An interactive learning environment to empower engagement in Mathematics

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Abstract. This paper is focused on understanding if the use of interactive activities based on problem solving and automatic formative assessment in a blended learning environment can promote the development of engagement in Mathematics for students of grade 8. In this context, engagement is characterized as a multidimensional construct composed of an emotional component, a cognitive component and a behavioral one. The discussion is based on the results of a didactic experimentation conducted with 299 students of grade 8 who, during one entire school year, had access to an online platform rich in interactive learning materials used in blended modality. Through an initial and a final questionnaire, evolutions in their engagement levels were measured. We found that the initially most disengaged students and those coming from lowest social classes are those who mainly benefitted of the interactive activities in order to improve their engagement levels.

Keywords: Automatic Formative Assessment, Engagement, Interactive Activities, Learning Technologies, Mathematics Education.

1 Introduction

There is no doubt that education has a strong impact on the society and that it can support changes in the world of work [1]. Literacy in the STEM subjects, with Mathematics at their core, is becoming more and more fundamental to keep up with the technological development that affects workplaces [1]. Developing a Mathematical understanding is essential to comprehend and to find innovative and competitive solutions to the rising issues that the rapid evolution of the society brings along [2]. Equity in the access to education is desirable and should be guaranteed to everyone, but it is not always sufficient: every student should have the opportunity to be deeply engaged in the educational system as a key to achieve formative success [3]. In fact, engagement is one of the most powerful driving forces that moves learners forward in a learning experience. When students are engaged in a task, they tend to keep focused, to enact deep learning strategies and self-regulation, to achieve good results and even to get satisfaction and enjoyment out of their activity [4]. Engaged learners usually enter a virtuous circle: when they obtain good results because of their work, their self-efficacy beliefs are intensified, and this keeps them engaged and makes them continue succeeding. On the other side, disengaged students who have difficulties in achieving good results may be trapped in a negative rather than positive loop, which hinders them from success [4]. Students in low socio-economic status might find it harder to be engaged in learning activities than students coming from medium-high social classes, due to the little support they may find in their families, or to the greater difference they may perceive between their school and home environments [5]. These might be the root cause for drop-outs and early school leaving, and that is why supporting didactic projects aimed at enhancing learning engagement especially for students with challenging backgrounds is often a key strategy pursued by policymakers and institutions, interested in improving the quality of education on the territory [6]. In Mathematics, which is often considered a "hard science", engagement is related to the development of strong aspirations for carrying on advanced studies in this field [2]. Since the development of Mathematical understanding is a crucial access key for workplace in the modern society, much attention to student engagement in Mathematics should be paid by teachers and educators from the very early school years.

Even more than for traditional schooling, engagement is an essential aspect of online learning. In particular, it has been shown to be a strong predictor of MOOC retention [7]: studying solutions aimed at keeping users engaged is crucial to increase the completion rates, which are often very low due to the weak motivations of the enrolled students to complete the courses [8]. Interactive technologies often support the engagement process: learning materials provided through gamification, simulation or interaction seem to be more effective than static resources in keeping the users involved. Moreover, in virtual environments, the large amount of data registered and made available by the systems can provide useful information that help researchers understand the processes activated during learning situations, evaluate the effectiveness of teaching strategies and support decision-making [9].

The goal of this paper is understanding if interactive learning activities based on problem solving in a digital learning environment can promote engagement in Mathematics at school level. After the discussion of a theoretical framework for the definition of engagement and the design of the learning activities, the results of a didactic experimentation involving 299 8^{th} grade students are presented in order to show how interactive activities can support the development of engagement, especially with students with challenging background or low levels of engagement.

2 Theoretical Framework

Engagement is highly studied in the educational research field, and it is possible to find many different definitions and characterizations of this construct in literature. Some authors associate engagement with the level of attention [10] or with motivation [11]; others conceptualize it in terms of visible students' behavior which should reflect the way they engage with learning materials [12], in terms of intensity and quality of students' involvement in learning activities [13], or in terms of effort and investment students expend in the learning task [14]. In all these researches, active participation is a central theme for understanding engagement. In this paper we accept the definition given by Ng, Barlett and Elliott [4], who refer to engagement as "students' dynamic participation and co-participation in recognition of opportunity and purpose in completing a specific learning task". This definition characterizes engagement as an interactive and purposive process and it allows to examine how it may change over time and vary according to situations and contexts. Engagement has a fluctuant nature, this meaning that it depends on specific situations and it may change over time: when students participate eagerly to a specific learning activity, they deploy appropriate strategies, regulate processes, and monitor their actions. They feel happy, spend time and effort on the task, and show high levels of focus and concentration. However, sometimes students can fail to plan their actions, feel worried or not so willing to make efforts, or they can become distracted. Thus, engagement is not a mere personal property, but it is a set of actions undertaken by a person in a specific context where interactions with other people, artifacts and tools occur. Engagement has a focal object, it is situational and malleable: it can be modified by changing task design, support or rules [4]. This malleable nature means that it is possible to create repeated episodes eliciting engagement and so, in time, contribute to these students establishing positive stable beliefs and behaviors [15].

Despite the number of definitions, researches on engagement agree on the fact that it is a multidimensional construct [16]. In line with the main trend, we recognize the three main components of student engagement identified by Fredricks, Blumenfeld and Paris: behavioral, emotional and cognitive [17]. Behavioral engagement (BE) draws on the idea of participation and it includes behaviors such as effort, perseverance, attention, concentration, and completion of work [14]. It also concerns positive conduct, such as following rules and participating to social or school-related activities [4]. When the focus is on homework, effort expenditure and timely completion are indicators of behavioral engagement. However, strict adherence to norms is not a good indicator for high-order thinking, enjoyment and interest: students could just keep quiet and pretend to pay attention, their level of interest being indeed very low [18]. Emotional engagement (EE) is understood as students' affective reactions in a classroom, which can vary from interest to boredom, from happiness to sadness, from satisfaction to anxiety. Interest and value for learning are important indicators of emotional engagement [17]. It is linked to several outcomes, such as learning achievements, liking school subjects and a positive attitude towards school [4]. Cognitive engagement (CE) is the mental investment people make in learning; it involves the use of deep strategies, self-regulation, openness to problem solving and positive coping in the face of failure [17]. A high level of cognitive engagement can be detected when students enter into an interactive dialogue to generate new knowledge [12]. Students with high levels of cognitive engagement are less likely to give up their learning and more likely to keep engaged with school [4].

In analyzing the effects of engagement during learning activities, a distinction should be made amongst these components, labelled as "indicators" of engagement, and the "facilitators" of engagement, which can be cognitive and social [11]. Among cognitive facilitators, the most acknowledged ones are self-efficacy, autonomy, interest and achievement goals, that are students' perceived purposes to learn. Social facilitators refer to social conditions, interactions, and relationships which promote engagement; especially for adolescents, the influence that peers, teachers, family and the environment have on them is critical for their behaviors and emotions [19].

Low levels of engagement and low achievements are often related. In a study conducted by OECD after PISA 2012 survey, it emerges that low performers in Mathematics are less interested in Mathematics than better-performing students. They report low levels of perseverance. They do not devote enough time to homework, and their effort in school related activities is not very productive. Moreover, they tend to skip classes and they show little sense of belonging at school [3]. Students with a disadvantaged background are more likely low performers than top ones: socio-economic status has a great influence on school achievements as well as on attitudes and beliefs towards Mathematics [20].

2.1 Engagement and Learning Technologies

Student engagement in technology enhanced learning environments includes any interaction of the learner with instructors, peers or learning content through the use of ICTs; this can happen face to face or remotely, and the courses involved may be entirely online, blended, or classroom-based [21]. The potential of technologies can open up new ways in the research about engagement, contributing both to the measurement of the indicators and to the creation of facilitators of engagement.

When the focus is the detection of engagement, technologies offer many sources of data such as logs, registration of dialogues and answers that can be usefully integrated in the research [13]. Many authors agree that the mere number of logs is not a reliable indicator of BE, if considered alone: the amount of time and actions spent on activities may vary largely among students according to their cognitive needs or to external factors. However, the data provided by automated systems can be combined in order to generate meaningful information about user experience [21].

On the other hand, digital technologies can contribute to the creation of cognitive and social facilitators of engagement for several reasons: they enhance the possibilities to activate learning by doing strategies, which enable students to intellectually engage in the task [22, 23]; they increase the chances of interactions among peers and with the instructor [13]; they facilitate self-regulation and adaptive learning through formative assessment [24, 25]; asynchronous activity enables learners to study at their own pace and to reflect on the learning process [26, 27]. In Mathematics and other STEM, real-world problem solving activities help create a connection between the subject and the environment, making Mathematics interesting and relevant; the use of software for advanced computation and data analysis makes students analyze real and complex data and solve the problems [15, 28].

2.2 Engagement and Automatic Formative Assessment

If online learning can provide new tools to engage students, its effect when combined with formative assessment should be promising. In fact, formative assessment strategies such as prompting discussions, providing feedback that move learners forward, activating students and peers as protagonists of their learning have, as their main consequence, that of acting on student engagement [29].

Our research group proposed a model of automatic formative assessment for developing learning activities using an automatic assessment system particularly suitable for Mathematics; the model has been experimented using Moebius Assessment [30], a system based on the mathematical engine of Maple, which allows the definitions of mathematical formulas, graphics and algorithms running behind questions. In particular, it is possible to define grading codes aimed at evaluating mathematical answers for their mathematical meaning, to create worksheets with several possibilities of interaction, step-by-step guided resolutions, and to allow students to enter graphs or symbolic formulas [31, 32]. The model was shown to bring enhancement both to teaching and learning [24, 33], acting on competence and on self-regulation [34, 35], as well as on engagement [36]. According to this model, learning activities created with an adequate automatic assessment system should have the following features:

- Availability. Assignments are always available to students, who can attempt them at their own pace, without limitation in data, time and attempts.
- Algorithm-based questions and answers. Random values, parameters or formulas make questions, and the relative answers randomly change at every attempt. This can be realized through the implementation of algorithms running behind the questions. Via algorithmic variables, different representational registers (words, numbers, symbols, tables, graphics, schemas) can be shown in questions and feedback.
- Open answers. The multiple choice modality is avoided whenever possible, to make room for open answers, where students are asked to respond in one of the different registers listed above.
- Immediate feedback. Results are computed in a few moments and they are shown to the students while they are still focused on the task.
- Interactive feedback. Right after answering one question, the system can show whether it is correct and go through a step-by-step guided resolution which interactively shows a possible process for solving the task. Students who fail to answer autonomously to the main question are asked questions about prerequisites or simpler tasks. At each step, if they give the wrong answer, the correct one is shown, that has to be used in the following step. They can gradually acquire the background and the processes that enable them to solve the initial problem. They earn partial credits for the correctness of their answer in the step-by-step process.
- Contextualization. Whenever possible, questions refer to real-world issues which can be relevant to students as well as for the discipline.

Fig. 1 shows one example of question created through Moebius Assessment according to the previously described model. Students can follow the step-by-step solving process in order to understand the solution of a problem involving zeros of linear functions. Through the steps, students can explore the situation in different representational registers: tabular, algebraic, numeric and graphic. A preview of the graph of the function entered is provided to students before grading the answer, in order to enable them to self-assess their answer. When students fail one answer to one of the sub-questions, the correct solution is given and it can be used in the following steps, so that students can individuate mistakes and correct them before proceeding. Numeric answers are accepted within a tolerance and formulas are matched with their mathematical meanings. Students can try the question again and find the same problem with different values, so they have to autonomously repeat the reasoning.

The activities with automatic formative assessment developed according to our model should be cognitive facilitators of engagement: when students fail one answer, the interactive feedback activates them through the solving process, making it possible to individuate the exact source of the mistake, thus acting on self-efficacy. Students can try the task again and find different parameters, so they have to autonomously repeat the solving process. Multiple attempts before showing the correct solution act on autonomy as well. The immediate feedback helps them focus on mistakes as a source of knowledge and to set mastery goals instead of performance goals. Adaptivity allows the creation of personalized learning paths, in order to tailor the learning experience on the students' needs. Lastly, real-world settings act on the student's interest for the subject, connecting abstract Mathematics to the real world [37, 38]. Similar activities can also be used to support collaborative class work, becoming social facilitators of engagement: well-organized peer discussions foster students' participation in learning activities and contribute to the creation of a comfortable learning environment, which is fundamental for school well-being [19].

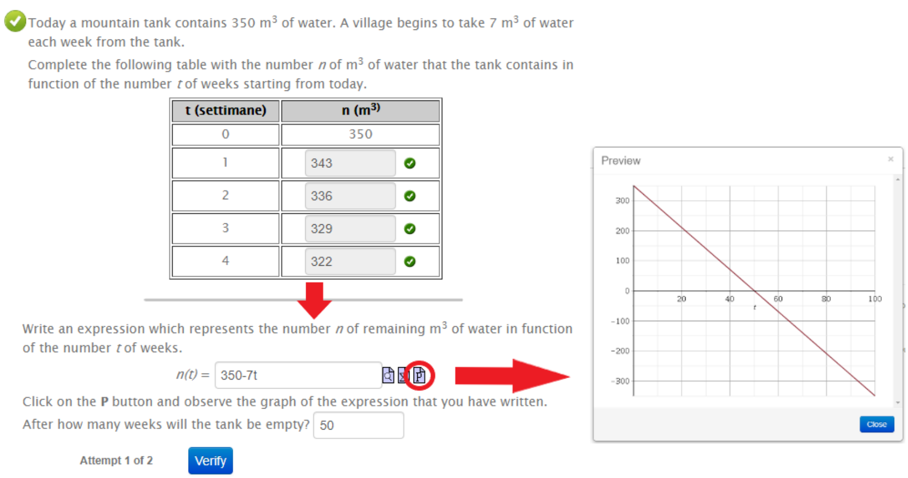

Fig. 1. An example of question with interactive feedback.

3 Research question

The use of automatic formative assessment with interactive feedback in digital learning environments is not so common at school: it is a novelty coming from the research world and it requires that teachers and the whole school system make a great investment to integrate this methodology into the daily teaching practices. Educational politics need evidences that it works before introducing it in teacher training programs. Therefore, it is clear how studies on the effectiveness of the use of automatic formative assessment for learning under different perspectives are important. In this research we tried to understand the relationship between engagement and the use of interactive learning technologies with automatic formative assessment, answering to the following research question: could the use of interactive materials with automatic formative assessment and interactive feedback in blended and online situations improve the engagement level of students who, at the beginning of a learning path, show a weak engagement in Mathematics or come from challenging backgrounds? The target of this research are Italian 8th grade students, who can be considered a high-risk category, since they are in a delicate transition period from lower to upper secondary school when students, in Italy, begin to make decisions about their future studies. Data tell us that in this period the “early school leaving” phenomenon has its origin; this phenomenon is correlated with the familiar economic situation, well-being and educational level [39]. This target could really benefit from the use of interactive learning technologies which allow the personalization of learning. Since engagement, as seen before, is strictly connected to the quality of learning, acting on it could have a dramatic impact on their future life, especially for demotivated and disinterested students or those coming from challenging backgrounds.

4 Research method

In order to investigate the research question, a didactic experimentation has been designed and realized in the city of Turin (Italy) in 2017/2018 school-year [40, 41] by the University of Turin in collaboration with the National Research Council. The experiment has been carried out as part of a larger research project called “Educating City: teaching and learning processes in cross-average ecosystem” funded by the Italian Ministry of Education as part of the Technological National Cluster “Technology for the Smart Communities”. The experimentation involved 299 8th grade students attending 6 different lower secondary schools in different areas of Turin. In particular, about half of the students belonged to low socio-economical class, while the other half to middle-high social class. The sample was composed by randomly selecting 13 classes from the 6 schools, which were entirely included in the project with their Mathematics teachers.

All the students filled in an initial questionnaire in November 2017, which aimed at investigating the initial level of students’ engagement toward school and, more specifically, toward Mathematics. The questionnaire was administered online; it was composed of 35 Likert-scale questions inspired to PISA 2012 student questionnaire [42]. Table 1 shows the items in the questionnaire. The emotional engagement subscale includes items aimed at investigate the extent to which students are interested in and value Mathematics; the behavioral engagement subscale includes items on students’ effort and completion of work, perseverance and participation to school and social related activities; items of the cognitive engagement subscales are related to the perceived control of success, self-regulation and openness to problem solving. All items were on a 4-points Likert scale (strongly disagree/disagree/agree/strongly agree) except for the items from IQ21 to IQ25 on perseverance and items from IQ31 to IQ35 on openness to problem solving, where, through a 5-point Likert scale, a neutral position was allowed.

Table 1. Items of the initial questionnaire.

Subscale	Code	Items
Emotional Engagement	IQ1	I like lectures about Mathematics.
	IQ2	I can't wait for Mathematics lessons
	IQ3	I do Mathematics because I like it
	IQ4	I am interested in the things that I learn in Mathematics
	IQ5	Making an effort in mathematics is worthy because it will help me in the job that I want to do later on
	IQ6	Mathematics is an important subject for me because I need it for what I want to study later on
Behavioral Engagement	IQ7	I finish my homework in time for mathematics class
	IQ8	I work hard on my Mathematics homework
	IQ9	I am prepared for my Mathematics exams
	IQ10	I study hard for mathematics quizzes
	IQ11	I keep studying until I understand Mathematics material
	IQ12	I pay attention in Mathematics class
	IQ13	I avoid distractions when I am studying mathematics
	IQ14	I keep my Mathematics work well organized
	IQ15	I talk about mathematics problems with my friends
	IQ16	I help my friends with Mathematics
	IQ17	I do Mathematics as an extracurricular activity
	IQ18	I do Mathematics more than 2 hours a day outside of school
	IQ19	I play chess
	IQ20	I program computers
	IQ21	When confronted with a problem, I give up easily
	IQ22	I put off difficult problems
	IQ23	I remain interested in the tasks that I start
	IQ24	I continue working on tasks until everything is perfect
	IQ25	When confronted with a problem, I do more than what is expected from me
Cognitive Engagement	IQ26	If I put enough effort, I can succeed in Mathematics
	IQ27	It is completely my choice whether or not I do well in Mathematics
	IQ28	Family demands or other problems prevent me from spending a lot of time for my Mathematics work
	IQ29	If lessons were different, I would try harder in Mathematics
	IQ30	Whether I study or not, I am bad at Mathematics
	IQ31	I can handle a lot of information
	IQ32	I am quick at understanding things
	IQ33	I seek explanations for things
	IQ34	I can easily link facts together
	IQ35	I like to solve complex problems

From December 2017 to June 2018 some experimental activities took places in all the classes. All students with their teachers had access to an online course in a Moodle platform appositely designed for the project, populated with interactive materials designed by the research group according to specific educational models related to problem solving and formative assessment [43, 44]. The materials were interactive worksheets with real-life mathematical problems, created through an Advanced Computing Environment (ACE) [28], which is an innovative tool to do Mathematics, coupled with online quizzes with automatic formative assessment created through Moebius Assessment. Problem solving tasks were designed to actively involve the students in the exploration of data, in the pathways towards the solution and in the generalization of the situation that leads to the abstraction of the mathematical model used in solving the problem. The automatically assessed questions followed the principles of the model of automatic formative assessment previously mentioned [34].

The online course covered the whole program for 8th grade Mathematics, ranging from negative numbers to solid geometry, from linear functions to equations. Materials and methodologies were shared with teachers through periodic focus groups in order to enable them to use the materials autonomously, in class through the Interactive White Board (IWB) or in a computer lab, or to ask students to work on them as homework. In the classroom students mainly worked in small groups on the problems, using paper and pen or tablets, while the interactive materials at the IWB could support the following collective discussion, aimed at comparing and justifying different solving processes. A set of lessons in each class were held under the supervision of research group members. At home students could find all the materials on which they worked in classroom, plus other assessment activities through which they could check and improve their understanding, guided by the interactive feedback.

Fig. 3 shows one example of an interactive activity in the online platform used for collaborative working. Students can explore the situation filling the interactive tables with the numbers. The graphs of the points in the tables will appear below. The task actively involves the students, who are also asked to insert data from their own experience and to compare them with the problem situation.

At the end of the school year the students were asked to fill a second online questionnaire conceived to evaluate the impact of the project's activities on engagement. This questionnaire was composed of three main subscales as well, corresponding to EE, CE e BE. Items in the emotional engagement subscale focused on the affective reactions to the classroom and online activities, such as interest, enjoyment and value for the learning activities; items in the cognitive engagement subscale were related to cognitive and metacognitive processes enacted by the learning materials, such as understanding, the use of deep strategies for problem solving and self-regulation; the behavioral engagement subscale included items on attention, persistence, effort and completion of work. Part of the questions are related to the activities which took place in the classrooms using the materials designed for the experimentation; other items are related to the individual use of the platform, with particular reference to automatic assessment. The 37 items are reported in Table 2; they are all 5-point Likert scale.

Table 2. Items of the final questionnaire.

Subscale	Code	Items
Emotional Engagement	FQ1	The classroom activities were interesting.
	FQ2	The classroom activities were enjoyable.
	FQ3	I think that I will remember the things learned during the classroom activities in the next months.

Subscale	Code	Items
	FQ4	I think that the classroom activities will be useful for my future studies.
	FQ5	Using the platform during the classroom activities was useful.
	FQ6	Using the platform made Mathematics lessons more interesting.
	FQ7	Having the materials available in every moment is useful.
	FQ8	The proposed problems are interesting.
	FQ9	The tests are useful to practice.
	FQ10	It is useful to visualize the correct answer after submitting a response.
	FQ11	The online assignments are a valid help for studying.
	FQ12	Online assignments made me appreciate the topics studied more.
Cognitive Engagement	FQ13	The classroom activities were comprehensible.
	FQ14	During the classroom activities I could learn new things.
	FQ15	The classroom activities were useful to better understand some Mathematical topics.
	FQ16	The classroom activities were useful to make connections among different areas of Mathematics.
	FQ17	The classroom activities were useful to see Mathematics in a different way.
	FQ18	The possibility to see the materials used in the classroom again from home is useful.
	FQ19	Using the platform in the classroom helped me understand the topics covered.
	FQ20	Using the platform from home helped me identify the topics on which we worked in class.
	FQ21	The online tests helped me better understand the topics studied.
	FQ22	The online tests helped me understand if I understood the topics studied.
	FQ23	The immediate feedback helped me understand how the task should be solved.
	FQ24	Problems with step-by-step resolution helped me understand the solving process.
	FQ25	Online assignments helped me autonomously solve Mathematics exercises.
	FQ26	Online assignments helped me become more confident about my capabilities.
	FQ27	Online assignments helped me acknowledge my preparation.
Behavioral Engagement	FQ28	I paid attention during the classroom activities.
	FQ29	I completed the homework assigned after the activities through the platform.
	FQ30	This year I was very involved in my work with Mathematics.
	FQ31	I paid attention to the lessons when we used the platform.
	FQ32	I used the platform to review the topics on which we worked.
	FQ33	I used the platform to do my homework.
	FQ34	I used the platform to prepare myself for the final exam.
	FQ35	I used the platform to prepare myself for the INVALSI tests.
	FQ36	I used the platform to study Mathematics.
	FQ37	When I gave an incorrect answer, I used to try the exercise again.

In order to evaluate the impact of the learning activities on student's engagement, an initial profile of all the students has been depicted through their answers to the initial questions. Answers to IQ21, IQ22, IQ28, IQ29 and IQ30 were reversed so that higher answers correspond to higher attitudes. Factor analysis was used to confirm the classifications of the items into three main sets, corresponding to emotional, behavioral and cognitive components of initial student engagement; continual and categorical variables were defined as indicators of the initial level of engagement in the three components.

Similarly, questions of the final questionnaire were split in three subscales, related to emotional, cognitive and behavioral engagement; three continuous variables were created as indicators of the final level of emotional, cognitive and behavioral engagement. As additional behavioral indicators, the number of logs to any course activity, the number of submissions of automatically assessed assignments and the average rate of submission per assignment were collected and taken into consideration. The reason for the consideration of such variables is to double-check data from the self-assessment questionnaires, which were filled after the activities, with data automatically collected by the use of technology during the activities, when the engagement process took place. Technical data can reflect the effective participation to online activities and they are not affected by personal and subjective evaluations; however the amount of logs and visualizations can vary from student to student according to their needs: scholars do not agree on which is the most appropriate measure to understand how engagement changes [21].

The final level of engagement in each subscale was compared with the initial one; analyses were conducted using SPSS 25. The reliability of all the questionnaires and the subscales were checked through Cronbach Alpha.

Students' socio-economic factor was determined using data from national surveys; the sample has been split in two categories: students from low social class and students from medium or high social class. The division broadly coincides with the division in schools: 4 out of 6 schools considered for the experimentation were mostly attended by students with low socio-economic status. The two schools attended by students from medium-high class participated to the project with more classes.

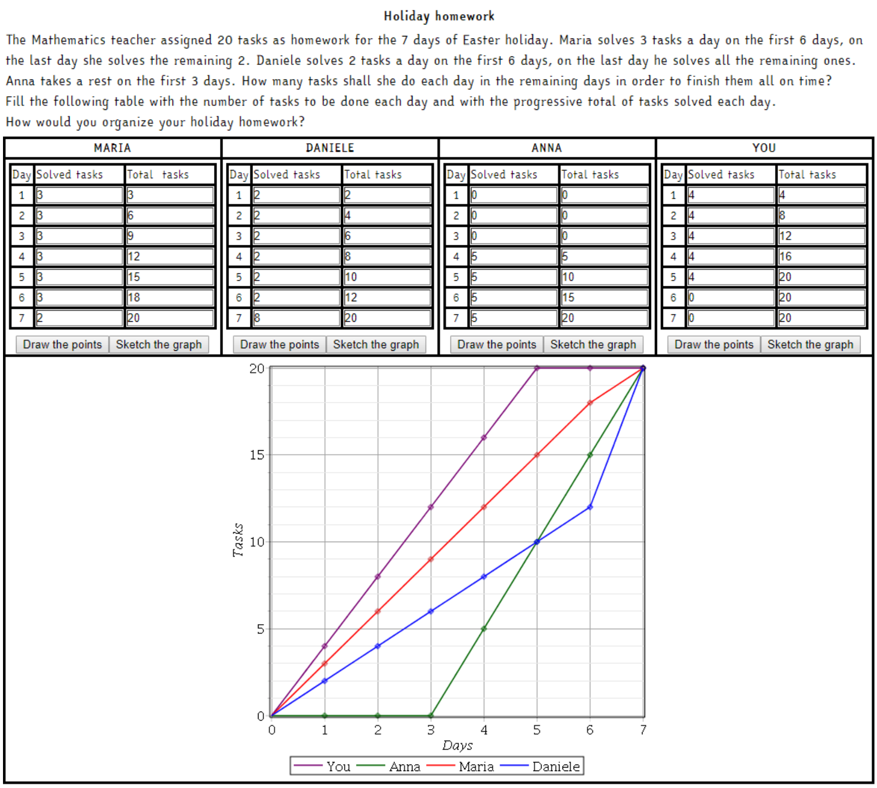

Fig. 2..An example of interactive worksheet used during the activities.

5 Data Analysis and Results

The initial questionnaire was answered by 278 out of 299 students (93%). Students who did not answer to the questionnaire were excluded from the sample. The reliability of the survey was checked through Cronbach Alpha, which resulted sufficiently high (0.82). An initial factor analysis lead to the elimination of 5 variables: IQ7, IQ19, IQ20, IQ28 and IQ29. As for the last two eliminated variables (related to playing chess and programming computers), they are probably not common actions for 8th grade students, so they didn't contribute effectively to the detection of Mathematics behavior. IQ28 and IQ29 ("Family demands or other problems prevent me from spending a lot of time for my Mathematics work" and "If lessons were different, I would try harder in Mathematics") probably concerned external factors compromising students' success more than interior control of their actions. Although the effect of the teacher and the family environment may be important factors for learning and developing competences, they are usually not so influential as to impede school work and the achievement of success [3]. Regarding completing homework before classes (IQ7), it has been previously noticed that the mere compliance with rules does not necessarily imply engagement: the homework can be finished just to avoid punishments (at grade 8 many teachers are usually very strict in demanding that homework is done on time) but this does not necessarily mean that behind the homework there is effort, and it could also be copied from classmates. Factor analysis also showed a distinction between two groups of items in the emotional subscale: IQ5 and IQ6 seemed to conceal a different nature with respect to the first four items. Actually, IQ5 and IQ6 refer more to the extrinsic motivation to study Mathematics than to an intrinsic involvement with the subject. Therefore, we only considered items from IQ1 to IQ4 in the emotional engagement subscale. The Cronbach Alpha computed on the remaining 28 items increased to 0.85. Through factor analysis, three standardized variables were created as linear function of students' answers to the remaining items: emotional engagement (EE_i); behavioral engagement (BE_i), composed by the remaining items on Mathematics work ethic, Mathematics behavior and by perseverance; cognitive engagement (CE_i), to which the remaining items on perceived control of success and on openness to problem solving contributed.

Three categorical variables were built on the basis of the sum of students' answers to questions in the subscales. The variables had values 1, 2 or 3, meaning low, moderate high and high attitudes. In particular, for emotional engagement (EE_cat), the value of the sum of the answers to the four items could range from 4 to 16; a low level was defined for values equal to or below 8; a medium-high level was defined for values ranging from 9 to 12 and high level for values higher than 12. For cognitive engagement (CE_cat) the cut-off values were 21 and 29 in a range from 8 to 37; for behavioral engagement (BE_cat) the cut-off values were 37 and 53 in a range from 16 to 69. Table 3 shows the distribution of students in the three levels of initial emotional, cognitive and behavioral attitudes.

The final questionnaire was answered by 85% of students; all of them had previously completed the initial questionnaire. Cronbach Alpha was very high (0.93), showing that the items were sufficiently reliable.

In order to exclude the hypothesis that students who did not answer to the final questionnaire were concentrated in the lowest levels of initial engagement, a Chi-squared test was run to verify the incidence of having or not having answered to the final questionnaire on the distributions of the initial levels of emotional, cognitive and behavioral engagement. None of the tests gave significant results (p=0.56 for EE; p=0.78 for CE; p=0.35 for BE), meaning that answerers and non-answerers were equally distributed in terms of initial engagement.

Table 3. Percentage of students in the three levels of each subscale of initial engagement.

Initial engagement level	EE	CE	BE
Low level	8.4%	20.9%	15.8%
Moderate high level	24.3%	52.1%	72.6%
High level	68.3%	27.0%	11.6%

As a preliminary analysis, variance analysis (ANOVA) was conducted over the students' answers on all the single final questionnaire items of the three subscales, considering as independent variables the corresponding level of initial engagement, emotional, cognitive or behavioral. We found that the initial level of engagement explains only the variables related to emotional and behavioral engagement concerning classroom activities (such as FQ1, FQ2 and FQ28), while for all the items related to cognitive engagement and all the items explicitly involving the use of the platform of the other subscales the initial level of engagement does not explain students' answers (p>0.1). For some items the trend was even decreasing, meaning that students with low levels of engagement showed a higher interest for this kind of activities than their classmates. Table 4 reports some examples of students' answers to some items of the cognitive subscales, analyzed for levels of the relative engagement.

Table 4. Examples of students' answers to the final questionnaire for levels of respective engagement.

Initial EE/CE/BE level	**Means of students' answers**				
	FQ11	**FQ18**	**FQ20**	**FQ23**	**FQ36**
Low level	3.62	3.74	3.59	4.07	3.30
Moderate high level	3.31	3.70	3.53	3.96	3.15
High level	3.66	3.56	3.66	4.30	3.11
p-value	0.23	0.31	0.75	0.16	0.84

These results are interesting: students in the highest initial levels of engagement tended to give higher - or similar - answers than students from lowest levels, however it seems that the use of the interactive materials designed for the project had some impact on the levels of engagement, in particular on students from initial lower levels. These results are worth investigating.

Factor analysis on the items of the final questionnaire left the original schema unchanged: thus, three standardized variables, expressing the emotional, cognitive and behavioral engagement, were created as output of the factor analysis; they embed the students' answers to the items considered in Table 2. Moreover, ANOVA analysis was conducted over these variables, considering the corresponding initial engagement levels (EE_cat, CE_cat and BE_cat) as independent variables. Results showed a slight dependence of emotional and behavioral engagement on the relative initial levels; the final cognitive engagement follows the same trend of the initial one, but results are not significant. It seems that the initially most engaged students remain the most engaged at the end of the path, but we do not have information on how engagement evolved with the project's activities.

In order to investigate whether any effect occurred on changes in the factors of student engagement, the difference between the level of EE with online activities observed with the final questionnaire and the initial level of emotional engagement was computed; the same was done for CE and BE. The variable expressing the difference in EE (EE_diff) had mean -0.061 and standard deviation 1.186; the variable expressing the difference in CE (CE_diff) had mean -0.028 and standard deviation 1.345; the variable expressing the difference in BE (BE_diff) had mean -0.046 and standard deviation 1.045.

Through ANOVA, the dependence of EE_diff from the initial categorical level of emotional engagement (EE_cat) was tested. Results are reported in Table 5: students with initial low levels of EE improved their level by 1.302, which is more than one standard deviation. The difference decreases as the initial engagement level increases. ANOVA test shows significant relations among the variables ($p<0.001$); Eta test shows that this relation is moderate, explaining the 16% of the variance (Squared eta: 0.157, $p<0.001$). We restricted the sample to students with initially low levels of emotional engagement and calculated the effect size of the interactive activities on their EE levels using Hedges' *g*, which is the more appropriate effect size's index for small samples [45]. In this case, we have $g = 1.53$, which is a very high value: it means that the classroom and online activities dramatically increased the emotional engagement level for students who, at the beginning, showed a low level of EE.

A similar analysis was conducted for cognitive and behavioral engagement; Results are reported in Table 5. By analyzing, through ANOVA, the dependence of CE_diff on the CE_cat., we can notice that students with initial low levels of CE improved their level by 1.264, which is almost one standard deviation. The difference decreases as the initial engagement level increases, reaching -1.122 for initially highly engaged students. ANOVA test shows significant relations among the variables ($p<0.001$); Eta test shows that this relation is strong, explaining the 37% of the variance (Squared eta: 0.368, $p<0.001$). The effect size, considering only students having low initial levels of engagement, is $g=1.26$, which is a very high value as well: it shows that students who at the beginning where little cognitively engaged with Mathematics, perceived a noticeable increasing in their CE level by means of the project's activities.

As for behavioral engagement, students with initial low levels improved their level by 0.942, which is almost one standard deviation as well. The difference has a decreasing trend, reaching -0.939 for initially highly engaged students. ANOVA test shows significant relations among the variables ($p<0.001$); Eta test shows that this relation is strong, explaining the 20% of the variance (Squared eta: 0.204, $p<0.001$). The effect size, considering only students having low initial levels of engagement, is $g=1.16$, which is again a high value, meaning that the experimental activities had a strong impact on the BE's levels of initially little engaged students.

Table 5. Differences between initial and final levels of engagement, per level of initial engagement

Initial level of EE/CE/BE	EE_diff	CE_diff	BE_diff
Low level	1.301	1.264	0.942
Moderate high level	0.351	0.164	-0.486
High level	-3.171	-1.122	-0.939
p-value	<0.001	<0.001	<0.001

Since the technologies can contribute to the measurement of engagement providing important data on the students' real use of the platform which can be integrated into the research [10], we decided to consider as additional behavioral variables the number of logs registered in the platform, the number of submitted assignments on the platform and the rate of submission per assignment. Considering data from the informatic systems offers the advantage that they were collected for the whole 100% of students, so there are no missing data; however, they reflect only the individual work and not the participation to classroom activities, when the students often worked on paper and only the teacher was logged in the platform, displaying the activities through the IWB. Table 6 shows means and standard deviations of the three variables.

Table 6. Data from the platform usage

Variable	Mean	Standard Deviation
Number of logs	96.51	72.48
Number of assignment submissions	18.65	17.15
Rate of submission per assignment	1.66	0.87

From the literature we already know that logs are related to behavioral engagement, but they can be influenced by other factors [21]. As a matter of fact, in our analysis 28% of variances of the number of logs and 26% of variances of the number of submissions is explained by the class teacher: probably the way teachers asked students to do the online activities and the way they checked the homework impacted on students' work. These variables turn out to be weakly associated with the initial level of behavioral engagement, as shown in Table 7: students with a low level of BE tended to work less on the platform than their classmates. For the number of submissions, the relation is statistically significative; for the number of logs, however, there is not statistical evidence. Both variables are correlated with the variable that measures the final level of behavioral engagement built using data from questionnaires (R-squared are respectively 0.30 and 0.28, $p<0.001$).

The situation changes when considering the average rate of resubmission per assignment. Recalling that the assignments have unlimited attempts, that numbers and situations change at every attempt and that mistakes are explained through interactive feedback, when students try questions again it means that they are eager to autonomously solve the problem, that they understood the solution and want to challenge themselves once again: thus, the task managed to engage students. This variable seems not to be related to the initial BE level, as shown in Table 7 ($p=0.21$).

Even students with initially low levels of BE could be engaged in activities with automatic formative assessment. This variable is not correlated with the final level of students' BE considered in the above analyses (R-squared: 0.075, p=0.37). This means that it measures something different, namely the rate of engagement generated by the interactive activities and their feedback, while the variable expressing BE is linked more to attention in classwork and mere completion of homework.

Table 7. Average data from the platform, per level of initial behavioral engagement

Initial level of BE	Number of logs	Number of submissions	Rate of submissions per assignment
Low level	78.52	14.52	1.75
Moderate high level	97.33	18.45	1.60
High level	116.06	25.56	1.89
p-value	0.079	0.020	0.210

Lastly, we focused on the socio-economic status of the students, with the purpose of verifying that the online activities experimented were useful also for students with challenging backgrounds. Through ANOVA tests, we noticed that the two groups registered similar values in the difference between final and initial EE and BE (p=0.99 and p=0.57 respectively). From a cognitive point of view, engagement level grew significantly more in students from a lower social class than in those from a higher one (p=0.01); the same trend was registered in the rate of submission per assignment (p=0.027). Results are displayed in Table 8. Since the sociocultural origin is a strong predictor of scholastic success [20], acting on the engagement level of students from disadvantaged background is extremely important for the promotion of school success and for the prevention of drop-out rates.

Table 8. Impact of engagement on students of different socio-economic status

Socio-economic status	EE_diff	CE_diff	BE_diff	Rate of submissions per assignment
Low	-0.063	0.319	-0.065	1.80
Medium-high	-0.061	-0.245	0.035	1.54
p-value	0.993	0.013	0.573	0.027

6 Discussion and conclusion

Through the data analysis above, we positively answered to the research question "Could the use of interactive materials with automatic formative assessment and interactive feedback in blended and online situations improve the engagement level of students who, at the beginning of a learning path, show a weak engagement in Mathematics or come from challenging backgrounds?". In fact, we compared the initial and final levels of emotional, behavioral and cognitive engagement in students who participated in a didactic experimentation for Mathematics using interactive materials with automatic formative assessment, and found that the biggest increase in the engagement level was observed in the students who started the path from the lowest levels of engagement. Moreover, belonging to a lower social class did not influenced the increase in the engagement levels, except for cognitive engagement, for which it is related to the biggest increases.

The theoretical framework on engagement helped us understand what engagement is, distinguish its components and find useful indicators to build questionnaires in order to measure the students' one. Moreover, a clear understanding of the nature of engagement and its components allowed us to build meaningful learning activities which could promote its development. It also provided us with a useful frame to analyze the answers and interpret the results, thus understanding which factor is mainly involved and how didactic activities can act on it.

We observed that cognitive engagement is the subscale where the effect is more evident. CE is linked to self-regulation and persistence with school work and cognitively engaged students are less likely to give up their learning and more likely to keep engaged with school [4]: the fact that the students who had the biggest increases in the CE levels are the initially less engaged ones, or those coming from lowest social classes, suggests us that the methodologies used in this experimentation can be useful to prevent early school leaving and reduce the drop-out rates. A key role in this process seems to be played by the automatic formative assessment, and in particular by the interactive feedback designed in the online tasks, as the answers to the questionnaire's items show. In fact, the interactive feedback offers the possibility to understand mistakes and be guided in a possible solving path, being actively involved. The results related to the rate of submission to the assignments show that the chance to repeat the reasoning with different numbers was indeed taken by the students, especially those with initial low levels of engagement or coming to lower social classes, in order to improve their results: it means that they were really engaged by the interactive feedback, that they were activated as owner of their learning. Thus, the digital learning materials acted as cognitive facilitators of engagement. We argue that also other features of the tasks, as the real-world settings, but also the mere use of the technology as school activity, which is still an unusual practice in the majority of 8^{th} grade classes in Italy, could contribute to capture students' interest and attention. Classroom activities were managed through group working: the peer collaboration and the collective discussions are social facilitators of engagement and they contributed to the creation of an active learning community.

These activities were not occasional practices, but they were regularly repeated over the school year: we can suppose that the effects on students' engagement could become stable and influence students' attitudes and beliefs towards Mathematics. Related researches show that, in Mathematics, engagement is linked to the development of aspirations for challenging Mathematics: similar educational models might even contribute to the students' choice of undertaking scientific careers [4].

The effect of these activities on students from low social classes is of considerable importance. According to our results, they do not increase the social inequalities; rather, they overturn them, offering disadvantaged students tools to reengage with school. During the classroom activities we could perceive a higher level of attention in schools located in disadvantaged areas of Turin than in schools located in the city center, and despite the potentially lower availability of digital technologies in their homes, students from low social classes used the online platform at the same extent, or even more, than students coming from richer families. It is shown that school disengagement is related to disaffection, disruptive behaviors, bullying and early school leaving, and these problematics are more common in disadvantaged areas [11]. Developing interest for and understanding of Mathematics in poorly educated families may improve the capacity of young people to actively engage in the society and in workplace, thus opening the possibilities of social mobility.

We also showed that the teachers had a major impact on the amount students' online work, in particular on the number of logs and submissions. The teacher's role is always fundamental in learning processes at school level, especially when the technologies are involved: the way they are confident with innovative methodologies and convinced of their effectiveness influences the students' activities. Teacher training is therefore important for the success of similar projects. The teachers involved in this experimentation soon realized that the adopted methodologies lead to important learning results, so they were motivated to change their teaching practices by adopting these methodologies. Most of them enrolled to a teacher training course the following year, aimed at making them autonomous in the preparation of interactive learning materials with automatic formative assessment.

The experience of Educating City can be replicated in other contexts in order to improve the quality of Mathematics teaching and learning. In particular, the didactic methodologies, whose effectiveness to improve engagement has been shown in this research, have been proposed to enhance the teaching and learning of Mathematics of all Italian teachers through the "Problem Posing and Solving" (PP&S) Project, supported by the Ministry of Education with the aim of renewing Mathematics teachers' practices [37]. The materials used during the project were made freely available to all the Italian teachers enrolled to the PP&S Project; they can use all of them, edit and adapt them to their needs. A specific training on these methodologies is offered to the participants. In March 2020, when all Italian schools were closed due to the COVID-19 pandemic, the platform of the PP&S Project was open to all Italian teachers of every subject, even non-scientific. Thus, the materials elaborated according to the didactic methodologies presented in this paper could help a considerable number of Italian students keep on learning in an emergency situation.

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