can to express its area.

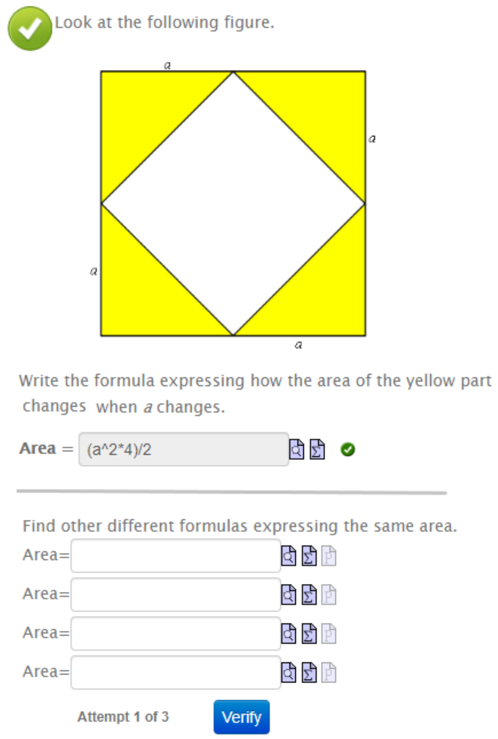

Figure 2: Part of the activity on symbolic computations.

In the first section, they have 3 attempts to write a formula for the area. In the second one, they are asked to fill other 4 response areas with different formulas expressing the same area. The intent is to make them explore the symbolic manipulation of an algebraic formulas through the geometric context, to confer a more concrete meaning to the technical operations. In the last part, students have to substitute the variable with a given value and compute the area. This activity was tested in a classroom-based setting in an experiment involving 97 students of 4 different classes of grade 8. In the classrooms there were the teacher and 2 researchers of our research group; the students worked in pairs using a computer or a tablet. The work and discussions of some pairs of students were recorded through a video camera. Data from the platform were analyzed through the diagram of the interactions in a DLE presented in the previous section; the video recordings were analyzed as well.

4 RESULTS

We analyzed the videos realized during the activity in the classrooms, to understand how the interactions among the components of the DLE changed and how the formative assessment strategies took place during a group activity. We choose some episodes which we considered most significant. Here, the learning community includes a class of students and a teacher; the digital activities are created in a LMS integrated with an AAS, and the devices used to access them are an IWB and computers.

The first episode involves the teacher who illustrates the task to the class. The teacher was at the IWB and was pointing at the figure shown.

TEACHER: Look at this figure. Write the formula which expresses how the area of this figure varies when *a* varies. That is, [pointing at one of the sizes of the yellow triangles] how long is this side?
STUDENTS: *a*
TEACHER: Well, you have to calculate the area of this figure using *a*. Those sides measure *a*. What does it mean? What is *a*?
STUDENTS: A variable.

In this excerpt, the teacher introduced the activity and explained to the students what their task was. The explanation took the form of a dialogue, as he engaged the students with questions to make sure that they were following the discourse. The teacher exploited the "delivering and displaying" function of the technology to display the task and, in particular, the figure; then, she interacted with the students. If we consider the diagram, we are in the right part; the parts of the model involved in this excerpt are shown in yellow in Figure 3. While explaining the tasks, she developed the KS1 "clarifying and sharing learning intentions and criteria for success". The KS2 "engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding" was accomplished during the phase of the creation of this activity by the researchers (that we can include in the "Teacher" subject of our analysis) through the "creating and managing" function of the technologies; it is also activated when the teacher asks questions to the class aimed at making students reason in the correct direction.

The second episode involves Marco (M) and Giulia (G), two students of medium level who were trying to solve the first part of the activity, working together. In the beginning, they observed the figure displayed on the screen of their computer and tried to understand the task.

M: We have to compute the area, but we don't have any data!
G: But we have a.
M: But a is not a number!
G: Ok, but we can compute the area using a.
M: Teacher, how can we compute the area without numbers? Can we use a?
T: Yes, it is like a generic number.
G: We have to write a formula using a, isn't it?
T: That's right.

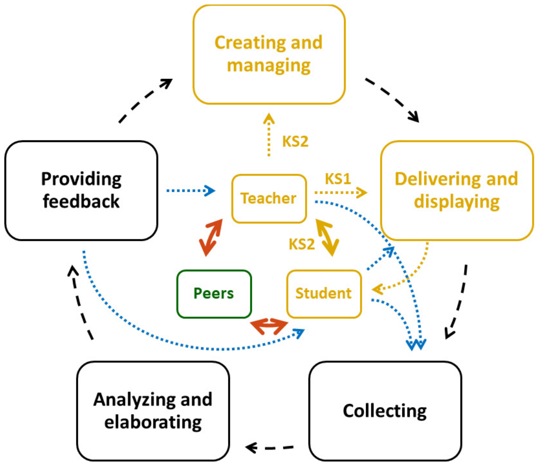

Figure 3: Diagram of the formative assessment strategies enacted in the first episode of activity 2 through the interactions in the DLE.

The two students started reasoning together on the figure trying a way to compute the area. After about 15 minutes, they came up with a quite complex formula, built subtracting the area of the inner white square to that of the external square. They used the Pythagorean theorem to compute the length of the white square's side. They inserted the formula in the response area and the system returned a green tick with positive feedback. They passed to the following part, which asked them to find other 4 formulas for the same area. For the first two formulas, they reasoned algebraically, manipulating the original formula. For the other two, they reasoned geometrically, developing new ways to compute the area. The peer discussion allowed them to correct mistakes before entering the formulas in the response areas, so their answers were marked as correct at their first attempt.

In this episode, the students look at the task displayed on the screen through the "delivering and displaying" function, then interact among them discussing the task. They also interact with the teacher asking questions about their doubts. Then they insert their answers in the system, which collects them through the "collecting" function, analyzes them, and returns feedback. They repeat the same cycle several times. The students activate KS4 "activating students as instructional resources" when discussing in pair. KS5 "activating students as the owners of their own learning" is enacted when they insert their answers in the AAS, and KS3 is developed when they receive feedback from the AAS, but also by the teacher. The yellow parts in Figure 11 schematize the interactions that occurred in this episode and the formative assessment strategies developed.

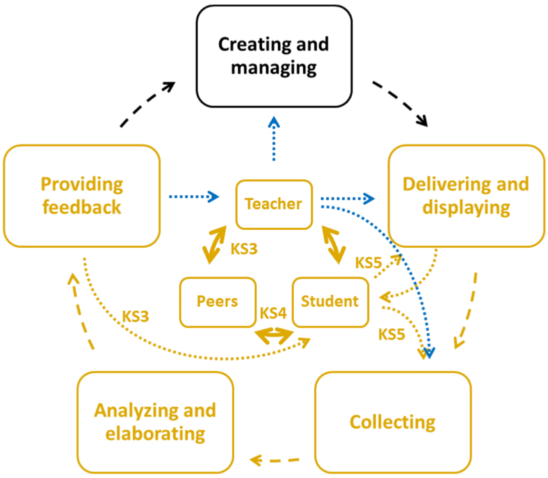

Figure 4: Diagram of the formative assessment strategies enacted in the second episode of activity 2 through the interactions in the DLE.

5 DISCUSSION AND CONCLUSIONS

The episode presented in the previous section helps clarify how the interactions among the members of a DLE occur during AFA Mathematics activities in a classroom-based setting. The main feedback is provided by the social interactions within the learning community and especially among peers; in fact, Marco and Giulia reasoned more time on the tasks and they tended to answer correctly at the first attempt. In other cases, we could observe that the computerized interactive feedback has a key role in providing a feedback and in engaging the students. The design of the activity enables KS3 and KS5, which keep students engaged with the task until its full comprehension, demonstrated by the repeated attempts. Similar activities can lead to a deep understanding of fundamental Mathematics concepts; the technologies and methodologies used – in particular, an AAS based on a mathematical engine and AFA – supported the design and implementation of interesting activities for the development of mathematical competences.

The diagram used for the analyses helped clarify what functions of the technologies and through which kinds of interactions the formative assessment strategies are elicited in different situations. In particular, we can see that all the Black and Wiliam's strategies of formative assessment can be enacted through AFA activities, and all of them are identified and located along the arrows of our diagram, that is during the interactions among the human components of the DLE or between human and technological components. Thus, we can include a fourth agent in Black and Wiliam's framework: in the DLEs that we consider, the technology is also an agent of the formative assessment strategies, especially for providing feedback and engaging students (KS3 and KS5).

Through the analysis of the interactions among the members of these DLEs, we can also point out that the three outcomes mentioned in our framework are achieved. In particular: the analyzed learning environments are interactive, since students are actively engaged in the activities, they are stimulated to reflect and have the opportunity to achieve important understanding; the formative assessment is promoted by the activities, as all the 5 key strategies are enacted; collaboration among students is supported, especially in the classroom-based settings where students are asked to work together.

The diagram used in the analyses allows us to conceptualize the DLE as an ecosystem: we can see that the human and technological components are strictly related, and the interrelations among them cause the development of the learning community, in terms of learning processes, knowledge, and competences gained; but also an improvement of the learning activities on the base of the results obtained.

The analyses conducted in this study have a qualitative nature: they are aimed at showing how the schema of the interactions among the components of a DLE can be used to model formative assessment practices, especially when the AFA is adopted. However, they can be a starting point for the research about learning analytics for formative assessment. This model can be used to create a taxonomy of the interactions occurring in a DLE, identifying which support formative assessment or other learning processes. Since interactions in a DLE can be described using log data, this model can also be used with extensive learning data to identify the formative assessment strategies or other learning processes occurring in large online courses. This would allow us to identify the learning activities which are better related to the development of knowledge, abilities, and competences or the elicitation of interactions and engagement. The results of similar analyses could help adjust and improve the digital materials in online courses. Using other technologies and different learning methodologies to build suitable activities, this model of analysis could also be adapted to other disciplines.

REFERENCES

Abdelraheem, A. Y., 2003. Computerized Learning Environments: Problems, Design Challenges and Future Promises. *The Journal of Interactive Online Learning*, *2*(2), 1–9.

Barana, A., Brancaccio, A., Conte, A., Fissore, C., Floris, F., Marchisio, M., & Pardini, C., 2019. The Role of an Advanced Computing Environment in Teaching and Learning Mathematics through Problem Posing and Solving. In *Proceedings of the 15th International Scientific Conference ELearning and Software for Education*, *2, 11-18*.

Barana, A., Conte, A., Fioravera, M., Marchisio, M., & Rabellino, S., 2018. A Model of Formative Automatic Assessment and Interactive Feedback for STEM. In *Proceedings of 2018 IEEE 42nd Annual Computer Software and Applications Conference (COMPSAC)*, 1016–1025.

Barana, A., Conte, A., Fissore, C., Marchisio, M., & Rabellino, S., 2019. Learning Analytics to improve Formative Assessment strategies. *Journal of E-Learning and Knowledge Society*, *15*(3), 75–88.

Barana, A., Fissore, C., & Marchisio, M., 2020. From Standardized Assessment to Automatic Formative Assessment for Adaptive Teaching. In *Proceedings of the 12th International Conference on Computer Supported Education*, *1*, 285–296.

Barana, A., & Marchisio, M. (2016). From digital mate training experience to alternating school work activities. *Mondo Digitale, 15*(64), 63–82.

Barana, A., & Marchisio, M., 2020. An interactive learning environment to empower engagement in Mathematics. *Interaction Design and Architecture(s) Journal - IxD&A, 45*, 302–321.

Barana, A., Marchisio, M., & Miori, R., 2019. MATE-BOOSTER: Design of an e-Learning Course to Boost Mathematical Competence. In *Proceedings of the 11th International Conference on Computer Supported Education (CSEDU 2019)*, *1*, 280–291.

Black, P., & Wiliam, D., 2009. Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, *21*(1), 5–31.

Borba, M. C., Chiari, A. S. de S., & de Almeida, H. R. F. L., 2018. Interactions in virtual learning environments: New roles for digital technology. *Educational Studies in Mathematics*, *98*(3), 269–286.

Di Caro, L., Rabellino, S., Fioravera, M., & Marchisio, M., 2018. A model for enriching automatic assessment resources with free-text annotations. In *Proceedings of the 15th International Conference on Cognition and Exploratory Learning in the Digital Age*, 186–194.

Fissore, C., Marchisio, M., & Rabellino, S., 2020. Secondary school teacher support and training for online teaching during the covid-19 pandemic. In *European Distance and E-Learning Network (EDEN) Proceedings*, 311–320.

Gagatsis, A., Michael-Chrysanthou, P., Christodoulou, T., Iliada, E., Bolondi, G., Vanini, I., Ferretti, F., & Sbaragli, S., 2019. Formative assessment in the teaching and learning of mathematics: Teachers' and students' beliefs about mathematical error. *Scientia Paedagogica Experimentalis*, *56*(2), 145–180.

García-Holgado, A., & García-Peñalvo, F. J., 2018. Human Interaction in Learning Ecosystems Based on Open Source Solutions. In P. Zaphiris & A. Ioannou (Eds.), *Learning and Collaboration Technologies. Design, Development and Technological Innovation. LCT 2018* (Vol. 10924, pp. 218–232). Springer.

Giovannella, C., Passarelli, M., & Persico, D., 2020. The Effects of the Covid-19 Pandemic on Italian Learning Ecosystems: The School Teachers' Perspective at the steady state. *Interaction Design and Architecture(s) Journal - IxD&A*, *45*, 264–286.

Guetl, C., & Chang, V., 2008. Ecosystem-based Theoretical Models for Learning in Environments of the 21st Century. *International Journal of Emerging Technologies in Learning (IJET)*, *3*(1), 50–60.

Hattie, J., & Timperley, H., 2007. The Power of Feedback. *Review of Educational Research*, *77*(1), 81–112.

Khan, B. H., 1997. Web-Based Instruction: What Is It and Why Is It? In B. H. Khan, *Web-Based Instruction, Educational Technology Publications* (pp. 5–18). Englewood Cliffs.

Marchisio, M., Rabellino, S., & Sacchet, M. (2020). Start@unito as Open Educational Practice in Higher Education. *Journal of E-Learning and Knowledge Society, 16*(4), 46–55.

Marchisio, M., Remogna, S., Roman, F., & Sacchet, M., 2020. Teaching Mathematics in Scientific Bachelor Degrees Using a Blended Approach. In *Proceedings - 2020 IEEE 44th Annual Computers, Software, and Applications Conference, COMPSAC 2020*, 190–195.

Suhonen, J., 2005. *A formative development method for digital learning environments in sparse learning communities*.

Uden, L., Wangsa, I. T., & Damiani, E., 2007. The future of E-learning: E-learning ecosystem. In *Inaugural IEEE International Conference on Digital Ecosystems and Technologies*, 113–117.

Väljataga, T., Poom-Valickis, K., Rumma, K., & Aus, K., 2020. Transforming Higher Education Learning Ecosystem: Teachers' Perspective. *Interaction Design and Architecture(s) Journal - IxD&A*, *46*, 47–69.

Watson, W. R., & Watson, S. L., 2007. An Argument for Clarity: What are Learning Management Systems, What are They Not, and What Should They Become? *TechTrends*, *51*(2), 28–34.

Wilson, B. G., 1995. Metaphors for instruction: Why we talk about learning environments. *Educational Technology*, *35*(5), 25–30.

Wilson, B. G., 1996. *Constructivist learning environments: Case studies in instructional design*. Educational Technology Pubns.