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LEARNING ANALYTICS TO IMPROVE FORMATIVE ASSESSMENT STRATEGIES

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In digital education, learning analytics should support active monitoring and dynamic decision-making during learning processes; they are mainly based on digital assessment, through which it is possible to collect and elaborate data about students' progresses. In this paper we start from Black and Wiliam's theoretical framework on formative assessment, which identified 5 key strategies that 3 agents (student, peers and teacher) pursue when enacting formative practices in a context of traditional learning, and we integrate it in a framework of innovative didactics. In particular, we consider the use of a Digital Learning Environment integrated with an Automatic Assessment System based on the engine of an Advanced Computing Environment to build interactive materials with automatic assessment according to a specific model of formative assessment. In this framework, rooted in activity theory, the Digital Learning Environment plays the role of mediating artifact in the activity of enacting the strategies of formative assessment. Through several

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examples of application of automatic formative assessment in several contexts and modalities, we show how it is possible to use the data gathered by the Digital Learning Environment to improve the enactment of Black and Wiliam's strategies of formative assessment, strengthen and evaluate their action.

1 Introduction

Big data and algorithms are the keywords of modern society: nowadays, even the most traditional workplaces, such as mechanic's or carpenter's workshops, require data analysis expertise to perform market surveys and make decisions about how to manage business (World Economic Forum, 2018). Education is not left out of this panorama: the increasing adoption of learning technologies enables the production of data, which can be used to understand, guide and optimize learning processes. Here the field of learning analytics comes to life. The call of paper of the First Learning Analytics and Knowledge Conference ("LAK 2011" https://tekri.athabascau.ca/analytics/) introduced the definition of learning analytics later adopted by the Society for Learning Analytics Research (SoLAR): "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs". Unlike the general use of statistics to provide evidence of the effectiveness of learning methodologies, learning analytics should support active monitoring and dynamic decision-making during learning processes (de Waal, 2017). The data gathered and elaborated should inform not only teachers and researchers, but also students about their achievements, thus letting them keep control of their learning path.

Learning analytics are based on assessment (Knight & Buckingham Shum, 2017), which is often the main source of data in a digital environment; assessment can be seen both as summative, which is aimed to certify the achievement of knowledge and skills, or formative, that is aimed to support progresses in learning (Black & Wiliam, 1998). Learning analytics are not the mere introduction of algorithms into teaching: it is essential that data collection and analysis are driven by a theoretical framework rooted in pedagogy (Friend Wise & Williamson Schaffer, 2015). The theory has a key role in guiding the researcher in the choice of the variables that should be included in a model, in focusing on some results and drawing relevant conclusions out of large datasets. In this contribution we consider activities of formative assessment in a digital environment. We try to organize existing theories in order to provide a theoretical approach useful to create activities of formative assessment and analyze their results. We start from Black's and Wiliam's theoretical framework of formative assessment, to study the formative assessment strategies and the

subjects involved. We present our model of automatic formative assessment with the technologies used and their functionalities. Then we discuss how to move from formative assessment to LA (experimentation and data collection) and from LA to formative assessment (use of data to implement formative assessment strategies), showing examples.

2 Formative Assessment

Black and Wiliam (2009) wrote one of the most acknowledged definition of formative assessment (FA), conceived for a general context of traditional education: "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". This definition entails not only the collection of evidence, which can be gathered through tasks or questions, but also the interpretation and use of the information gathered in order to act on learning. According to this definition, the mere collection of students' answers without using them to make decisions in order to tailor their learning path is not to be considered formative assessment. The abovementioned definition entails three agents: the teacher, the student, and the peers, who are activated during formative practices. Black and Wiliam (2009) further developed a framework, individuating 3 different processes of instruction, that are:

- establishing where the learners are in their learning;
- establishing where they are going;
- establishing what needs to be done to get them there.
- Moreover, the researchers theorized 5 key strategies, enacted by the three subjects during three different processes of instruction:
- clarifying and sharing learning intentions and criteria for success;
- engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding;
- providing feedback that moves learners forward;
- activating students as instructional resources for one another;
- activating students as the owners of their own learning.

3 Technology Enhanced Formative Assessment

When formative assessment is paired with technologies, applying learning analytics techniques is possible, in order to enhance the potentialities of FA. In this paper, when we talk about "learning technologies" we refer to a Digital Learning Environment (DLE) integrated with an Automatic Assessment System

(AAS) (Barana *et al*., 2015) based on an Advanced Computing Environment (ACE), a powerful system for doing Mathematics (Barana *et al*., 2017b). In such a DLE, collaborative or interactive activities can be alternated with automatic assessment; the ACE engine allows questions to be algorithm-based and to accept open mathematical answers independently of the form in which they are provided. Similar systems are flexible enough to be used in several ways and at different educational levels:

- face to face, with students working autonomously or in groups through digital devices, in the classroom or in a computer lab, or solving tasks displayed on the Interactive White Board with pen and paper, especially with classes of lower grades, such as lower secondary school level;
- in a blended approach, that is using online activities to integrate classroom work, asking students to complete them as homework, with students of secondary school or university;
- completely online, using the DLE as a true e-learning platform in online courses in secondary and higher education, proposing automatic assessment activities to help students keep track of their progresses.

The definition of FA that we have mentioned before can be adapted to consider the contribution of the technologies. Pachler *et al*. (2010) define formative e-assessment as "the use of ICT to support the iterative process of gathering and analyzing information about student learning by teachers as well as learners and of evaluating it in relation to prior achievement and attainment of intended, as well as unintended learning outcomes". We adopt this definition as it highlights the role of ICT as a support for the process of formative assessment, and is open to several modalities of using the technologies (face to face, blended and online).

In the perspective of activity theory (AT) (Engeström *et al*., 1999) – a sociocultural theory aimed to study and interpret actions mediated by instruments through a model visible in Fig. 1 – we can consider the activity where the object is performing formative assessment and where the subjects are, in turn, the students, the teachers and the peers. The strategies of formative assessment individuated by Black and Wiliam are mediating artifacts through which the action is completed. In this framework, the technologies are mediating artifacts as well. The outcome is the improvement in learning and, according to AT, it can be the result of the action carried out by at least two activity systems. Rules, community and division of labor are those that are typical of the environment where the action takes place (a classroom, a DLE), which varies on the basis of the modality of use of the technology (face to face, blended or online). When we consider the activity of enacting one of the key strategies of formative assessment, such as providing feedback that moves the learner forward, the strategy

is the object of the action and the technology used is the mediating artifact. It is useful to analyze the formative assessment activities according to this model, as it helps to distinguish what causes learning. According to the AT, when the interactions between the elements face some contradictions, the systems modify themselves through expansion and this provides learning (Engeström, 2001).

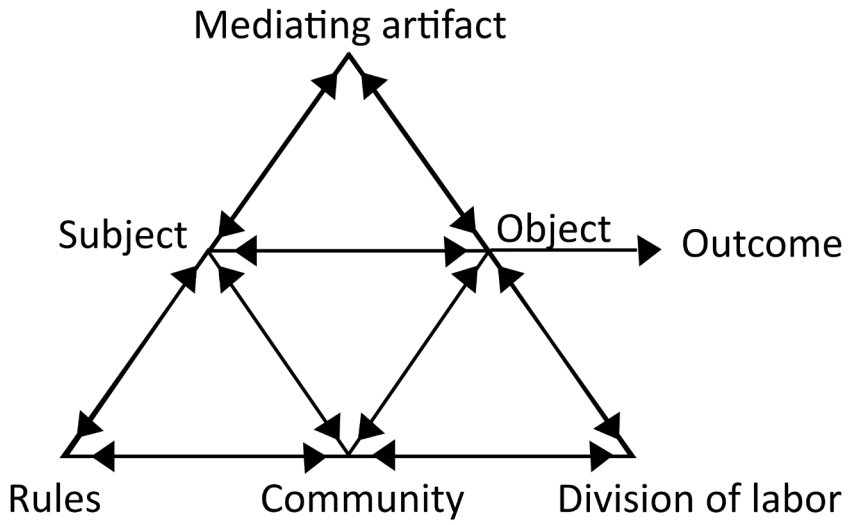

Fig. 1 - One activity system, the unit of analysis of action in activity theory.

From this perspective, a DLE integrated with an AAS has therefore a mediating role in the practice of formative assessment. After years of use of DLEs, we have come to identify as essential the following functions through which a DLE can support the activities:

- creating: to support the creation of materials (interactive files, theoretical lessons, glossaries, videos, etc.) and activities (tests, chats for synchronous discussions, forums for asynchronous discussions, questionnaires, submission of tasks, etc.) by teachers, but also by students or peers;
- delivering: to make the materials and activities available to users;
- collecting: to collect all the quantitative and qualitative data concerning the actions of the students, the use of materials (for example if a material has been viewed or not and how many times) and the participation in the activities (for example number of interventions in a forum, number of tasks delivered, number of times a test has been performed, evaluation achieved, etc.);
- analyzing: to analyze and elaborate the data inserted by the students in the learning activities, possibly using a Mathematical engine to assess

answers formulated in a scientific language;
- providing feedback: to give the student feedback on the activity carried out;
- providing elaboration of data: to provide an elaboration of all these data to the teacher, but also to the students.
- Through these functions it is possible to achieve the following outcomes:
- to create an interactive learning environment;
- to support collaborative learning;
- to share materials in a single environment, making them accessible at any time;
- to offer immediate feedback to students about their results, the knowledge and skills acquired and their level of learning;
- to offer immediate feedback to the teachers on the students' results and the activities they perform.

The identification and classification of the functions of a DLE can allow us to analyze the contribute of the technology during the formative assessment process; it is necessary to separate the functions from the outcomes in order to have a clear frame and find causal connections when analyzing large quantities of data.

Using an AAS based on an ACE, the Department of Mathematics of the University of Turin has designed a model for the creation of activities for the automatic formative assessment of Mathematics (Barana *et al*., 2018c). The model is based on the following principles:

1. availability of the assignments to the students, who can work at their own pace;
2. algorithm-based questions and answers, so that at every attempt the students are expected to repeat solving processes on different values;
3. open-ended answers, going beyond the multiple-choice modality;
4. immediate feedback, provided to the students at a moment that is useful to identify and correct mistakes;
5. contextualization of problems in the real world, to make tasks relevant to students;
6. interactive feedback, which appears when students give the wrong answer to a problem. It has the form of a step-by step guided resolution that interactively shows a possible process for solving the task.

The last one consists in a step-by-step approach to problem solving with automatic assessment, but it is conceptualized in terms of feedback, highlighting the formative function that the sub-questions fulfil for a student who failed the main task. For example, after the first section the student receives a first

feedback in a form of green tick or a red cross depending on whether s/he answered correctly or not; the following sections give interactive feedback about how s/he was supposed to develop his/her reasoning in order to reach the solution. The interactive nature of this feedback and its immediacy prevent students from not processing it, a risk well-known in literature that causes formative feedback to lose all of its powerful effects (Sadler, 1989). Moreover, students are rewarded with partial grading, which improves motivation (Barana *et al*., 2019a). This kind of formative activities are mainly conceived to be individual; however, they can be integrated in a DLE with other interactive resources and used in collaborative situations or coupled with different activities of collective discussion and collaborative work.

4 From Formative Assessment to Learning Analytics

Our research group has used formative assessment activities developed through our model, using these kinds of technologies and their functions several times and in different ways and contexts. As DLE we have mainly adopted Moodle platforms, integrated with Moebius Assessment, an AAS based on the engine of Maple ACE. For example, at lower secondary school level in a face to face modality (Barana *et al.*, 2018a), at lower and upper secondary school level in a blended modality (Barana *et al*., 2017c; Brancaccio *et al*., 2015), in online modality at upper secondary school level (Barana & Marchisio, 2016; Barana *et al*., 2019b) or in a university context (Bruschi *et al*., 2018; Marchisio *et al*., 2019).

Through the "collecting" function of these technologies, it is possible to collect many different types of data about the activities carried out by students: evaluate the use of the DLE (such as number and time of logins), qualitative data concerning the use of materials (such as the completion of activities) and specific quantitative data for each type of activity. Evaluation data, elaborated through the "analyzing" function, is automatically saved in the AAS gradebook, also integrated within the grader report. All these data can provide a description of the activity carried out by the student and the possibility of keeping these data in memory can allow to obtain an overview of the student's learning path over time. These data can be made available to students and teachers through the "providing elaboration of data" function, via different tools: for example, progress bars provide students with visual information about their completed activities, while the grader report allows teachers to see the activities carried out by the students, their progress and thus highlighting the students at risk. Data can be combined and analyzed with various Learning Analytics techniques (such as dashboards, recommender systems, predictive analytics, and alerts/warnings/interventions) in order to address concerns related to a broad range of

teaching and learning areas. These areas include: retention and student success; improvement of learning design, units, courses and teaching practice; the development of personalized learning pathways; and student support (West *et al*., 2018). In order for LA to help improve formative assessment, it is important to refer to an exact pedagogical framework for the interpretation of the data and to be able to use them for future actions. In our case, we used the framework described above for FA with technologies.

5 From Learning Analytics to Formative Assessment

In this section we focus on how the extensive data that can be collected in a DLE can be useful to "go back" to the previously mentioned FA strategies and support their implementation. Taking in account the reference to the LA definition of Solar (2011), we show some examples of collection and analysis of different types of data relating to students and their activities, to support formative assessment strategies and consequently to optimize DLE and learning. The examples described below reflect the theoretical framework of AT in which technologies are the tool that mediates the action of the subject (student, teacher or peers) towards the object (implementing or improving the FA strategy).

Clarifying and sharing learning intentions and criteria for success

For this strategy, the data on the use of materials and interactive activities by the students can be analyzed and related to their assessment data, to evaluate the effectiveness of the materials and activities. In this way, it is possible to improve the teaching materials and increase the internal coherence of the contents of the platform often organized in Learning Objects, that are a collection of content items, practice items, and assessment items that are combined based on a single learning objective. An analysis of this type has been carried out on the Realignment Course in Mathematics of Orient@mente (Barana *et al.*, 2017a), a platform of self-paced open online courses aimed to guide students in the choice of a scientific university program of our University (Barana *et al*., 2018b). The lessons in the course have many activities, such as online readable books; interactive activities of exploration or simulation; pages with theory applications and curiosities; automatically assessed online tests; exercises with their solutions. The evaluation data have been related to the completion data of the various resources (viewed/not viewed) to understand if the student had completed the other activities or used the other resources before trying the test. Our analysis showed that the students who used the activities before the test did better than those who completed the test based only on their knowledge. This shows that the materials made available were effective and consistent with the test. Different results would have been a clue of the need for a redesign of the course contents, to make materials more effective, or the tests more coherent

with the learning activities.

Engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding

For this strategy of formative assessment, it is possible to use the gradebook to view assessment data organized by test, by student, or by question item, and the gradebook statistics. In this way it is possible to analyze indexes such as the discrimination index of the items, the rate of correct answer and the common mistakes made by students. The teacher can identify the topics that are not clear, in order to improve the existing Learning Objects, create new ones or prepare activities in the classroom to clarify the unclear points. An example of this FA strategy was carried out within MATE-BOOSTER, a project conceived to strengthen the mathematical competences of students attending the first year of a technical upper secondary school through an online course (Barana *et al.*, 2019a). The analysis of the learning needs, which preceded the development of an online course, was carried out through an entry test to assess the initial competence and a questionnaire to understand students' motivations. Results of the entry test aggregated by content areas showed the most difficult topics; moreover, the questions with low discrimination indexes identified common misunderstandings and areas for improvement. In light of the results of the entry test and of the questionnaire, researchers and teachers listed the learning outcomes of the course. The design of the teaching materials was made considering the frequent mistakes of the students, emerged both from the entry test and the teachers' experience.

Providing feedback that moves learners forward

To provide more detailed and therefore more effective feedback that moves learners forward, the data collected in the gradebook can be used, in particular the percentage of correct answers to a question in subsequent attempts with interactive feedback. In this way, it is possible to evaluate the effectiveness of interactive feedback, to improve feedback itself and provide useful activities for learning. In (Barana *et al.*, 2018c), some examples of this strategy are presented. The results showed that there was a high trend to make more than one attempt on the assignments developed according to the model of automatic formative assessment and containing interactive feedback. This means that letting students repeat the assignments is an effective way to make them aware that the information from the feedback was useful to improve their performance, as well as to make teachers and researchers sure that the feedback was well built. From the analysis, it emerged that the feedback effectively made students improve their results. In fact, for each student, the average of their grades considering only their first attempt on every assignment was compared with the average

of the grades considering only their last attempts through a pairwise student t-test. It resulted that the activities were effective for making students use the information obtained through the feedback to persevere and improve.

Activating students as instructional resources for one another

To activate the students as instructional resources for one other, it is possible to consult the grader report to analyze the relationships and interactions between the students, in order to verify that the activities supported learning. In this way it is possible to study the effectiveness of the collaborative activities and eventually improve them.

An example of this strategy was used in the Digital Math Training project (Barana & Marchisio, 2016) and presented in (Barana & Marchisio, 2017). We analyzed the resolutions of the same problem by two groups of students, one in a context of individual work during a competition, and the other in a context of online collaborative work in the Project's platform. In the second group, the students could discuss their resolution though an asynchronous forum. The analysis of the scores of the second group of students, which were better than those of the first group, and of the interventions in the forum showed that the collaborative activities supported learning and the development of mathematical, problem solving, computer, digital and collaborative work skills.

Activating students as the owners of their own learning

For this FA strategy, it is possible to use the data of the interactive activities and the questionnaires in the grader report to study the relationship between students' performance and engagement. The objective is to evaluate the effects of interactive activities on engagement, one of the most powerful driving forces that pushes students forward into a learning experience. Some examples where presented in (Barana *et al.*, in press) and in (Barana *et al.*, 2018a). These papers are focused on an experimentation where interactive technologies were used in order to improve students' engagement in Mathematics at grade 8. For the whole school-year, all students involved in the project with their teachers had access to an online platform populated with interactive worksheets with real-life mathematical problems coupled with automatically assessed quizzes. According to the results of initial and final questionnaire, the level of engagement increased in particular in students that initially showed low levels of engagement. It is believed that engagement was elicited by the nature of interaction enabled by the interactive files and by automatic assessment, which supported the exploration and the understanding of complex concepts, facilitated teachers' explanations in the classroom, and allowed students to self-correct and understand mistakes. Increasing students' engagement in such environments is

an outstanding goal. The online activities managed to catch students' attention thanks to the use of the computer and the interactive feedback, which opens a dialogue between students and the system and encourages them to understand solving processes.

6 Challenges

Being a new approach to formative assessment, the application of LA techniques is not free from risks and challenges. Firstly, the creation of tasks and activities in a DLE to be used with formative purposes requires technical skills and knowledge of the tools, as well as a pedagogical preparation in the strategies and models of formative assessment, otherwise there is the risk to merely replicate traditional instruction with digital tools without reap the benefits that can be gained from a correct, informed and conscious use of these technologies. This can be tackled through a specific training dedicated to the teachers or the instructors that will author the learning activities. Our research group has designed and experimented a model of teacher training that involves face-to-face and online training sessions through which many secondary school teachers became skilled in the adoption of automatic formative assessment through a DLE (Brancaccio *et al.*, 2015). The teacher training is flanked sharing the produced materials in a virtual community of practice, where the contribution of the trainees and the control of tutors from the University assures that high quality materials are proposed to students.

But this is only a part of the risk mitigation: as Black and Wiliam stress (Black & Wiliam, 2009), it is not the mere use of proper tasks at the appropriate time that makes assessment formative: data from the assessment need to be used to take decisions in the instruction process. Here the learning analytics techniques can facilitate the visualization and analysis of learning data. However, it is not easy, especially for school teachers, to do the analyses and to use the results just in time to influence next steps in instruction. Sometimes they need the help of researchers to complete the analyses, some time is required to gather the data and start the analyses, and the results are not immediately available, so that they can undermine the dynamism of the decision-making process that takes place in a classroom (De Waal, 2017). In order to tackle these difficulties, it is possible to act on the automatization of the analyses processes and on the improvement of the visualization of the results directly into the DLE; teachers and instructors need to be trained to read these results and use them in their daily practices.

Conclusion

In this paper we have illustrated and discussed a possible theoretical framework for the creation and analysis of formative assessment activities using a DLE, connecting frameworks on Activity Theory, Formative Assessment and Automatic Formative Assessment. In particular, starting from Black and Wiliam's theoretical framework on formative assessment to study the formative strategies in a context of traditional learning, our research group proposed a model of formative automatic assessment with technologies (DLE integrated with an AAS based on an ACE), in accordance with the theoretical framework of AT. With these technologies one can create materials with automatic formative assessment according to our model and it is possible to add other interactive and collaborative activities for students, resources, questionnaires etc. These materials and activities have been tested on multiple occasions and the numerous and various data obtained have been analyzed with various learning analytics techniques. When formative assessment is paired with technologies, applying learning analytics techniques is possible, in order to enhance the potentialities of FA. The examples discussed show how the data coming from the use of a DLE and the evaluation data can be used in order to improve the enactment of strategies of formative assessment, strengthen and evaluate their action. Certainly, it may be significant to carry out new research on the use of LA to improve formative assessment strategies and learning processes in general.

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