Phygital Education through Storytelling and Learning by Doing: the Binario 9 ¾ project

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Abstract. Alternatives didactic methods, based on the educational theory "learning by doing", have been suggested in the transition from Curricula Based Education to Competence-Based Education (CBE). An example of alternative methods employed in this project is phygital education, which can be used as a profitable framework to implement innovative teaching method of STEM disciplines at school. In this paper we present a recent project, namely Binario 9 ¾, where phygital education has been developed through virtual communities of practice and digital storytelling adoption, to support students of middle school with learning disorders or difficulties to bridge the gap with others. The project was split into two phases: the first one from September 2019 till December 2021, characterized by COVID pandemic during which the developed materials have been mainly used in presence to support student with learning difficulties in mathematics due to language speaking; the second one from June 2022 to September 2023 during which the materials have been completely revised to be used online by students with specific learning disorders too (like dyslexia). The results reported in this paper show how inclusion, scholastic and educational success for students with learning disturbs or cultural barriers can be successfully obtained using the proposed approach.

Keywords: Competence-Based Education, Phygital Education, Digital Storytelling, Virtual Communities of Practice, Learning by doing.

1 Introduction

As reported in [11], competency-based education (CBE) can be defined in multiple ways and interpreted differently across academic (and, by extension, scholastic) programs. In a CBE model, learning is structured from both the horizontal and vertical perspectives [2]: horizontal learning means that the student must learn to integrate what they learn across the curriculum; vertical learning means that the student must master the content of each course in depth.

Today, as highlighted in [19], successful implementation of CBE curricula should be based on teachers' ICT use and adoption. This is due to many reasons; indeed, technological innovations have completely changed our mindset. Nowadays students are part of the digital world and teachers must align their teaching methods with the new technologies, in order to guarantee to all students enough digital skills to keep on

going by themselves [10]. Moreover, governments have worldwide invested in the integration of ICT in education at all levels due to the effects of globalization and rapid changes in technology on the knowledge-based economy of 21st Century, to provide learners with necessary skills and competencies [23]. Indeed, these skills and competencies, as well as digital equipment to obtain them should be guaranteed to impaired students too. Many studies point out the crucial role of digital technologies in reducing distances between impaired students and their buddies, but most of them are focused on physical impairments, like hearing [12], visual diseases [18], and so on.

In this conceptual framework, the recent COVID-19 emergency has pointed out the importance of both distance learning and virtual communities that could provide a sort of direct contact when it was not physically possible. A recent paper [7] introduced the term *phygital education* to indicate the extensive adoption of digital technologies at school during COVID-19 pandemic and their subsequent maintenance in the post COVID-19 emergency era: this term is interesting, since it focuses on the need for a balance between the traditional curricula, based on physical presence of students at school, and the totally at-distance one. The main advantages of this kind of solution is preserving the social nature of Education, naturally intrinsic in the pupil-teacher relationship, taking advantage from the new possibilities offered by digital technologies from the innovation of didactic methods point of view.

As reported in [3], t*echnology can empower learners, close educational gaps, and support a more inclusive and equitable educational environment by removing access barriers, expanding learning opportunities, and providing affordable alternatives… Each learner is different from the next, with their own interests, skills, and preferred learning methods. Technology gives teachers the ability to customize lessons to meet the needs of each student.*

Virtual Communities of Practice (VCoPs), as proposed by [14], are probably the most important supporting tool (and, by extension, environmental platform) to implement didactic frameworks based on phygital learning, competency-based education, being based on a good trade-off between in-presence and at-distance activities. For this reason, they have inspired us in the development of the Binario 9 ¾ project, that is the main subject of this paper.

The exact purpose of Binario 9 ¾ is that moving the subject of the project, i.e. a student with learning difficulties, from a Content and Curricula based education, focused on concepts, to a Competence-based one, centered on *constructivism theory* [17]. Based on this theory, one of the most important issues for learning activities is actively engaging the pupil, through gamification approaches for the design and implementation of didactic units using Scratch platform[1].

The educational theory involved is *learning by doing*: using Digital Storytelling students learn Mathematics concepts practically rather than theoretically; a didactic unit is thought as a part of a story the pupil can follow in a concrete way, being able to close the gap between the theory and the practice in a more natural way, resulting positively influenced by his/her experience.

The effectiveness of Digital Storytelling in mathematics education compared with traditional teaching emerges from various studies [21]: through programming and

[1] https://scratch.mit.edu/

computational thinking, students can gain key competences crucial for this historical period, that could be as important in their everyday life as in their working life evolving from a lurker condition to a knowledge contributor of, in a Virtual Community of Practice [22], increasing the intra-group cohesion, encouraging the overall sense of belonging and inclusion.

The rest of the paper is organized as follows: section 2 briefly reviews the literature about virtual communities of practice, its main components and legitimate peripheral participation, focusing on Education. Section 3 reflects about Competence-Based Education and its relationship with learning by doing, thanks to the adoption of storytelling in the VCoP development. Section 4 introduces our case study to show in practice how Binario 9 ¾ works. Section 5 present results obtained from the project from the project application to two different schools in Novara (Italy) and briefly discusses them. Finally, the paper concludes with some considerations about possible future works.

2 Virtual Communities of Practice

Communities of Practice are groups of people bound by informal relationships sharing common practices [6]. Virtual Communities of Practice are a type of CoP that uses the Internet and/or digital platforms as a development environment.

Each CoP member shares his/her own knowledge for the benefit of the community, to create a global knowledge that everyone in the community can freely access. All participant's skills become essentials, and the close dependency on other members promotes the sense of belonging to the group [24].

In this paper, we analyze how Binario 9 ¾ VCoP, that is shown in **Fig. 1**, has helped foreign students and/or students with learning difficulties to improve their level in Math and their inclusion. Math is often difficult to understand and to master properly, for this reason there is a strong presence of lurking phenomenon: as stated above, the adoption o of Digital Storytelling by means of stories implemented in Scratch aimed at improving the student participation in VCoP, simplifying their access to activities [24].

In a VCoP there are three distinct roles: knowledge contributors, knowledge seekers and lurkers [22].

Knowledge contributors are those who contribute actively by sharing their knowledge within the system. The sharing action can take place both occasionally and repeatedly. They play an important role in the development, growth and maintenance of the Virtual Community System (VCS).

In Binario 9 ¾ VCoP, they are teachers and developers: teachers possess the knowledge to build the Virtual Community System, and they pointed out which mathematical topics should be included, based on students' difficulties. Developers created and implemented VCS and educational material.

Knowledge seekers are those who search within the system for the information they need and then uses the material for their purpose. Their actions on the system are occasional and passive, since they don't support it with new material or changes, as the contributors.

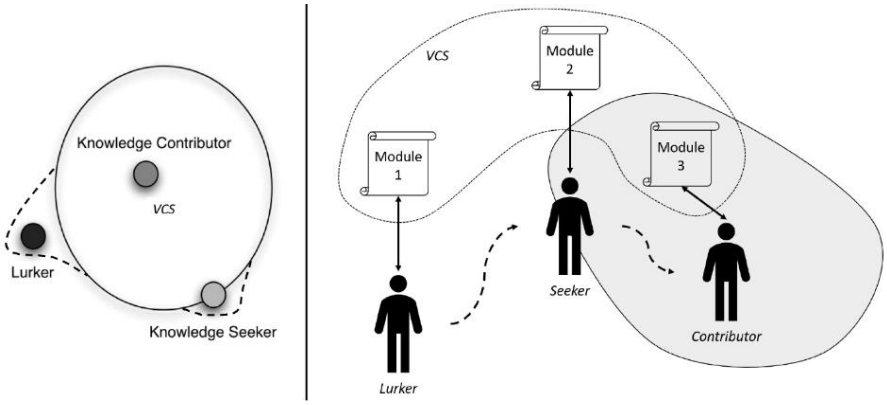

Fig. 1. VCoP roles and position in relation to the system.

In this case, they are tutors, who know the system well and can move within the VCS to support the activity of students.

The lasts are lurkers, passive users who are outside VCS, and who refrain from participating in the activities supporting the construction of the VCoP [26]. At the beginning, they are the students: they have educational material available for them, such as a collection of exercises and lessons in Scratch platform.

VCoP have no formal structures: the positions aren't predetermined; every participant can move from a role to another one according to individual's needs and skills. In fact, VCoP are active communities that can evolve over time.

Legitimate Peripheral Participation is the most important aspect of a VCoP, which ensures the growth of VCS [22]. The ability to actively contribute to the system, measured by the term Sense of Virtual Community [5], is not innate in the participants and needs methodologies to be improved. Inside a VCoP, the roles are quite stable, so it's difficult to satisfy the LPP. However, Scratch programs are designed to make students evolve from the initial condition of lurkers. Furthermore, since many students were familiar with Scratch syntax and environment, and this helped us to promote them, we also set out to teach Scratch language to students, guiding them in the personal production of mathematical Digital Storytelling, encouraging their evolution to knowledge contributors role.

3 CBE and Learning by Doing: the Crucial Role of Storytelling

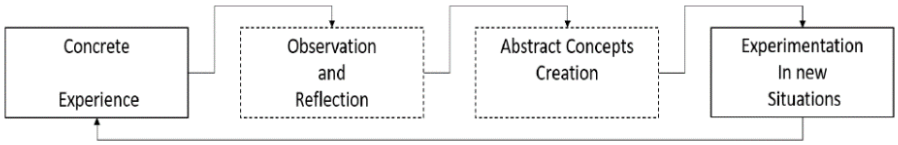

Fig. 2. Learning by doing steps.

Learning by doing educational method motivates the students in the learning process and reveals themselves useful in a Competence-Based education model [25]. Learning by doing method links theory to practice, and it is divided into four steps [22], sketched in **Fig. 2**:

- *Concrete experience*: first practical phase, where students face reality through games or practical examples;
- *Observation and reflection*: theoretical phase, where the previous example is more formally analyzed, extracting its structure;
- *Abstract concepts creation*, where mathematical rules are assimilated and concepts are acquired;
- *Experimentation in new situations*: the last practical phase, where students become able to apply the newly learned knowledge in other similar contexts.

Fig. 3. A Story in the Binario 9 3/4 Project.

Every mathematical topic has been divided into three chapters, based on these steps, logically correlated in the form of a *story*, as depicted in **Fig. 3**. The first chapter appears as a simple game, a metaphor of an implicit mathematical problem, yet unknown to the student. He/she has to think about the problem, trying to solve it. At this level, pupil is still, typically, at lurker level. The second chapter consists of the

theoretical part about the story topic: student can find every explicit notion needed to solve previous problems. This program is implemented as a lesson, in the form of interactive slides explained by a parrot sprite, and some interactive exercises introduced by a pirate sprite. In this phase, the student becomes, ideally, a knowledge seeker, as he searches for information needed to understand the topic, increasing his/her own knowledge. The third chapter is another game, sometimes the same as the initial game, where the student has to use the recently acquired knowledge to reach the solution.

The mathematical metaphor of this game becomes explicit, and the pupils should be able to generalize the problem solving method using learned rules. In the last step of learning, student becomes knowledge contributor: thanks to an expert help, he/she can experience the development of Scratch educational programs. The Scratch language structure itself encourages the evolution, thanks to the adoption of block syntax that makes programming intuitive and funny to younger students. Twelve stories have been developed, for a total of thirty-six chapters, each one related to a specific mathematical topic suggested by the community of experts (i.e. middle school teachers) involved. Through these three chapters, the student is guided in the practical use of Math to solve common problems, moving from an implicit use of mathematic concepts hidden in concrete situations, as in the first step, to their explicit adoption to tackle the same concrete situations or similar ones, as in the final step, in order to be able to recognize how mathematics can be found in everyday life: Learning by Doing using technology has proven useful for quick and effective implementation of CBE [20]. From the CBE perspective, students acquire many competences, as knowledge to manage mathematical rules and other skills, or problem solving, computational thinking and programming skills.

The process of building Math knowledge takes shape from students' direct experience and active use, rather than studying it during frontal lessons. Students learn to simplify even the most abstract Math concepts and apply mathematics in other new situations [11, 27]. Programs are characterized by many interactive parts where the student has to answer questions or solve games. In case of mistakes, compensatory feedbacks guide him/her to problem-solving hints, helping him/her to become more confident of his/her skills and less worried about the possibility to fail. Scratch is designed for the creation of Digital Storytelling, in fact it is based on the interaction between characters, namely Sprites, on a Stage. Its structure refers to theatrical performances. It also supports interactivity, an essential feature for educational use, as it allows to interact directly with the student, through questions, games and exercises. This makes the student the protagonist of the story, and not just a simple external observer. The didactic material follows two narrative strands: the journey of a pirate with his parrot, and the holiday of a group of friends. These settings were chosen to make the teaching materials appealing to the students, and because they provide an excellent connection between Math and concrete experience.

4 Binario 9 ¾ project: Science Club

Binario 9 e ¾ project is addressed to middle schoolers characterized by learning difficulties for language barriers, for example different nationalities. The main issue

of this project is to promote scholastic and educational success: supported by the Inter-reg Italia-Svizzera 2014-2020 Program, it has been carried out in Novara city and in the Grigioni Swiss Canton.

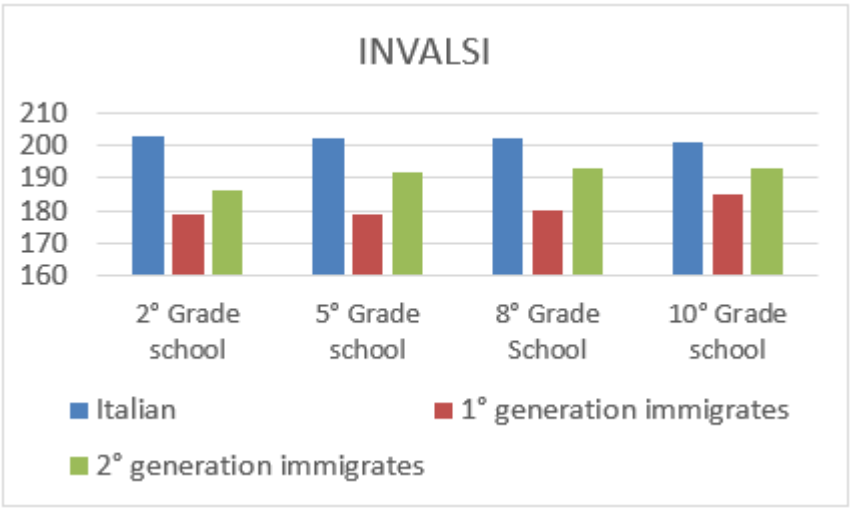

Fig. 4. INVALSI results: gap between Italian and foreign students in different School grades.

There are two main activities, namely Italian and Math Labs. In this second one, to explain theoretical concepts Digital Storytelling is employed, an innovative teaching method where the concrete self-experience of the students is involved to fill the gap with the others. As the name of the project suggests, the scope is "discovering an alternative rail, a new starting point to change perspective and look to the future with new eyes" [4].

Considering foreign students, the school aim should be the their inclusion in the educational process; since they don't speak Italian as mother-tongue buddies, their starting point is lower than other students. Learning local language is crucial both for verbal communication and to understand new concepts.

Fig. 4 shows the huge gap between foreign students and the Italian ones due to cultural differences and, sometimes, due to worse economic conditions as emerging INVALSI tests [15]. Similar situations exist in other countries in Europe, both in Euro and in Non-Euro nones; in particular, Switzerland and Italy are comparable: the aim of this project is decreasing the gap and promoting the entrance of foreign students to the high school. Thanks to the Moodle support (see This promotes the evolution from *lurker condition* to *knowledge seeker* and *contributor* roles; the customization of learning, shaped on the characteristics of the student, who can jump from one topic to the next one and dedicate all the necessary time that deserves to complete each of them; the autonomous pursuit of knowledge, stimulated by the playful theme. Binario 9 ¾ project has been developed in two phases: the first one was a practical experiment, started in 2020 in Italy. It involved 33 students from IC Bellini School in Novara, led by 18 tutors. However, the project was interrupted at the beginning due to COVID-19 lockdown.

Fig. 5), students can independently "sail down the river of Math", looking for the content they wish, according to their own needs. Each content is a *landmark*, where the student can live a story about a specific content.

This promotes the evolution from *lurker condition* to *knowledge seeker* and *contributor* roles; the customization of learning, shaped on the characteristics of the student, who can jump from one topic to the next one and dedicate all the necessary time that deserves to complete each of them; the autonomous pursuit of knowledge, stimulated by the playful theme. Binario 9 ¾ project has been developed in two phases: the first one was a practical experiment, started in 2020 in Italy. It involved 33 students from IC Bellini School in Novara, led by 18 tutors. However, the project was interrupted at the beginning due to COVID-19 lockdown.

Fig. 5. A sketch of the Moodle site of Binario 9 ¾ project.

The activities restarted the following year and involved two middle schools: IC Bellini, where 48 hours of lessons were held for 24 students, and IC Convitto Carlo Alberto Morandi, where 26 hours of lessons were held for 50 students. Activities were carried out in presence, with temporary interruptions due to COVID-19 lockdown and quarantine periods of some classes. In total, 39% of the students had foreign nationality, while 53% were Italian (8% of students didn't provide their personal data). In Switzerland, activities involved 30 students from two middle schools in Coira. The course addressed the entire class, observing a greater attention to foreign students. After the first practical experiments, we also gathered tutors' opinion belonging taking part in the VCoP, discussing any faced challenge to understand how the project has worked, from their point of view.

Many suggestions to improve didactic materials and teaching experience emerged from this discussions: some of these concerned program graphic user interfaces, others were related to interaction with students and their engagement. As for GUIs, the first problem was the reading difficulty due to font and background. Moreover, it was not always clear to students how to interact with programs, making tutor presence essential. Sometimes tutors themselves were not able to solve students' problems, either because they did not have solutions, or because they didn't know the answer. Regarding students' engagement, tutors observed they showed reduced interest in topics that were already clear, or they were distracted when programs had long theoretical sessions with poor interaction. The Moodle support has allowed to reduce pupils' disinterest, with great benefits from the lurking reduction point of view. Moreover, too long theoretical parts have been revised by reducing longer texts and providing only essential information, adding interactive parts too where they weren't. Inspired by these suggestions, the educational materials have been completely revised by means of structural changes to improve graphics and to further optimize programs for students with learning disturbs, as shown in **Fig. 6**). Greater attention has been paid to readability, changing the fonts and simplifying the graphical interfaces.

Fig. 6. Revised material on the right, compared to the original programs, on the left. In this case, we also added interactive games: students have to choose the correct type of brackets on the podium.

Each program has instructions explaining how to interact, and requests are stated in clear and consistent methods. The characters of *pirate* and his *parrot* has been given precise roles (see **Fig. 7**): the parrot is responsible for explaining theoretical concepts and rules or asking questions. Each costume has a different purpose, so that users better understand how to interact with the program. The pirate, on the other hand, guides the student through the practical parts, providing suggestions on how to deal with exercises, or how to solve it.

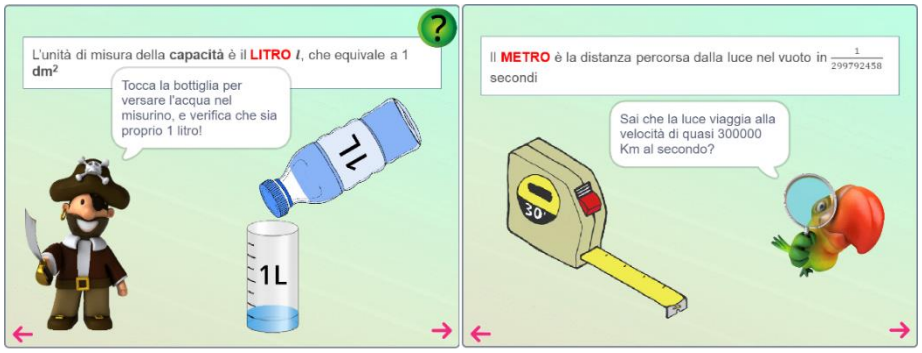

Fig. 7. Different roles for each character.

It is important to notice that the overall VCoP members has taken part in the success of the project:

- some students participating in the project (supported by the tutors) has become capable to feed the developed VCS with new stories developed in Scratch, about parts of the program not covered by the project; in this sense, they have evolved from the initial condition of lurkers to the knowledge contributor one, demonstrating how the approach founded on Competence-based learning was the important for them;
- the scalability of the VCS is a key factor for phygital learning implementation, meant as a *way to combine online and offline tools* [16] : in Binario 9 ¾ phygital education emerges from the possibility for the student to practically learn mathematics from an interactive story tailored on his/her characterics, maintaining the contact with physical context given by the existence of the VCoP. In other words, the student can obtain benefits from the gamification of the contents to learn without the drawbacks to feel left to his/her own device during the learning activities;
- as a consequence of the previous point, it is important to highlight the role of the VCS in increasing the student performance in his/her learning process. The target student of Binario 9 ¾ is characterized by specific learning disorders or cultural barriers, like difficulties in understanding Italian language. The development of learning by means of digital stories in Scratch, exploiting opportune fonts and texts has been thought to support them to overcome these barriers, without using too

aggressive or immersive technologies (like e.g. virtual reality), in order to help them to familiarize with Italian language and mathematics maintaining a more traditional approach (in line with the phygital guidelines). In this sense, results obtained (described in the next section) have been encouraging.

During the second phase of the project, ended in September 2023, activities have been carried out at distance, exploiting the Moodle website, and the VCoP has been extended to teachers too. The website is still active and is still possible to visit it to access the contents.

5 Results and Discussion

During the first phase of experimentation, skills tests and satisfaction tests were conducted to evaluate the improvement achieved, and to assess the appreciation of this teaching method [4].

Table 1. Evaluation Test Results at IC Bellini before and after Binario 9 ¾ content adoption.

IC Bellini - Initial and final skill tests				
Class	**Attendance (48 hours)**	**Average Initial Results**	**Average Final Results**	**Variation**
1st	83.33 %	56.70 %	90.60%	59.79%
2nd	88.19 %	8.10 %	78.30 %	866.67%
3rd	52.77 %	42.10 %	41.70 %	-0.95%

Table 2. Evaluation Test Results at IC Convitto Morandi before and after Binario 9 ¾ content. adoption

IC Convitto Carlo Alberto Morandi - Initial and final skill tests				
Class	**Attendance (26 hours)**	**Average initial result**	**Average final result**	**Variation**
Remedial group	78.60 %	29.8 %	58.90 %	59.79%
Enhancement group	91.46 %	72.4 %	83.90 %	15.88%

Two distinct tests have been submitted to target students, at the beginning and at the end of the project respectively. The tests contained both theoretical questions and practical exercises about the topics explored during the training sessions, grouped according to the student age. **Table 1** and **Table 2** presents the results obtained by the students. At IC Bellini School, students from first and second classes have greatly improved their performance in all topics, as shown in **Table 1**. Most of the students recovered from the very poor results of the initial tests, confirming the project effectiveness. As for the third grades, most of the students failed to achieve proficiency in all topics. This may be a result of the extended quarantine period that affected these students. At *IC Convitto School*, students were homogeneous with respect to the age feature, thus they were divided into two groups according to their initial level of skills, on the basis of results obtained in the entrance test: *Remedial group* was composed of students with a low level of competence, for which the aim of the project was to support them in developing an opportune problem solving method for maths problems and exercises through Scratch stories; *Enhancement group* was made of students with a discrete/good level of competence, for which the aim of the project was to increase their overall performance in solving problems and exercises by means of Scratch stories.

Although not all the students have reached sufficiency, almost all of them showed improvements, as presented in **Table 2**: in particular, the variation between the entrance and the final test reflects the nature of the groups and the different impact of the developed VCS on them. In this sense, we can certainly state that both goals of the project introduced above have been fully met. A satisfaction survey has been submitted to students to evaluate the impact of the Binario 9 ¾ project on their learning capabilities. The questionnaire was composed of 8 questions evaluated on a 5-point Likert Scale. At the beginning of the project, 43% of the students thought they were very bad or bad in Math. At the end, 44% of them thought they have improved thanks to the project.

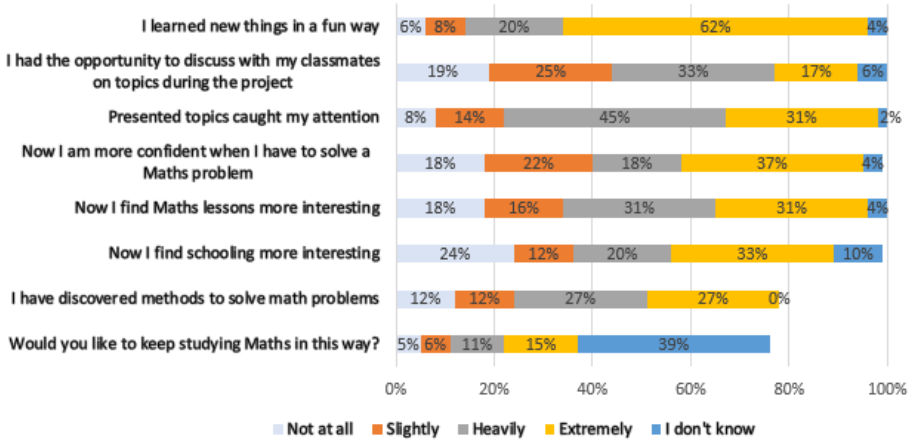

Fig. 8. Answers percentages to some of satisfaction test questions.

Fig. 8 shows the questionnaire content together with the percentage of answers obtained. It is possible to deduce that: 82% of students found the activities enjoyable; 76% of them said the topics caught their attention; 62% of students consider they have increased their interest in Math, and 55% have been able to increase their confidence in solving mathematical problems. An interesting point to highlight is that, although the overall usefulness perception, only 26% of students stated they would like to continue studying Math in this way, while many students (39%) had not opinion about that. Comparing the answers to this question between the two schools, as shown in **Fig. 9**, it is important to point out that most of IC Bellini students answered more positively than IC Morandi ones: this could be probably due to the continuity of the project in this school, which was less affected by lockdowns. Another difference may be the interest in school activities as a result of this project, with higher improvements among IC Bellini students rather than IC Convitto Morandi ones. Comparing these two schools, it's clear there is a gap between them in the perception of a self-improvement in maths: at IC Bellini more than the half of the students believed they have improved, while at IC Morandi the percentage is lower. This result seems to confirm what stated above on lessons duration and interruption.

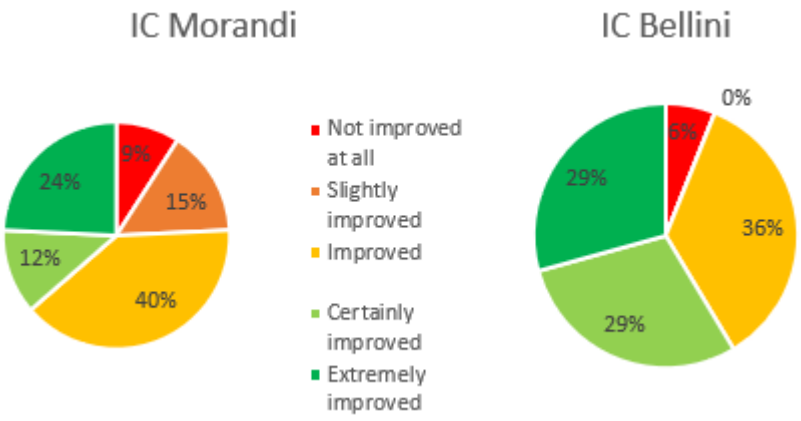

Fig. 9. Math improvement perception, compared in the two schools.

6 Conclusions and Future Works

The Binario 9 ¾ project finished last September, but the Moodle website is still active and it is still possible to register and use the proposed materials, acting both as a student and as a teacher. Indeed, one of the scope would be the test of this learning method on a larger community of students, to enhance the amount of data collected about its effectiveness. On the other hand, an interesting direction to address future research would be to consider the Binario 9 ¾ VCoP from the teachers' perspective:

to this aim, we are going to launch a research project in the field with the support of the Department of Informatics, Systems and Communications of the University of Milano-Bicocca, in the frame of the Piano Nazionale Lauree Scientifiche[2].

This point will allow to build up a new measures of performance based on the application of *sense of virtual communities* (SOVC) indexes. In [1] the authors proposed recently to adopt a revised version of SCI [8], namely SCI^2 [9]: this index consists of 24 closed-ended items measured on Likert-like scale. The items are grouped into four dimensions: reinforcement of needs (RON), membership (MEM), influence (INF) and shared emotional connection (SEC). The total sense of community index (TSOC^I) is the summary of the Q_i, where Q_i is the value in the range [0...3] given by the user to the i-th question. In our study, we are interested in evaluating if the underlying virtual community systems can support communities of practice to evolve. To this aim, we will apply the notions of lurking, seeking, or contributing communities on the basis of their TSOC^I value . In addition to teaching Scratch to middle school students, the production of Math Digital Storytelling as a class project could be proposed as final assignment, to further increase cohesion and to train other skills, such as teamwork skills and collaboration. To this aim, a final goal of the project could be the distribution of the educational material to other communities, like e.g. the Scratch programmers one.

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