Συνέδρια της Ελληνικής Επιστημονικής Ένωσης Τεχνολογιών Πληροφορίας & Επικοινωνιών στην Εκπαίδευση

Τόμ. 1 (2016)

10ο Πανελλήνιο και Διεθνές Συνέδριο «Οι ΤΠΕ στην Εκπαίδευση»

A socio-technical environment affording social creativity in the design of digital education resources for Math and Environmental Education

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Abstract

This study focuses on social creativity as manifested in the boundary crossing interactions that take place between educational professionals of diverse disciplinary backgrounds in the course of designing digital educational resources (called 'c-books', c for creative), aiming at fostering mathematical creativity. A socio-technical environment incorporating innovative technology for designing a new genre of authorable e-books (the C-book technology) has allowed designers to interact and communicate with boundary objects supporting the generation, refinement and appropriation of creative ideas, a process that culminated in the production of a c-book on 'Climate change'. By exploring and supporting these processes, the study has given us important insights into collaborative design that draws on social aspects of creativity.

Keywords: social creativity, socio-technical environments, creative mathematical thinking, design of digital educational resources, MC2 project

Introduction

Social Creativity has been proposed as a theoretical frame and as a construct for understanding and fostering creativity in collectives operating within specially designed technological environments, inseparably forming socio-technical environments (e.g., Fischer, 2001; 2005; 2011). Social creativity thrives on the diversity of perspectives that emerges when professionals from diverse domains are brought together in Communities of Interest (CoIs) (Fischer, 2001), in order to solve a design problem of common concern. A CoI is thus characterized both by heterogeneity in the disciplinary and/ or professional backgrounds of its members, and by the members' shared interest in dealing with a particular problem or task. The performance of the CoI members is facilitated and/or boosted in close interaction with 'technical' infrastructures specifically designed to amplify the outcome of their collaborative efforts. In such settings, challenges arise from the need to synthesize different perspectives, to exploit collisions between concepts and ideas coming from different disciplines, and to manage large amounts of information relevant to the design task (Fischer, 2011).
Socio-technical environments should exploit existing boundaries between diverse perspectives, disciplinary domains or knowledge systems that may cause breakdowns in communication, but are also proven to be unique sources of social creativity (Fischer, 2001). According to Akkerman & Bakker (2011) boundaries are defined as sociocultural differences leading to discontinuities in action and interaction which can be overcome through

T. A. Mikropoulos, N. Papachristos, A. Tsiara, P. Chalki (eds.), Proceedings of the 10th Pan-Hellenic and International Conference "ICT in Education", Ioannina: HAICTE. 23-25 September 2016. ISSN 2529-0916, ISBN 978-960-88359-8-6.

boundary crossing processes, i.e., efforts made by individuals or groups 'at boundaries' to establish or restore continuity in action or interaction across practices, leading to learning, identity development and re-conceptualization of practice. Boundary crossing is facilitated by 'objects' that fulfill a bridging function (Star, 2010) between intersecting practices. In CoIs, boundary objects support communication and shared understandings across the boundaries of different knowledge systems (Fischer, 2005). They come in the form of artifacts (such as specially designed computer tools), discourses (as a common language), or processes that allow the coordination of actions. Social creativity can be thus viewed as being located in and nurtured by the boundary crossing encounters among the CoI members, in the mechanisms and strategies employed and as an outcome of them. In fact, Akkerman & Bakker (2011) distinguished between four learning mechanisms triggered by boundary crossing encounters: (a) Identification of the boundaries between two (or more) 'worlds', when people come to act in these 'worlds' simultaneously. Although discontinuities may not be overcome, the learning potential resides in a renewed sense-making of different practices and related identities related to each of these 'worlds', (b) Coordination of activity flow acknowledging diverse 'sites', leading to the overcoming of boundaries, in the sense that continuity is established, facilitating future effortless movement between different 'sites', (c) Reflection on the differences between practices through perspective-making and perspective-taking, leading to a new and more enriched view of the world and one's identity, (d) Transformation leading to changes in practices, potentially the creation of a new, in-between practice, through dialogue and collaboration between individuals at either side of the boundary.

The study presented here addresses social creativity as manifested in the collective design of a c-book on 'Climate Change'. It is conducted in the context of the project 'Mathematical Creativity Squared' (MC2, www.mc2-project.eu), which aims at identifying new settings and methods for boosting creativity in the collaborative design of digital educational resources for creative mathematical thinking (CMT). These collaborative designs are based on the synergies between designers from diverse disciplinary domains, school levels or teaching subjects, such as those of Math and Environmental Education (Kynigos & Daskolia, 2014) and are being accomplished through the development and use of a new genre of technological environment for the design of digital educational resources for mathematics, that is an authorable e-book we call 'the c-book'. For the purposes of the MC2 project, social creativity in the design of c-books has been operationally defined as the generation of ideas and digital artefacts (widgets instances and the c-books) stemming from the combination of diverse knowledge systems and disciplinary domains, which result from the various boundary crossing interactions among CoI members and between them and the C-Book technology, and are considered – at least by the CoI members – to be: i) novel, ii) appropriate, and iii) usable to support creative mathematical thinking in their end-users (students). This definition employs the criteria of novelty, appropriateness and usability to qualify and rate creativity, as among the most widely acknowledged and used creativity criteria. Moreover, the project's approach to CMT is focused on the 'c-book CMT affordances', identified by the CoI members as guiding principles for designing c-books and evaluated in terms of the six main aspects of mathematical creativity stated in the literature: fluency, flexibility, novelty, elaboration, the social and affective aspect. In fact, our approach is mostly influenced by the problem solving - problem posing view of CMT (Silver, 1997).

The "Climate Change" c-book: theme, design process and product

The "Climate Change" c-book was designed with the aim to foster CMT in its prospective users (secondary school students), by inducing mathematical concepts and thinking processes in reference to identifying and/or analysing various dimensions of the climate change issue, and by promoting the students' active engagement and experimentation with them. Six CoI members were involved in this challenging task of designing a digital educational resource interweaving sustainability concerns about climate change with mathematical concepts and thinking processes. The whole design process lasted four months (25/3/2015- 21/07/2015) and resulted in a c-book comprising two sections: a) 'The Living Earth', dealing with the causes and effects of climate change (in 17 pages), and b) 'Making the Impossible Possible', focusing on the human role in inducing and enhancing climate change and practical solutions to reduce its impact (in 8 pages). In total 18 widget instances designed by using nine diverse widgets/widget factories were incorporated in the c-book.

The narrative devised revolves around George, a 12-year-old boy, inhabitant of an island located in the Pacific Ocean, who is forced to flee his homeland and become an 'environmental refugee'. Soon he decides to get into a journey around the world and to set up a youth movement against climate change using social media. George comes across several facets of climate change and becomes aware of the causes (the greenhouse gases) and consequences of it (global warming, melting of the ice sheets, rise of the sea levels, etc.), and the impact of various human activities on raising the levels of carbon dioxide emissions. As the narrative unfolds, several mathematical concepts 'emerge' or have to be 'identified' to facilitate the understanding of the various facets of the climate change issue. Students are prompted to experiment and tinker with widget instances to explore correlations between variables, estimate mathematical models, construct and interpret multiple representations, design 3D shapes (see, Fig. 1), make and investigate assumptions, draw and extend conclusions related to climate change dimensions, etc. Students' mathematical creativity is triggered through opportunities to establish connections between various representations of a concept (e.g., they are asked to depict and compare CO_2 emissions by drawing circles and disks), or to handle open problems (e.g., they use relevant information to estimate footprint values).

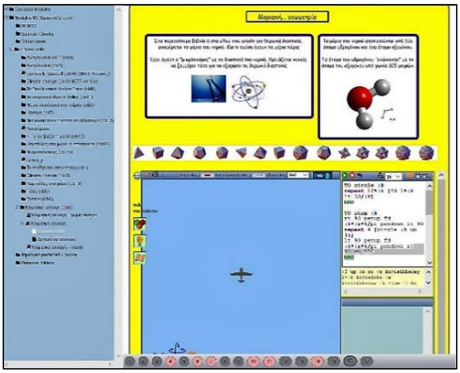

Figure 1. A 'climate change' c-book page asking users to correct the code for designing a 3D water molecule model

Method

The six Greek CoI members involved in the design of the 'Climate Change' c-book were teachers with different disciplinary backgrounds and expertise in mathematics, mathematics education, environmental education, drama in education and the design of digital tools for mathematics education. This diversity in knowledge domains, perspectives and cultures was meant to enhance the CoI's creative potential.

The C-book environment provides the 'CoICode workspace' (see, Fig. 2), a mind map for organized asynchronous discussions, wherein CoI members post and signify their contributions as being 'alternative', objectionable', 'contributory', or 'off task'. In their posts the CoI members can attach and refer to 'objects', such as online resources, texts or widget instances that reside in the c-book under construction. Furthermore, the CoICode tool provides the designers with the possibility to rate any idea or widget production in the form of CoICode contribution against the three criteria: a) novelty, b) appropriateness, and c) usability of the contribution, on a yes/no basis. A creativity score per contribution is then automatically calculated as the aggregate score from the votes received on each criterion and across raters. Based on this score all generated ideas per c-book can be classified in terms of creativity, as well as in terms of their degree of perceived novelty, appropriateness, and usability. For identifying highly creative ideas we devised the criterion of an idea having received a novelty score and/ or a creativity score equal to or above 50% of the number of CoI members. Thus, ideas in the 'Climate change' workspace that scored 3 or above at novelty and/ or creativity (with a maximum score of 5), were qualified as highly creative.

In addition, the C-book environment contains a platform which is the space for authoring (i.e., the C-book authoring tool) and the space where the students/users interact with the c-book (i.e., the C-book player). The authoring environment is designed to incorporate pages with dynamic and configurable widget instances accompanied by corresponding narratives. Designers/authors can write text, attach links, files or widget instances choosing from a set of available tools (e.g., MaLT, a 3D Logo-Based Turtle Geometry software, is a widget factory and a microworld of this factory is a widget instance). For the purpose of the current study the data collected and analysed were: a) the 270 contributions uploaded in CoICode from the outset of the design process until the final version of the c-book was released, b) the actual c-book produced in terms of structure (pages) and contents (the 'script', the widget instances and the respective narratives per page), and c) the creativity score calculated per idea posted as contribution in the CoICode workspace. Based on this score all generated ideas per c-book can be classified in terms of creativity, as well as in terms of their degree of perceived novelty, appropriateness, and usability. The analysis of the contributions posted in CoICode involved the selection and analysis of critical episodes of social creativity, i.e., selected segments of an activity (including discourse activity) with a single theme as a focus. Furthermore, we traced paths of socially creative ideas, which stretch over longer periods of time and include several critical episodes, in terms of the critical moments in their evolution from the initial to the final idea (i.e., an idea implemented and incorporated into some part of the c-book). The emphasis was on unveiling the social nature of the processes involved in the development of ideas and in the examination of the C-book environment features which added to the formulation, elaboration and cross-fertilisation of the CoI members' ideas. Generally speaking, the aim was to apply an in-depth lens on the boundary-crossing processes that took place between the CoI members and with the ideas and tangible artefacts produced out of their exchanges and interactions with the C-Book technology. The identification of creative ideas was guided and supported by the data automatically collected and analysed by CoICode, such as the creativity scores extracted per idea.

Results

Out of the 249 contributions (leaving out 'off task' posts) in the 'Climate change' workspace, 39 ideas were rated as highly creative. It is the case that most of the ideas that had a high rating in novelty scored high in creativity as well, as novelty weights more than appropriateness and usability in determining the creativity score of an idea.

The evolutionary path of a highly creative idea

The path presented below is related to the evolution of the idea of calculating and depicting the footprint of two main cities by circles and the negotiations it underwent until it was reified as a widget instance in the c-book. This idea received a high score in creativity according to the votes of the CoI members (see Table 1). The path includes in total 34 contributions that can be traced in different trees spread over the workspace. Part of it is shown in Figure 2. Below we provide decisive contributions from individual CoI members and stress the social nature of the processes involved in the development of the idea from its birth to its incorporation into a widget instance.

Table 1. Creative idea basic elements

				Score			
Code	**Date**	**Initiator**	**Title**	**Novel**	**Appropriate**	**Usable**	**Creativity**
39451	13/5/2015	Eirini	Math widgets	4	5	3	4

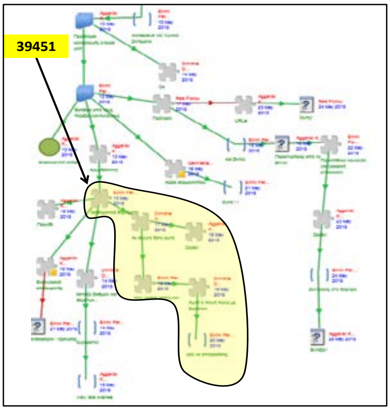

Figure 2. Excerpt from the CoICode workspace depicting the path of the footprint idea

The birth of the idea

The discussion begun with the suggestion of a new idea about the narrative of the c-book:

- Rea (environmental education researcher), 26/4/15: *"[...] I was thinking that for approaching the issue on a global level we could create a main character, an adventurous traveller (a backpacker) who wanders around the world and is confronted with the consequences of climate change [...]."*
- Eirini (mathematician and developer), 27/4/15: *"I like the idea. Let's have a look on it."*

- Kostas (environmental education researcher), 27/4/15: *"This is a very nice idea. Adventure and travelling appeal to kids of all ages [...] I believe that the following interactive maps that depict the dimensions of climate change at several parts of the world will help us develop the script and the widget instances. What do you think?"* (Kostas attaches two links to interactive maps to exemplify his idea.)
- Angeliki (math education researcher), 29/4/2015: *"This map can be compared with this one (attaches a link to an interactive map that depict global carbon footprints), so that we can pose questions like the following […]."*

According to her, such maps can aid students in comparing CO_2 emissions in different parts of the world, in making conjectures about the reasons behind such differences and in relating climate change to socioeconomic factors as well. At the same time in another CoICode tree a discussion was going on about prospective students' age. Angeliki (29/4) suggested designing activities for upper primary school students, such as calculating their own carbon footprint and comparing it to the average footprint of the inhabitants of Greece. Eirini (13/5) contributed to the discussion by attaching an external link to an online footprint calculator that students might use. It was not until then that Eirini (13/5), in a response to Angeliki, synthesized these two ideas, i.e., calculating and depicting on a map carbon footprint values and suggested the design of a widget instance where students compare and represent visually on a map CO_2 data for two main Greek cities, Thessaloniki and Athens.

The reification of the idea as a widget instance - negotiations on its pedagogical affordances

Dimitris (17/5), another mathematician and developer of the CoI, started designing the respective widget instance while being concerned about its complexity and the amount of data the students should have at their disposal in order to calculate their own and the average footprint of their city. Eirini (18/5) then gave Dimitris some instructions on how to better design the widget instance and after a few exchanges the discussion was suspended. Later on, Dimitris (10/7) proposed a new version in which students were to use demographic data and data from previous activities. At that point divergent pedagogical considerations fuelled a vivid debate on the inclusion of open-ended activities. On the one hand, it was argued that creativity can be stimulated by fuzzy activities, whereas on the other hand it was stressed that activities should have a clear focus and rationale to provide sound learning opportunities. A compromise was reached when Dimitris (20/7) reduced the degree of complexity of the activity including an online tool suggested by Angeliki. The activity was generally accepted as appropriate and was incorporated in the final version of the c-book (see Fig. 3).

Throughout this path a communicative exchange between an environmental and a mathematical perspective were brought together giving rise to a series of new, appropriate and usable ideas and widget instances to be generated and applied in the c-book. In addition, the role of resources in the development of creative ideas was critical. The interactive maps suggested by some CoI members were used as 'boundary objects' to translate them in different ways but also to enable understanding and bridge the diversity in the perspectives. For environmental educators, they were used to depict facets of the climate change impact (supporting a systemic approach to climate change by focusing on its global impacts), whereas for mathematicians they served as tools to represent and compare different amounts of CO_2 emissions by the size of a circle or a disk. However, at the same time they enabled the coordination of the activity so that both practices were combined efficiently in the design of widget instances, which were consequently rated by the designers themselves as creative. The successive versions of widget instances were thus employed as boundary objects, not only by facilitating communication and collaboration between the CoI members in the design of the c-book, but also because they enabled perspective-making and perspective-taking, managing this way to be transformed into 'creative' ideas and constructions. The specially developed socio-technical environment constituted of diverse practitioners bringing in their own perspectives and resources, enabled the articulation, synthesis and elaboration of ideas as well as their technological implementation. Thus, creative ideas could not have been realized if not supported by the affordances of the C-book environment.

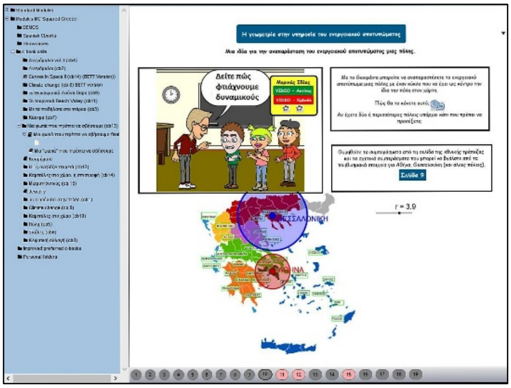

Figure 3. Calculating and depicting the average carbon footprint of two Greek cities

Discussion

Our study draws on Social Creativity, Boundary Crossing and their intersections as the most appropriate frameworks to identify and study social creativity in the design of c-books by educational designers. The findings suggest that the interactions enabled by an appropriately designed socio-technical environment enhanced the CoI designers' capacity to come up with ideas which they rated as creative. The affordances of the C-Book technology were at the centre of these interactions facilitating the generation of objects to 'think-with' and 'to-negotiate-about' (Fischer, 2011) and the continuous collaborative versioning of the various constituent parts of the c-book. What is more, it allowed the enrichment of the CoI's collective resource system through the sharing, reflection and transformation of individual resources to boundary resources, so that CoI members could draw on their own areas of expertise to contribute to the emerging, shared constructions. The diversity and complementarity of perspectives and identities within the CoI fuelled boundary crossing interactions. Two important boundary crossing mechanisms seem to have played a role as depicted in the evolutionary path of the creative idea reported here: coordination, as an important condition for establishing a communicative connection between the CoI members in terms of design suggestions and moves, revealing their efforts of translating them to each other's 'language', so that dialogue is maintained and shared design work proceeds and develops; and reflection as for example when the CoI members got into perspective-making and perspective-taking to identify and build on the others' contributions and shared key resources, or when they actually managed to collectively improve and turn an initial idea into a better elaborated idea or a new widget instance.
Our approach values the engagement of teachers in the design of digital educational resources acknowledging them as active contributors in participative cultures (Fischer, 2011)

and not only as practitioners involved in top-down integrations of technology in the classroom as suggested by other frameworks, such as TPACK (Mishra & Koehler, 2006). Involving teachers in all stages of the design process of learning activities involving the use and design of digital tools can transform them from passive users into active agents in the process of creating new cultures of practices capitalizing on the possibilities of digital tools (Fuglestad, Healy, Kynigos, & Monaghan, 2010). Socio-technical environments, like the one employed in this study, can serve as settings to study and deploy teachers' collaborative design of resources and act as a driving force for classroom innovations (Kynigos, 2015).

Acknowledgment

The research leading to these results was co-funded by the European Union, under FP7 (2007-2013), GA 610467 project "M C Squared". This publication reflects only the authors' views and the Union is not liable for any use of the information contained therein.

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