# Creativity Enhanced by Technological Mediation in Exploratory Mathematical Contexts

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**Abstract.** Creativity is fundamental to the sustainable development of societies. However, lack a School model that promotes it. In Mathematics, exploratory open-ended and challenging tasks, based on the effective resolution of and well oriented confrontation and discussion moments are needed to foster this skill. The digital revolution brought a set of technological tools with great potential in the educational context, particularly to engineer collaborative work environments and to mediate communication. But, the use of these tools remains inadequate.

The main objective of this qualitative study was to evaluate the potential of digital technologies to construct collaborative environments and as communication mediation tools and how these dynamics influence the development of creativity and communication in Mathematics as well as students' (10–11 years old) digital literacy.

Preliminary results suggest that the implementation of these technologies allow to develop cross-curricular and specific mathematical skills and digital literacies, and truly change the current educational paradigm.

**Keywords:** Creativity · Technological mediation · Mathematics · Exploratory tasks

## 1 Introduction

The digital revolution is transforming the way we work, think, and "connect" with profound implications for cultural values (Castells 2007; Lévy 2010) and giving rise to new important societal challenges. We live in times of great uncertainty and unpredictability and one purpose of the "School" as an institution is to develop in its students an understanding of this fluid and changing world they live in. Ensuring a sustainable future for the next generations in this context requires a strong focus on innovation and creativity. However, our students have been taught and trained in mechanized procedures (Robinson 2011). Creativity, as a transversal skill to all areas of knowledge, has thus

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been systematically curtailed by the educational systems of the industrialized world (Robinson and Aronica 2009). Several investigations (Franke et al. 2007) confirm that Maths continues to be taught in the traditional routine way where moments of mechanized practice follow the instructional exposition and subjects are explored in a disconnected way, isolated from other disciplinary areas and everyday life (Franke et al. 2007). To counter this practice, and given the demands of our society, students should be given opportunities to undertake challenging mathematical tasks that promote mathematical reasoning, communication, and creativity, that flourishes from confrontation and collective discussion of exploratory learning tasks.

Digital communication technologies have been widely adopted by European educational institutions: 96% of schools have access to the Internet and 80% of teachers say they recognize advantages in using computers (Korte and Hüsing 2006). But they are used especially for administrative and management purposes and there were no significant pedagogical changes, namely in terms of teaching strategies, classroom resources and students' learning (Punie et al. 2006). In fact, pedagogical approaches, with decisive impact on students' learning, are rarely creative (Redecker et al. 2009) and technology remains, mostly, to support direct teaching techniques. Thus, understanding the relationship between technology and the development of creativity in Maths in exploratory learning contexts was the main question for this study. The main intention was to evaluate the potential of these digital technologies in the construction of collaborative learning environments and as mediators of communication and how these dynamics influence the development of creativity in problem solving, mathematical communication and, simultaneously, of technological skills. Thus, we sought to contribute to the multimedia in education field. In particular, we aimed to better understand the contexts and phenomena associated with Maths when mediated by technology, and how this relationship determines, in the early years (10–11 years old), the development of emerging skills such as creativity (Coelho and Cabrita 2017).

## 2 Theoretical Framework

Common people still see creativity as the product of talent and personality traits (Amabile and Pillmer 2012). Studies in the 1960s and 1970s (Davis and Manske 1968; Speller and Schumacher 1975) reinforced the idea that creativity was associated with innate individual talent of a few exceptional individuals and could not be learned and taught. But Silver (1997) states that creativity is associated with a deep and flexible knowledge, which implies hard work and reflection and, consequently, should not be focused on individual exceptionality but understood as a phenomenon capable of being developed through education and training. In creativity, novelty is a central aspect, but it is not a sufficient feature, products need to be relevant, effective, ethical and moral concerns should be attended to (Cropley 2011; Runco and Jaeger 2012). So, creativity can be defined as a social phenomenon that observes specific rules and can be promoted or inhibited through social factors (Cropley 2011). In Maths, Gontijo (2007) understands creativity as the ability to find differentiated (unusual) ways of solving problems and finding original resolutions for non-traditional problems.

Several authors (Alencar 1990; Leikin and Pitta-Pantazi 2013; Silver 1997) consider that creativity in Maths is characterized by several dimensions, which can be measured through: fluency – the quantity of different ideas produced on the same subject; flexibility – the number of responses of distinct categories, which reflects the capacity to change reasoning; originality – the ratio between the frequency of an infrequent or unusual response and the number of students observed; elaboration – the amount of details of a given idea and it can be measured by their quantity. Almost two decades have passed since Cropley wrote that conventional education often hampers the development of the skills, attitudes and motivation necessary for innovation and, among other things, it perpetuates the idea that there is always only one correct answer to each problem. In this context, students only acquire skills that are necessary to produce orthodoxy (Cropley 2009). It is astounding, yet at the same time disturbing, that this vision remains so current/prevalent.

The development of higher mathematical skills such as creativity is not compatible with low complexity tasks mainly focused in a specific mathematical topic. Rather, it requires challenging tasks capable of stimulate intra-mathematical, other areas and day-to-day connections. These tasks allow students to approach Maths in a more realistic and positive way and encourage more diverse approaches. After their effective resolution by the students, it is critical to discuss them collectively (Stein, Engle, Smith, and Hughes 2008), aspect that deserves special attention in this ongoing research. So, teacher's role must evolve from an "instructor" and "guardian of the mathematical correction" to the "engineer" of these learning environments (Stein et al. 2008).

Being *connected* is a characteristic feature of the Knowledge Society, but knowing when, what and how to connect is a critical meta-skill (Castells 2007; Downes 2012). Siemens (2004) proposes Connectivism, as a learning theory for the digital age, based on the creation, maintenance and use of network connections (nodes) by its users and whose relations arise from their common interests. Nowadays, these interactions, markedly mediated by technology, are amplified by the enormous potential of the multidirectional communication established between individuals and institutions, and constitute true virtual communities. But some studies point out the difficulty of controlling students' activities in lessons, such as Maths, which take place in computerized laboratories or by using portable devices with Internet access (Galluch and Thatcher 2011; Tarafdar et al. 2013). Classroom Management Software [CMS], such as iTALC, allows the effective performance of these functions within the digital classroom. And Microsoft Office 365 contains a set of applications and services integrated in the cloud (cloud computing) that allows the development and management of activities in technological contexts. These applications can help to create integrated learning environments with features like file/resource sharing and synchronous and asynchronous interaction between participants, for example to launch topics and discussions in forums and groups, provide content in different ways – text, video or audio – or to track and monitor students' work at home, in several platforms and operating systems and at multiple scales. Although these digital resources are widespread in schools, they rarely correspond to significant changes in pedagogical strategies. Hence, in these new educational scenarios, new approaches are required to enhance their advantages while minimizing any constraints. These strategies must develop more favorable attitudes towards Maths and essential skills such as creativity and critical thinking and foster a better understanding of mathematical concepts involved. Digital tools can offer a spatial and temporal expansion of the classroom, reducing, in certain contexts, costs for students. This can lead to a growing diversification of the school population, more personalized learning and develops students' autonomy (Farnsworth et al. 2015).

There are several ways of combining face-to-face and distance activities. The Flipped Classroom (Bergmann and Sams 2014) is a model that reverses the traditional instructional process. A distance education strategy is adopted, where teachers are responsible for making assignments with a careful choice of resources – audio and video casts, links to specific content and open educational resources – that are delivered, in a digital platform, to individuals. Then follows the presential moment with the discussion and exploration of the presented tasks carefully guided by the teacher (Bergmann and Sams 2014).

## 3 Methodology

The qualitative case study selected (Bogdan and Biklen 1994) focused on three groups of two 6th grade students (11 years old) to allow an in-depth study. Their selection and distribution considered their mathematical performance – low, medium and high –, their expectations regarding Maths (only the most performant group saw utility in the discipline) and they all attended to every moment of the instructional sequences performed in a learning Math lab. Every session was a complement to formal Maths classes and were developed in a context close to them but the frequency was voluntary. The researcher had an active participation since he conducted all the events resulting from this research. The data were collected through several techniques: participant observation carried out by the teacher/researcher, supported by field notes and Logbook; survey, through questionnaires and interviews with the case students and a documentary analysis of students' task resolutions, Initial and Final tests and official documents produced by the school. First, we applied an Initial Questionnaire (IQ) and a ICT test to obtain information about student habits and basic knowledge of digital tools and applications, including Dynamic Mathematics Software [DMS] and social networks. This allowed us to calibrate the exploratory tasks in the two instructional sequences. An Initial Test (IT) in the beginning of each, solved with paper and pencil, checked previous students' knowledge on several mathematical topics and advised adjustments in future tasks. It also allowed us to assess students' improvement, when results were compared with the same Final Tests (FT) at the end of each sequence. Throughout this initial stage, the customizable and secure cloud computing Office 365 platform was used. Mainly, was used social features, like Yammer, allowing the creation of groups with different levels of interaction and access; synchronous and asynchronous communication tools – Outlook Mail, Outlook Groups and Skype; the streaming application Videos, to broadcast audio and video content; OneNote, as the digital daily notebook when working with computers, tablets and smartphones, on iOS, Android and Windows platforms. We implemented two didactic sequences in several sessions throughout the year, each consisting in a set of exploratory tasks with increasing complexity, both mathematical and technical. Task resolution was supported by digital tools – Interactive Whiteboards, Roamer robots, DMS, visual programming environments, namely KODU – and measuring instruments, manipulatives and paper and pencil. The physical classroom environment was mediated by iTALC, which allows to monitor students' efforts, make simultaneous demonstrations on their desktops and remotely control their terminals. It also allows students to share, on the whiteboard, their own desktop, which was particularly important in the presentation and discussion stage of task resolution. The teacher's desktop was constantly projected in the interactive whiteboard to support real-time interaction with every computer/tablet in the classroom (see Fig. 1).

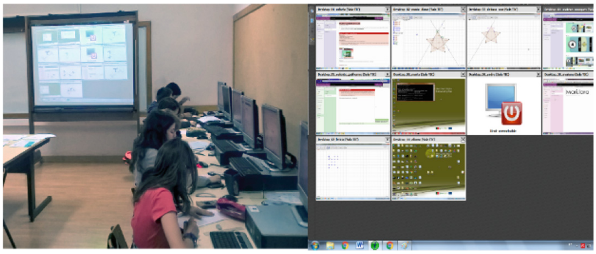

**Fig. 1.** The teacher's desktop projected *(left)*. iTALC with nine active workstations *(right)*.

The first didactic sequence was implemented at the beginning of the second trimester and was divided into three parts: the first one was aimed to develop basic skills to operate a Roamer robot in numerical, geometric and algebraic contexts, namely by exploring circuits and measuring and proportions and ratios through scales. The second part contained more open-ended tasks, using the Roamer to draw increasingly complex flat figures involving concepts related to angles, lines, perimeters and areas, measuring, spatial and proportional reasoning. The third part contained a set of programming tasks in Kodu. They were aimed to develop logical reasoning and to provide a strong understanding of the programming environment that would be critical to solve more advanced tasks. These included the construction of small two-dimensional geometric scenarios (involving areas and perimeters of flat shapes) and more open and complex three-dimensional "worlds" with advanced notions of volumes (see Fig. 2).

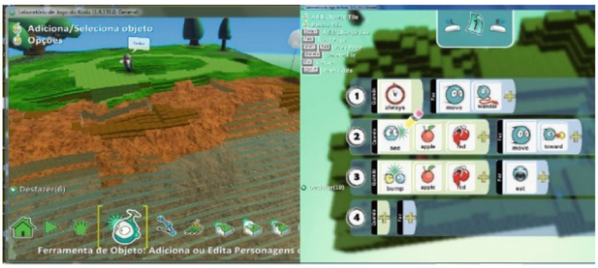


**Fig. 2.** 3D world *(left)* created by students in KODU and visual code lines *(right)*.

The second didactic sequence was implemented in the third and last trimester. The resolution of exploratory activities, with several open-ended situations, required instruments, paper and pencils and the DMS GeoGebra, while exploring (compositions of) isometries – translation, reflection and rotation – and the concept of symmetry associated with the last two transformations. Prior to physical classroom sessions, we provided critical content in different formats – video, audio and text – through the Office 365 services and applications.

Students reach the classroom sessions with good knowledge of the subjects, instruments and tasks to be carried out, having already begun discussions and previous analysis on the group forum (Yammer) and in OneNote digital notebook, which allows "handwritten" annotations (using a digital pen on the tablet) and which can synchronize in real-time. Thus, the face-to-face moment in the classroom was greatly optimized because students had a prior contact with the main concepts. So, the sessions were dedicated to solving and discussing more open and complex tasks, which contributed to a more solid mathematical conceptualization and to the development of mathematical competence. The presential moment was implemented in four different stages (Stein et al. 2008). In the first stage, the task was orally presented, and some relevant aspects were clarified by the teacher. In the next stage, all groups solved their tasks autonomously but under teacher's supervision through the CMS or OneNote when tasks were performed in the computer/tablet. In the third stage, the working groups presented their resolutions. Computer tasks were assisted by the CMS features. Finally, students drew conclusions writing short reports on the digital notebook. Every group's resolutions were discussed by the whole class and everybody took note of the main ideas. At the end of each session, we "collected" students' work and analyzed the field notes to improve the Logbook. All these documents were assessed before the next session, so that the plan could be changed, if necessary. We intended to create an environment where students could make mistakes, with time to reason at their own pace and with opportunities to discuss and share their own ideas with everyone. This environment, physical and virtual, was a "place" of confrontation and discussion where technology was used mainly as a social collaborative learning and mediation tool. An open "classroom" beyond physical walls and the constraints of institutional schedules, capable of strengthening a collaborative working culture.

After the implementation of the two didactic sequences, we used a Final Questionnaire (FQ) and conducted several interviews with the selected group students. The Final Questionnaire aimed to collect data on their opinion about the entire project. The IT and FT, in each learning sequence, had a double purpose: the IT gave us information on the pupil's knowledge and skills before the didactic sequence implementation and the FT allowed us to assess their progress throughout the study.

All collected quantifiable data are under statistical analysis using Excel and will be presented through tables and graphs. Qualitative data are being subjected to content analysis through qualitative analysis software, using categories related to: Geometry – Angles and lines; spatial reasoning; perimeters, area and volume; measuring and; isometries and symmetry; Proportional reasoning and dimensions of Creativity.

## 4 Results

A preliminary statistical and qualitative analysis, ongoing, of the collected data allow us to present some previous results. Direct observation and the analysis of students' answers to the FQ and to the interview show the importance they gave to the structure of the learning space/environment, to the technological nature of the task, its exploratory and open nature and how they were addressed and discussed in the classroom as well as their contribution to the development of their creativity. The comparative analysis of the IT and FT made it possible to verify that the students with lower performance in Maths seemed to benefit more from the technological nature of the environment and the tasks (see Table 1).

**Table 1.** Initial and final tests results (%).

| | | IT 1 | FT 1 | IT 2 | FT 2 |
|---|---|---|---|---|---|
| Group 1 | Pupil a | 28 | 46 | 36 | 51 |
| | Pupil b | 35 | 53 | 38 | 58 |
| Group 2 | Pupil c | 61 | 68 | 72 | 79 |
| | Pupil d | 52 | 60 | 57 | 68 |
| Group 3 | Pupil e | 86 | 91 | 87 | 95 |
| | Pupil f | 84 | 92 | 86 | 91 |

Most students stated in the interview that the proposed situations were familiar and exciting to them, and made sense of the mathematical contents. They further mentioned that the availability of content in various formats accessible through different platforms was very useful and versatile. They appreciated the prior contact (in Videos and OneNote) with the content since they could study and prepare the future session tasks. They also reported that synchronous (through Yammer and Skype) and asynchronous interactions (through Yammer, Outlook Groups and Email) with their colleagues and/or teacher helped them to clarify some doubts and to see other perspectives. At the beginning, students were unaware these applications but learned how to use them quickly and spontaneously – *"Several students began using the Yammer's synchronous communication tool to communicate between them and to ask me questions about the tasks. They did it from home computers and smartphones"* (Logbook entry, 06/01/2016). In these interactions, some students spontaneously assumed leadership roles – *"Two students asked to have admin rights in the Yammer forum. They are natural leaders and we gave them that role"* (Logbook entry, 14/01/2016). All students especially enjoyed the OneNote "digital notebook", wherewith they could receive real-time feedback, correct the resolutions, and complete assignments, anytime, anywhere, from home and in different devices, namely smartphones (see Fig. 3). But many mentioned that some software, such as instant messaging applications or social networks notifications, interfered negatively in their work, especially when it was accomplished at home. They added that they found it difficult to repress the curiosity and willingness to respond to their requests (Shirky 2014).

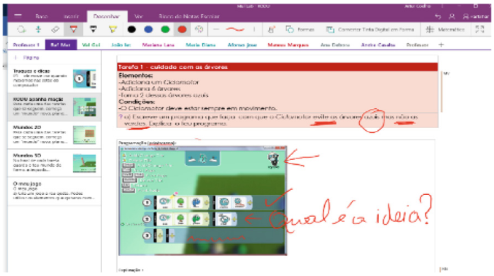


**Fig. 3.** Students solving a task in OneNote with real time feedback *(handwritten notes).*

Regarding creativity, we could also observe that the best performing students in Maths did not always look for alternative or improved resolutions to the tasks, and often was satisfied with a simply correct one. This also suggests that the exploratory open-ended nature of the tasks while having the potential to generate more creative resolutions (Fig. 4), needs an appropriate attitude to produce results.

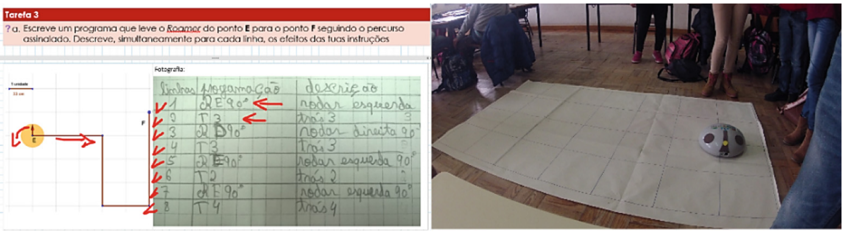


**Fig. 4.** To solve task Ia, 3students need to program the Roamer to draw the line on the left. This group use very peculiar way - every single instruction is reversed - but the solution is correct.

On this matter, two students stated in the interview that "*most teachers appreciate that the students respond to the questions as quickly and in as much agreement as possible with what they had been taught*" (15/06/2016). And that the factors that most inhibited them from freely participating in collective discussions were the criticism of colleagues and the overly sanctioning and, sometimes, aggressive attitude of some teachers. This is not due to technology. It is an attitudinal matter that the school must counteract. On the other hand, the group of students with better performance initially revealed some discomfort in sharing their resolutions. This attitude combined with a highly competitive spirit has proved an obstacle to the establishment of a true collaborative work culture, with impacts on the overall creativity. In contrast, it was observed that the group of students less "orthodox" in task resolution produced less calculated but riskier interventions, facing error in a more natural and relaxed way and tended to present more creative products – *"These group of students tried to solve the maze problem at least 5 times. Small but critical mistakes didn't draw them back. They still excited with the perspective of success."* (Logbook entry, 04/02/2016). Supporting this idea, several students answered, in the FQ, that they "lost their fear of making mistakes" realizing that trial and error strategies were part of the process (see Fig. 5). Several students also mentioned that when they observed the creative work of their colleagues and teacher's appreciation of it, they felt compelled to improve theirs – *"Original solutions tend to trigger strong reactions. Other students felt motivated and committed to improve their own work."*(Logbook entry, 20/04/2016).

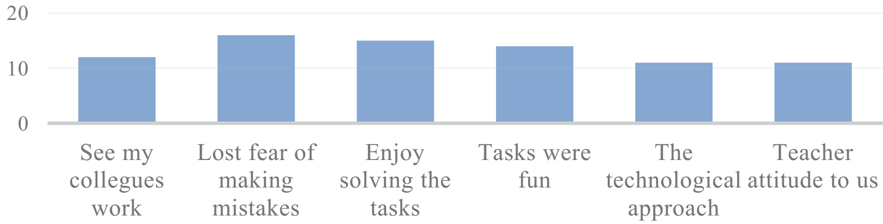


**Fig. 5.** Main aspects to foster creativity (number of students). Source: FQ.

All students declared, in the FQ and/or in the interview, that iTALC encouraged teamwork at classroom level. 80% of them also considered that this software was very important to manage the whole process of resolution, presentation and discussion, because it allowed the teacher to properly control all workstations. These aspects were highly valued by 85% of the students who noted the ease of interacting with the rest of the class and reported that knowing that the system was active kept them more focused on solving tasks. 90% of the students said that they *"strongly disagreed with the idea that this software's purpose was for controlling them."* It was also observable that the most fruitful discussions appeared when the students actually shared their ideas, and so they increased in number and quality throughout the study. And the increasing use of applications (even initially unknown) in specific contexts was observable (Fig. 6).

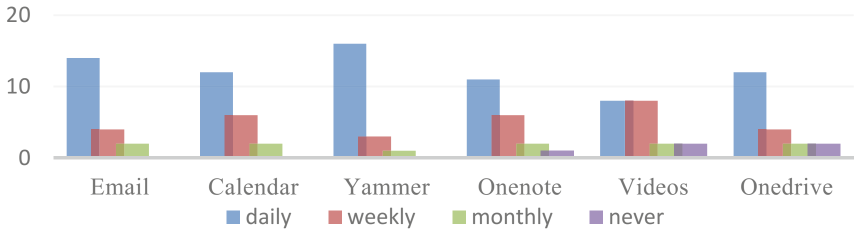


**Fig. 6.** The frequency of use of Office 365 applications (number of students). Source: FQ.

There was also an increase in the diversity of platforms used, in the access places and in the quality of the interactions, especially in OneNote. These facts support the perception of a sustained development of digital literacy in students.

## 5 Final Remarks

The research undertaken allows us to conclude, in a preliminary way, that the proper use of Office 365 Cloud Computing applications has several advantages that should be harnessed and enhanced. Gains in effectiveness in communication and interaction, through Email, Groups and Yammer, were high and using OneNote as a "digital notebook," capable of hosting a content library, task sequence protocols, and students' resolutions with real-time "hand notes", proved to be of great utility and versatility. These multi-system and multiplatform applications can really foster collaborative work within the class group, with other groups and with the teacher, anytime, anywhere. The availability of content, in different formats, in a digital platform and the use of synchronous and asynchronous communication tools together with a Flipped Classroom strategy can be used to build personalized learning environments not only of an intrinsic collaborative nature, but also very flexible and customizable, able to meet the specific needs of different students as stated by Bergmann and Sams (2014). The use of CMS in a classroom can foster dynamics interaction in a technological environment, providing opportunities to easily share ideas, to collaborate and to successfully support the discussion and confrontation moments, which reinforces results obtained previously by Coelho and Cabrita (2015). Associated with specific network filters, they also prevent students from diverting their attention to potentially disruptive requests, especially by social networks or instant messaging applications, thus keeping them focused and engaged with task resolution. Genuine interactions and sharing in a learning community are the core of a true collaborative working culture and, simultaneously, reinforce the sense of belonging and help to prevent the alienation of less proficient students, results that corroborate the defended by Farnsworth et al. (2015). These collaborative environments seem to increase students' autonomy and their levels of confidence, motivation and engagement, which implies a greater involvement in school life and a more favorable and interested attitude towards Maths.

We also concluded that implementing exploratory open-ended tasks in technological contexts seem to contextualize Maths, which becomes more clear, appealing and useful to the students. They felt challenged and motivated by these tasks and they worked hard to mobilize many mathematical concepts to solve them that are especially familiar to them when linked to technology. This aspect not only helped them to better understand Maths but also facilitated the emergence of more creative productions, collective and individual ones that grow from large group discussions and interactions, virtual and physical as stated by Levenson (2013). Students used different approaches when solving these tasks, and different procedures to find solutions, sometimes unique and with enriching details.

Therefore, there have been increases in various dimensions of creativity such as originality, fluency, flexibility and elaboration.

The study also indicates an effective and contextualized increase of students' digital literacies. Some of these aspects should be the object of much more extensive and detailed studies.

Their relevant role in teaching and learning Maths should have implications in teacher training.

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