MATHEMATICS EDUCATION IN LOWER SECONDARY SCHOOL: FOUR OPEN ONLINE COURSES TO SUPPORT TEACHING AND LEARNING

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ABSTRACT

In the light of an educational emergency aggravated by the health emergency following the COVID-19 pandemic, the DELTA (Digital Education for Learning and Teaching Advances) Research Group developed four open online courses available to lower secondary school students and teachers. The four courses, devoted respectively to Numbers, Space and Shapes, Data and Predictions, Relations and Functions, contain interactive materials to support the teaching and learning of Mathematics. We have made the four open online courses available to teachers, tutors, and students within two projects. Both projects are aimed at lower secondary school students, especially those with difficulties in Mathematics. In this paper we discuss the methodologies and technologies used to develop the online courses and we show an example of the interactive materials that can be found within the courses. The results show the appreciation of the resources by teachers, tutors and students, a sign that open online educational resources can foster a change in Mathematics teaching and learning.

KEYWORDS

Digital Education, Digital Learning Environment, Lower Secondary School, Mathematics Teaching, Open Educational Resources, Open Online Courses

1. INTRODUCTION

Education at every school level was strongly affected by the COVID-19 pandemic. The educational institutions' closures to reduce the spread of contagion during the first half of 2020 have had an effect on around 1.5 billion learners. In fact, in almost 100 countries schools were closed for several weeks, leaving more than a billion students at home (UNESCO, 2021). Several closures also took place during the school year 2020-21, further aggravating the situation. In light of this educational emergency, our University has proposed, during the school year 2020-2021, some projects intended to lower secondary school, aimed at reducing inequalities and further penalization of those students who were already at risk of exclusion.

One of the main projects, in collaboration with De Agostini Foundation, named "compiti@casa, curare la fragilità educativa" (i.e., "homework, curing educational fragility"), intends to support, through the modality of a distance tutoring, girls and boys in lower secondary school who need support in learning. The tutoring activities take place in an integrated digital learning environment and are carried out by tutors, university students selected by the University of Turin. The project addressed 100 students of the first and second year of lower secondary schools and involved 55 tutors. The participating students came from three different Italian cities: Novara, Turin and Milan. Students were divided into little groups of maximum three people and they were supported in their afternoon personal study of scientific subjects at home for two hours a week from February to May.

Another important project (Project 2016 ADR 00310 Con i Bambini - impresa sociale srl), named "Ragazzi Connessi: in rete per sviluppare talenti e offrire opportunità di apprendimento" (i.e., "Connected children: networking to develop talents and offer guidance opportunities"), is designed to tackle educational poverty, providing integrated interventions for the application of innovative learning methodologies in schools. This project has involved 113 students of lower secondary schools of Genoa with learning difficulties in Mathematics. Students were divided into groups of five to ten members. They were helped by eight tutors, for one hour a week, with Mathematics homework and review. Within both projects we also offered an online training course to the teachers of the students involved. The training meetings were aimed at introducing teachers to the innovative methodologies proposed within the projects and to basic training in the use of new technologies. The courses were attended by a total of 14 teachers of scientific subjects. Within these projects, our research group has designed and implemented four open online courses in Mathematics, containing materials and interactive activities for students and teachers of lower secondary schools and for tutors, who could use them in their afternoon remedial actions. These are Open Educational Resources, OERs, always available and accessible to facilitate the right to education for all citizens.

The four courses, aligned to the four areas of Mathematics established by the Italian National Indications (Numbers, Space and Shapes, Relations and Functions, Data and Predictions), have the main purpose of providing innovative didactic materials and interactive activities for learning and teaching Mathematics. At the end of the two projects we asked teachers, students and tutors to evaluate the materials of the four courses in terms of their effectiveness in supporting Mathematics teaching. In this paper we present and discuss the courses we implemented to support the teaching of Mathematics, and the tools we used for creating the interactive materials. The paper is structured as follows: Section 2 depicts the theoretical framework we referred to; Section 3 illustrates the research question and describes the methodology; Section 4 is devoted to the presentation and the discussion of the results; and Section 5 contains some concluding remarks.

2. THEORETICAL FRAMEWORK

In the last years, the use of technology for education in schools has increased quantitatively and qualitatively together with the improvement of technology itself. E-learning provides many advantages (Moreno and Mayer, 2007; Ross et al., 2010; Helder et al., 2017): it offers a variety of freely available materials; it allows students a more accessible education because all they need is an internet-connected device; it can accommodate everyone’s needs; it provides adaptive learning. In fact, using the information technologies to support learning can be an effective way for the realization of the declaration of Rights to Education primer (Tomaševski, 2001), which explains the essential features of all types of education: availability, accessibility, acceptability and adaptability. Nowadays several research projects are rising in the field of open digital education (Cronin and MacLaren, 2018), (OPAL, 2011). The main reason of this choice is the easy access to the World Wide Web via many kinds of devices everywhere and at all times. In this context, many institutions, and in particular universities, are devoting much of their research to the preparation of Open Educational Resources. Furthermore, the OERs play a central role in the new Digital Education Action Plan (2021-2027) (European Commission, 2020), that is a European Union (EU) policy initiative to support the sustainable and effective adaptation of the education and training systems of EU Member States to the digital age. The Digital Education Action Plan has two strategic priorities:

1. Fostering the development of a high-performing digital education ecosystem: this includes, among other things, creating high quality learning content, user-friendly tools and secure platforms that respect privacy and ethical standards.
2. Enhancing digital skills and competences for the digital transformation, that means basic digital skills and competences from an early age and advanced digital skills, to produce more digital specialists.

In this context, the use of the OERs is of fundamental importance for several reasons. First, they are characterized by accessibility, inclusiveness and a learner-centered design. Furthermore, OERs promote higher pedagogical and educational quality and respect students' diversity and cultural richness. Indeed, their use can certainly facilitate the development of a digital education ecosystem. The Digital Education Action Plan builds on the experiences of online and distance learning during the COVID-19 crisis to fully understand the needs that emerged in schools and rethink education and training for the digital age at all school levels. Before the COVID-19 pandemic, OERs were already widespread for higher education. There were already many providers of Massive Online Open Courses (MOOC), like EdX (https://www.edx.org/) and Coursera (https://www.coursera.org/). Many universities in North Europe and North America use these open platforms to make their courses available online. Also in Italy, there are platforms that provide online courses, like

EduOpen (Rui, 2016) and Federica (Calise and Reda, 2017). EduOpen is a project founded by the Italian Ministry of Education, University and Research that hosts several online courses about basic and professional disciplines and professional scientific research. Federica is the e-learning project of the University of Naples Federico II, with more than 300 free courses, available at any time, with contents organized in training modules.

Since the beginning of new century, also the University of Turin has taken an interest in digital education and in the creation of open resources, especially for university contexts and for upper secondary schools. One of the main projects providing numerous online, open, and free lessons is "start@unito" (Marchisio et al., 2019). It allows to follow courses while attending high school, before enrolling at university, and also during university career. The courses cover disciplines in almost all the University's study programs: from Physics to Sociology, from Computer Science to Zoology, from Law to Languages, designed specifically for those who are approaching university studies and for those who wish to study independently. In addition, many courses are taught entirely in English to promote internationalization. Other projects promoted by the University of Turin that make open and online materials available are "Orient@mente" (Barana et al., 2017b), "PP&S Problem Posing and Solving" (Brancaccio et al., 2015b) and the project "SMART Science and Mathematics Advanced Research for good Teaching" (Brancaccio et al., 2015a).

3. RESEARCH QUESTION AND METHODOLOGY

By considering the contexts exposed before, we have formulated one main research question, which has acted as motivation for our work:

How is it possible to integrate the teaching and learning of Mathematics in lower secondary school with the support of Open Educational Resources, with a particular focus on recovery actions?

3.1 OERs within a Digital Learning Environment

The four courses have been developed by our research group following principles consolidated by the experience in the field of e-learning for scientific disciplines gained in recent years by the University of Turin in online and blended courses (Barana et al, 2020). In other recovery actions, like "Scuola dei Compiti" project (Barana et al., 2017a), we already adopted a Digital Learning Environment (DLE). This indicates a learning ecosystem in which teaching, learning and the development of competence are fostered in classroom-based, online, or blended settings. Using a DLE can be very effective as it consists of two components: the human component and the technological component, and the interrelations among the two. Its human component, consisting of one or more learning communities, is focused on the interactions between teachers and students and among students themselves (Barana and Marchisio, 2021); its technological component includes a Learning Management System (LMS) along with other integrated tools, such as an Advanced Computing Environment (ACE) and an Automatic Assessment System (AAS). These allow the adoption of specific methodologies such as problem solving (Samo et al, 2017), supported by the use of an ACE and the formative assessment (Black and Wiliam, 2009; Hattie and Timperley, 2007) implemented by the use of an AAS. We used the Moodle LMS Moodle (https://www.moodle.org), the Maple ACE Maplesoft (https://www.maplesoft.com), and the Möbius Assessment AAS DigitalEd (https://www.digitaled.com), as it was already experimented for instance in (Marchisio et al, 2020) and in (Galluzzi et al, 2021). In particular, we made use of the ACE in order to create interactive materials, and of the AAS to create adaptive questions and adaptive assignments. Adaptive questions are composed of sections that are shown to the student depending on the previous given answer. In particular, it consists in a first section where the main problem is posed and the correct solution is directly asked. Students who answer correctly in the first sections receive a positive feedback and complete the question. Students who give a wrong answer are led to the solution step-by-step, one small question at a time with which a possible process for solving the task is shown (Barana et al, 2021). Adaptive assignments are composed of questions divided into groups according to their difficulty level, usually in number of three. Students start at one level, usually the middle one, and then they are promoted to the upper level if they answer correctly to a minimum number of questions. If they make a minimum number of mistakes, they drop to the lower level.

3.2 Structure of the Courses

We now describe the structure of our courses in relation to the design principles presented before. The four courses have been designed for students in lower secondary school and they are dedicated respectively to: Numbers; Space and Shapes; Data and Predictions; Relations and Functions. Indeed, we referred the Italian National Guidelines in which the objects of Mathematics studies are divided in these four categories. Each course is divided into sections, one for each topic, chosen from the main topics listed in the National Guidelines. In particular, we decided to focus on the following topics:

- In the course "Numbers": Fractions, Powers, Expressions and Mathematization, Percentages, Proportions, Scientific Notation;
- In the course "Space and Shapes" (shown in Figure 1): Angles, Triangles, Quadrilaterals, Pythagoras and Euclid, Similitudes, Solid Geometry;
- In the course "Data and Predictions": Statistics, Statistical Graphs, Average Values, Probability;
- In the course "Relations and Functions": Set theory, Proportionality, Equations, Functions, Symbolic Calculation.

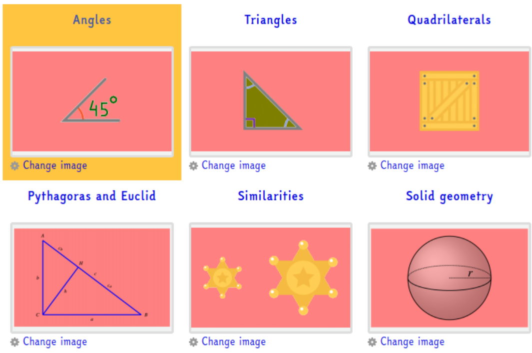

Figure 1. (left) : The "Space and Shapes" course and the relative sections

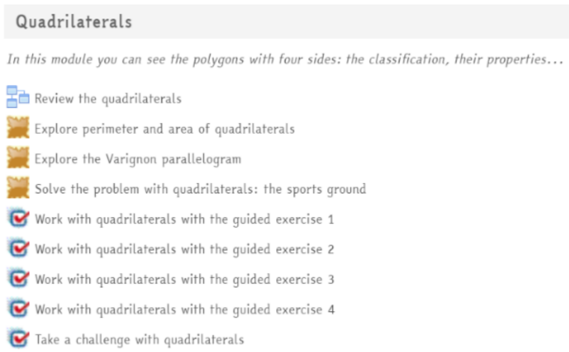

Figure 2. (right) : An example of the structure of a section in the course

Each section has a fixed structure (shown in Figure 2) and it contains:

- A lesson: it contains a theoretical review of the topic of the section, interspersed with short quizzes to verify learning. This material was created using a Moodle "book".
- Interactive exploratory materials: they allow to interactively explore one or more concepts of the topic studied in the lesson. These materials were created with the Maple ACE.
- Interactive problems: they allow to face the guided and interactive resolution of a problem. They are problems contextualized in real life that allow students to explore different situations that can occur in a particular mathematical context. They were also created with the Maple ACE.
- Tests and problems with automatic assessment: they allow to verify the learning of the subject. They provide immediate feedback and, if repeated several times, they present different data. They are mainly adaptive questions and adaptive assignments created with the Möbius Assessment AAS.

Students can browse freely through the four courses, and they can choose the order in which to address the contents. Moreover, students can try tests and problems with automatic assessment more than once, because they have algorithms so that the values change at every attempts. On the platform, the students can monitor their work: a progress bar shows clearly which materials have already been opened, and which ones are still to be done. Furthermore, students can also see the gradebook of all the results of the completed tests and, for each one, all the answers they gave, together with the correct answer and feedback comments so that they can better understand their mistakes. We now present some examples of activity that can be found within the four courses. Figure 3 shows an interactive exploratory activity of the section "Quadrilaterals" through which students can explore the area and the perimeter of different geometric shapes. In the worksheet students can chose a specific quadrilateral and visualize it, along with its perimeter and area formulas. Then, students can choose, through some sliders, the values of some lengths relative to the quadrilateral, and calculate perimeter and area, verifying the correct value. In this way, students become protagonists of their own learning, exploring the object of study independently. Figure 4 shows an adaptive question of the section “Quadrilaterals” through which students can test their previously acquired knowledge. The question presents a main problem focused on the area of a square. If students answer incorrectly, the questions release two more sub-questions that can help them understand how to answer the initial question correctly and recognize their own mistakes. Furthermore, the question is an algorithm-based question, so that students can try the question again finding different numbers, verifying learning.

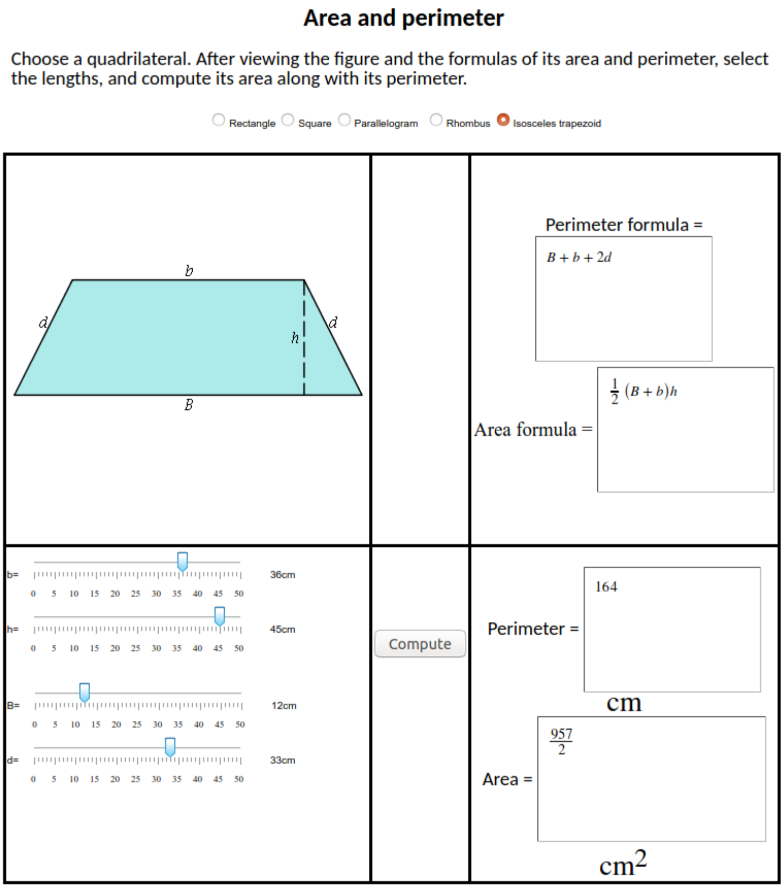

Figure 3. An example of an interactive exploratory material in the section “Quadrilaterals” of the course “Space and Shapes”

We made the four courses available as part of two projects aimed at reducing educational poverty through remedial actions in the afternoon. The tutors who helped students learn Mathematics had the interactive materials at their disposal, and so had the students, and they could use them to tackle new topics and review old ones. The students' teachers also had access to the four courses so that they could use them in the classroom. Indeed, in order to test the effectiveness of our four courses, we presented them in the two teacher training courses. We asked teachers to evaluate the courses materials to bring out strengths and weaknesses. In particular, we asked them to choose one interactive material made with *Maple* and one question with the automatic assessment and then we asked them to fill in a satisfaction questionnaire for each of them. At the end of the project, we also asked all the tutors and students involved their opinion on the materials they had available through a questionnaire.

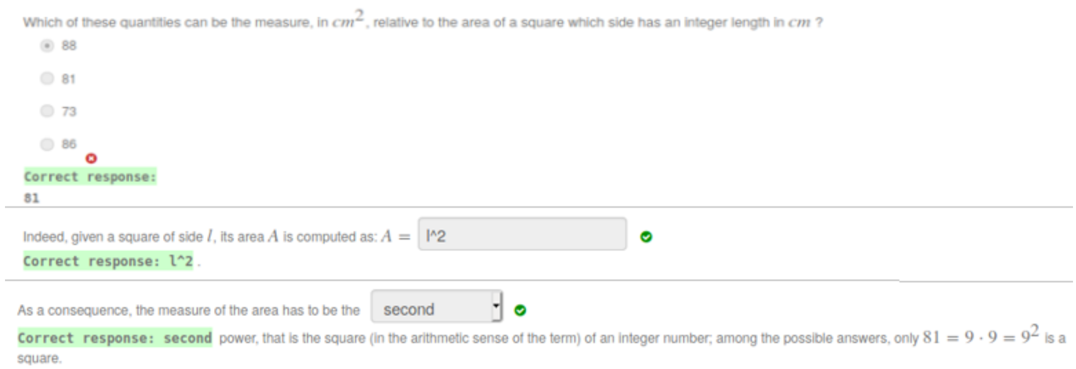

Figure 4. An example of an adaptive question in the section "Quadrilaterals" of the course "Space and Shapes"

The four courses are available at the link: https://ragazziconnessi.i-learn.unito.it/.

4. RESULTS AND DISCUSSION

All the 14 teachers responded to the questionnaires we submitted to them. The first questionnaire was about interactive materials created with the ACE. It emerged that 100% of the teachers liked the materials and would use them in class with their students. The questionnaire asked what the benefit of these interactive materials is, compared to a traditional lesson. Some of the answers were: "It is very engaging and allows students to both practice and self-correct their mistakes", "It captures the attention, allows the learner to explore, to work hands on" and "The possibility of using it at home and reviewing it several times and the presence of small quizzes to check comprehension of the subject". They were then asked how they would use the interactive resources with the students: 50% of teachers said they would use them to review topics before a test and for consolidation of concepts; 40% said they would use them to introduce a new topic; the rest would use them to keep their students' attention during the lessons. Finally, the questionnaire asked teachers for advice on how to improve the interactive resources and it emerged that it would be better to add color and a more readable font, especially for those students with visual difficulties. The second questionnaire concerned tests with automatic formative assessment. It emerged that 100% of the teachers would use the material in class with their pupils and that 100% felt that the tests were well designed. The questionnaire asked what the added value of these tests is, compared to a traditional lesson and some of the answers were: "Variety, adaptability, captures attention visually, offers immediate feedback, and because of this, shortens the distance between the subject and the student", "It allows students to get immediate feedback on their answer and indicates where they went wrong" and "By having immediate feedback, the learner is encouraged to look for the right answer, to reason and to get involved without waiting for external feedback. This should help the student to self-discipline". All teachers said they would use this material as a pre-test review and as homework. Finally, the teachers suggested improving the design of the tests, in order to catch the students' attention, adding color, images and video, and increasing the number of tests within the four courses.

At the end of the projects, tutors and students were also asked for their opinion on the interactive materials they could use in the afternoon meetings. A total of 61 tutors and 171 students filled in the questionnaires. By considering the questions relative to the interactive materials, 95% of the tutors stated that the afternoon tutoring sessions, in which they used the digital resources, helped the students to improve in Mathematics, not only in terms of their final grade, but also in terms of confidence, motivation and awareness. Subsequently, tutors were asked to respond about the usefulness of the didactic material available. In a Likert scale from 1 to 5, where 1 means "not at all" and 5 means "very much", 51% of the tutors responded 3 or more, thus finding the interactive materials provided by us useful. The questionnaire then asked tutors for advice on how to improve the interactive materials. Some tutors highlighted the difficulty of using the materials due to the limited time they had with the students, thus preferring to give it as homework. Other tutors suggested creating other materials, to cover all the topics studied during lower secondary school. In addition, certain tutors complained that the vocabulary in some teaching materials was too difficult for lower secondary school students.

Nevertheless, there was a relevant number of tutors who was generally satisfied of them, and did not ask for specific improvements. In the students' questionnaire, we asked them how useful they perceived tests with automatic assessment. In the same Likert scale as before, 53% students responded at least 4 and 78% at least 3. Then we asked them about the usefulness of interactive exploratory materials and problems. Students were satisfied, even more than before: 62% of students responded at least 4 and 85% at least 3. Table 1 shows some statistics about these questions, along with two other ones regarding their use of the materials.

Table 1. Statistics about use and appreciation of the materials by students

Question	Average	Median	St. Dev.
Did you use the materials on the platform during the meetings?	3.27	3	1.17
Did you use the materials on the platform independently, outside meetings?	2.68	3	1.31
How useful were the tests with automatic assessment?	3.46	4	1.17
How useful were the interactive review materials?	3.65	4	1.08

In light of the results obtained, it can be stated that the materials we created were able to satisfy all the stakeholders involved, with particular regard to teachers and students; about the latter, it has to be noted how they preferred their use *during* the afternoon meetings, showing some difficulty in using them individually, for example while doing homework. This can be explained by the fact that all the students involved had underlying difficulties, which required some time to be leveled; during the project, they were inevitably still affected by them, thus resulting in having moderately less interest and less capabilities in the autonomous fruition of the resources and the activities, although their use was anyway present. On the other hand, tutors were a little bit more critical about the materials, nevertheless giving some valid advice, and being in general eager to have them as available, even if sometimes they did not make use of them, for the above-discussed reasons. The motivation for which tutors expressed critics that teachers did not mention can be related to their different relation with the students, due to various factors such as a less marked age-difference, and a more informal setting of the afternoon meetings compared to the lectures students have with their teachers.

5. CONCLUSIONS

The emergency situation highlighted a pre-existing educational poverty and underlined the need for recovery action in a completely different way from what the school was used to before. So, this work sought to understand how it is possible to integrate the teaching and learning of Mathematics in lower secondary school with the support of Open Educational Resources, with a particular focus on recovery actions. Bearing in mind the University of Turin's past experiences in the field of remedial action, even before the pandemic, we proposed four open online courses within a Digital Learning Environment. In this way, the materials were easy for students to access, always available, and interesting thanks to their interactivity. The materials within the courses were implemented using an ACE for the creation of exploratory files and interactive problems and an AAS for the creation of questions with automatic formative assessment. All the resources we have made available to teachers, tutors and students have been appreciated and have helped the students to catch up in Mathematics, not only in terms of grades, but also in terms of their approach to the subject. The courses we presented, along with all the results and the observations collected, provided a possible valid answer to the research question enunciated at the beginning of Section 3. The next steps we want to take are to take advice from teachers, tutors and students to improve the four open courses. In particular, we appreciated the suggestion to make the resources attractive by adding color, images and videos where possible, and to simplify the language to make it more suitable for lower secondary school students, aspects which can constitute a future work on the materials. Furthermore, we want to create similar courses for nonmathematical sciences as well, in order to provide OERs for all STEM subjects covered in lower secondary school. The Science courses are already in the works, in order to help students also in the recovery of Physics, Chemistry, Biology and Geology. Finally, we would like to make our four open courses as widely known as possible so that they can be useful to as many students and teachers as possible, and in light of this a complete translation to English of all the resources and activities would be a good direction to follow.

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