Social Creativity in the Design of Digital Resources Interweaving Math with Environmental Education
The Case Study of the Climate Change C-Book

Maria Daskolia[1,2], Angeliki Kolovou[1,3] and Chronis Kynigos[1,3]
[1]*Computer Technology Institute (CTI) and Press "Diophantus", 26-28 Mitropoleos, Athens, Greece*
[2]*Environmental Education Lab, Department of Philosophy-Pedagogy-Psychology, University of Athens, Athens, Greece*
[3]*Educational Technology Lab, Department of Philosophy-Pedagogy-Psychology, University of Athens, Athens, Greece*

Keywords: Social Creativity, Socio-technical Environments, Communities of Interest, Creative Mathematical Thinking, Climate Change, Design of Digital Educational Resources, Mathematics Education, Environmental Education, MC^2 Project.

Abstract: This study focuses on how social creativity is manifested in the collective design of digital educational resources (called "c-books", c for creativity) aiming to foster students' creative mathematical thinking. We investigate social creativity as *a process* by focusing on the boundary-crossing encounters taking place within a socio-technical environment constituted of teachers of diverse expertise interacting with each other and with the C-Book technology, while designing a c-book on "Climate Change". The analysis of two critical episodes shows that during the design process the socio-technical environment allowed the communication and coordination of diverse perspectives enhancing the designers/ teachers creativity and leading to the transformation of initial ideas into 'tangible' objects.

1 INTRODUCTION

1.1 Social Creativity in the Design of Digital Educational Resources

'Social Creativity' has been proposed as a theoretical frame for understanding and fostering *creativity in collectives operating within particular technological environments*. This approach, which was primarily put forward and developed by Gerald Fischer (Fischer, 1999; 2000; 2001; 2004; 2005; 2011) and his team (Fischer and Ostwald, 2005; Fischer et al., 2005), is based on the assertion that no human creation has ever arisen in conditions of absolute isolation from either other people or other people's ideas and works. It addresses creative performance as it grows out of the interactions among members of a specific group or community, and between them and particular computational media, technologies and artefacts.

The synergy between all participating parts constitutes a '*socio-technical environment*', an appropriate and purposefully designed setting for supporting social creativity to attain specific goals. This system consists of a community of creative practitioners, the *Community of Interest*, whose performance is facilitated and/or boosted in close interaction with *'technical' infrastructures* specifically designed to amplify the outcome of their collaborative efforts towards fulfilling the task at stake (Fischer, 2004; Fischer et al., 2005).

More particularly, a Community of Interest (CoI), differs from a Community of Practice (CoP) (Lave and Wenger, 1991; Wenger, 1998) in that CoI members are representatives of more than one CoPs, who were brought together to solve a particular problem of common concern. A CoI is thus 'defined' 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. This combination is suggested as a prerequisite for developing new insights to a problem or a practice (Bonifacio and Molani, 2003; Csikszentmihalyi, 1996).

Social creativity as a construct has been mainly conceived in relation to the *design* practice (Fischer, 1999; 2000). Design problems are recognized as complex, open-ended, ill-defined and fuzzy problems requiring the contribution of various

Daskolia, M., Kolovou, A. and Kynigos, C.
Social Creativity in the Design of Digital Resources Interweaving Math with Environmental Education - The Case Study of the Climate Change C-Book.
In *Proceedings of the 8th International Conference on Computer Supported Education (CSEDU 2016) - Volume 1*, pages 134-143
ISBN: 978-989-758-179-3

actors. Collaboration among professionals with various backgrounds and expertise is therefore considered a necessary prerequisite for addressing them. 'Learning design' or 'design for learning' (Laurillard, 2012), defined as the practice of devising effective learning experiences aimed at achieving defined educational objectives in a given context, is a more recent strand in the design practice, opening up a new field for teachers' professional development in the 21st century education systems. Under this perspective, teachers are encouraged to work collaboratively both within their own Communities of Practice, but also and more importantly beyond these, with other education professionals or with experts outside the education sector, and with the aid of emerging technologies, to creatively design effective and innovative teaching and learning processes and resources. Their participation in such contexts can promote quality and innovation in education along with their professional development (Emin-Martínez et al., 2014).

The 'Mathematical Creativity Squared' (MC2) project, within which research presented here is being conducted, builds on these theoretical perspectives and rationale, with the aim to identify 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 among other things on the synergies between designers from diverse disciplinary domains, school levels or teaching subjects, such as those of Math and Environmental Education (Kynigos, 2015a; Kynigos and Daskolia, 2014). This is being accomplished through (a) 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'* (c for creative), and (b) the adoption of a specific methodology based on the generation of particular Communities of Interest (CoI) consisted of teachers with different disciplinary, epistemological and/ or teaching backgrounds, brought together to collaborate and create new learning designs for mathematics.

Two focal design specifications for the design of such creative educational resources (the c-books) is (a) to interweave learning activities with narratives, and (b) to center them all around the identification and investigation of real-life and real-world problems. Both were decided with the aim to motivate students to get them more actively and creatively involved in 'finding the mathematics' hidden behind some of the challenging current issues of societal concern. These issues are by nature ill-defined, complex, controversial, value-laden, and require the application of various perspectives simultaneously to grasp them holistically (Daskolia and Kynigos, 2012). However, it is exactly their inherent messiness and complexity that make them 'good' examples of creativity-triggering topics, and amenable to foster students' creative thinking. It also turns them into "boundary objects" (Star and Griesemer, 1989; Daskolia and Kynigos, 2012), that is entities which can be interpreted and employed by more than one groups or communities in ways that make sense to them.

Dealing with issues of these characteristics at a pedagogical level provides many opportunities for teachers and learners to get engaged in dialogical forms of meaning-construction and perspective-sharing. This expands the "boundaries" of their knowing of and being in the world, both inside and across the realms of their discipline (Kynigos, 2007; Daskolia and Kynigos, 2012). Processes of this kind can be identified as *creative* appropriation of subject-matter and pedagogical knowledge.

1.2 Boundary-crossing Interactions as Agents of Social Creativity

One way of approaching and studying social creativity in the context of M C Squared project is as being located in and nurtured by the 'boundary crossing' encounters taking place among the CoI members, in the mechanisms and strategies employed by them, and as outcomes of these processes. 'Boundary-Crossing' and 'Boundary Objects' have been proposed by Akkerman and Bakker (2011) as a framework for approaching the "*sociocultural differences that give rise to discontinuities in action and interaction*" (p. 139). A Community of Interest (CoI) is such a setting where boundary crossing processes most expectedly can occur. This is because the different 'worlds' of the CoI members (represented in terms of their knowledge background, disciplinary domain, professional expertise, life experience, pedagogical values and/or epistemological perspectives) inevitably cause 'discontinuities'. But, they can also act at the same time as springboards for creativity, by mobilizing learning processes and re-conceptualisations of practice to overcome these discontinuities, through "negotiating and combining ingredients from different contexts to achieve hybrid situations" (Engeström et al., 1995, p. 319).

Boundary objects are 'objects' employed by people engaged in such interactions to be used for the negotiation and overcoming of such discontinuities and the 're-establishment of action and interaction' (Akkerman and Bakker, 2011). They actually facilitate boundary crossing processes by fulfilling a bridging function (Star, 2010) between their 'intersecting social worlds'. According to Star and Griesemer (1989) what turns an 'object' into becoming a boundary object is:

- its *interpretative flexibility*: boundary objects have different meanings in different social worlds, but at the same time they have a structure that is common enough to make them recognizable across these worlds,
- the fact they act as *means of translation*: they allow different groups to work together, based on a back-and-forth movement between ill-structured use in cross-site work and well-structured use in local work.

Akkerman and Bakker (2011) propose the following four types of mechanisms as being employed during boundary crossing encounters taking place between or within individuals. These are:

(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.

2 THE "CLIMATE CHANGE" C-BOOK: A CASE STUDY

The study presented here focuses on identifying and understanding how social creativity was manifested in the collective design of a specific c-book, namely the "Climate Change" c-book, produced within the context of M C Squared project. This c-book was collaboratively designed by members of a Greek CoI, comprised of educational designers/ teachers from diverse disciplinary backgrounds, school levels and teaching subject practices, making use of the C-Book technology.

2.1 The "Climate Change" C-Book: Theme, Design Process and Product

The "Climate Change" c-book unit was designed with the aim to foster creative mathematical thinking (CMT) in its prospective users (secondary education students), by inducing mathematical concepts and mathematical 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.

The selection of "climate change" as the narrative theme of the c-book was not made arbitrarily. Climate change is recognised as one of the greatest societal challenges of our times, encompassing various (environmental, economic, health and safety, food production, and other) dimensions (Intergovernmental Panel on Climate Change, 2015). It is well-documented through various observational records that the rate of climate change is now much greater than in previous periods. The last decade was the warmest ever recorded since modern measurement on global temperatures began. Continued global warming has led to a systematic decline in the Arctic sea-ice cover, and there is similar evidence with regards to snow cover, glaciers and the Greenland ice sheet. These phenomena have enabled acceleration of ice-melting and an increase in the mean sea levels, both with detrimental consequences for some coastal areas. Extreme weather events, such as hurricanes, cyclones and floods, seem to be also closely connected with climate change. Although natural causes play a role in enhancing climate change, there is almost unanimous consensus that the greenhouse gas emissions released from industrial, transportation, agricultural and other human-related activities are the main contributors to climate change. Carbon dioxide resulting from the combustion of fossil fuels (such as coal, oil and gas) is the main culprit in human-induced climate change.

However, although climate science has evolved our understanding of these phenomena, there is still much complexity about the climate system and

acknowledged limitation in the potential of science to address it, which leads to a great deal of uncertainty, unpredictability and controversy as to how climate change works and can be mitigated in terms of sustainability. It is this fact that turns 'climate change' into a 'wicked' and 'ill-structured' problem' (Rittel and Webber, 1973) and thus a challenging topic to address and deal with in educational practice (Daskolia and Kynigos, 2012). This kind of 'problems' ask for transcending the 'boundaries' between mono-disciplinary approaches and practices to inter-disciplinary and trans-disciplinary collaboration in the construction of knowledge (Lotz-Sisitka et al., 2015).

Six Greek 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).

The narrative devised revolves around George, a 12-year-old boy, inhabitant of an island located somewhere 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 using social media as a means to fight against climate change. George first visits Venice (a coastal city at high risk due to the sea level rise caused by climate change) and then Athens (a city suffering from air pollution). In each of these visits he comes across several facets of climate change and becomes aware of the causes (the greenhouse gases) and consequences of it (global warming, sea-ice cover decline, melting of the ice sheets, rise of the sea levels, etc.), and the impact of various human activities on disproportionally raising the levels of carbon dioxide emissions (i.e., through calculating the carbon footprint.

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. The narrative together with the respective widget instances form a challenging learning environment in which the students build and apply mathematical concepts to make sense of a real-life issue. The students' mathematical creativity is triggered through the learning opportunities provided to the students asking them to establish connections between various representations of a concept (e.g., students are asked to depict and compare CO_2 emissions by drawing circles and disks), or to pose and respond to open problems (e.g., students use relevant information to estimate footprint values).

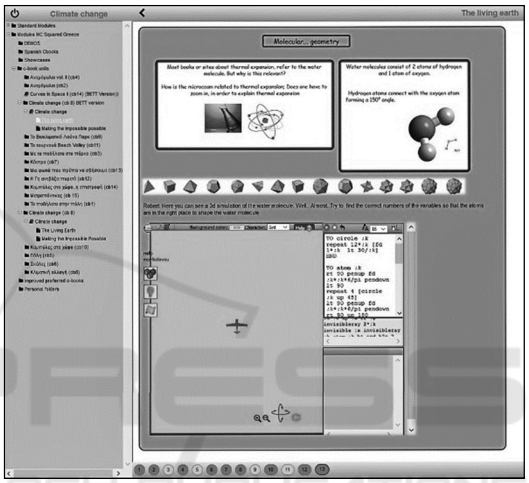

Figure 1: A 'Climate Change' c-book page asking users/ students to get involved in finding the best procedure to construct a 3D model of a water molecule.

2.2 Operational Definition for Social Creativity

Within the context of M C Squared project, social creativity in the design of c-books has been operationally defined as: the *generation of ideas* and *digital artifacts* (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 (CMT) in their end-users (students).

In this study we are interested in the processes that took place among the Greek CoI members and with the C-Book technology while designing the "Climate Change" c-book to foster CMT in

prospective users/ students. Our focus is on identifying the boundary crossing mechanisms that were employed in these interactions and how they affected the production of "creative" outputs, either ideas or more tangible products.

3 METHOD

3.1 Participants

The six Greek CoI members involved in the design of the "Climate Change" c-book were teachers with different disciplinary backgrounds and teaching 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.

3.2 The C-Book Environment

The C-Book environment provides the "CoICode workspace", a mind-map communication and collaboration platform for organized asynchronous discussions with compulsory meta-data, pertaining to the creativity aspects of the interaction process, e.g., the status of a post being' either 'alternative', 'objectionable', or 'contributory (see, Fig. 2). In their posts CoI members can also attach or refer to 'objects', such as online resources, text files or widget instances, as part of their exchange over the c-book under construction. Furthermore, the CoICode tool provides the designers with the possibility to rate any idea or widget production they have suggested and posted in the form of CoICode contribution. Their ratings can be against 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.

In addition, the C-Book environment comprises an 'authoring and playing' tool, which is a space allowing the CoI members to collectively design and construct the c-book (see, Fig. 3), and where the students can interact with it. Authoring of a c-book is based on the design and construction of a number of 'pages', each of them incorporating some dynamic widget instances (which can be configured by the c-book authors in order to fulfil specific design specifications) and are accompanied by

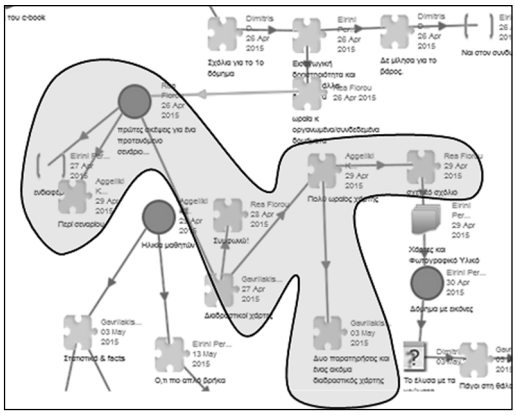

Figure 2: Excerpt from the CoICode workspace depicting CoI members' interactions as described in critical episode 1.

corresponding narratives. The designers/ authors can write text, attach links, files or widget instances out of a set of widget factories (e.g., MaLT, a 3D Logo-Based Turtle Geometry software, is a 'widget factory', and a microworld of this factory is a 'widget instance') which are available in C-Book.

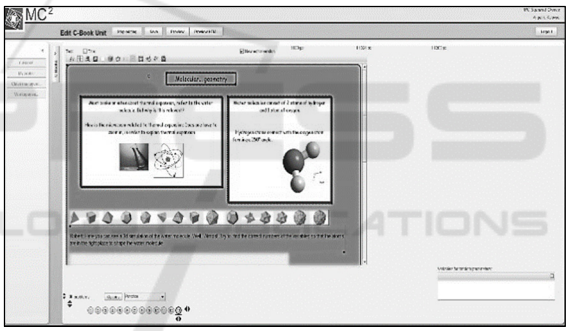

Figure 3: Snapshot of the authoring tool of the C-Book environment.

3.3 Data and Analytical Approach

The data collected and analyzed in the present study 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 scores calculated per idea posted as contribution in CoICode workspace.

The level of analysis employed in this case-study is in terms of identifying and discussing *critical episodes of social creativity,* i.e., selected segments of an activity (including discourse activity) with a single theme as a focus. 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 artifacts produced out of their exchanges and interactions with the C-Book technology. This qualitative approach to understanding social creativity in the design of c-books was chosen to shed light on the social nature of the processes involved in the design and development of the c-book. The identification of each critical episode was guided and supported by the data automatically collected and analysed by CoICode, such as time series interaction data and/or creativity scores extracted per idea.

4 FINDINGS

4.1 Critical Episode 1: The Design of Widget Instances as a Result of the Creative Interactions between Teachers of a Diverse Expertise

The first episode selected and presented here started one month after the outset of the design process. It lasted for 8 days and the participants in it were four members of the Greek CoI: two researchers in environmental education, a primary school teacher with an expertise in math education and a mathematician/ secondary school teacher. Their exchange is part of the evolutionary path of a specific idea, which received a high score in creativity according to the votes of the CoI members and was later reified as a widget instance in the c-book.

The discussion (see, Fig. 2) begun with the suggestion of a new idea about the narrative of the c-book:

Rea (environmental education researcher), 26/4/2015: [...] I was thinking that for approaching the issue on a global level we could create the main character as an adventurous traveler (a backpacker), who wanders around the world and is confronted with the consequences of climate change. [...]

Irini (mathematician), 27/4/2015: I like the idea. Let's have a look on it.

This idea was followed by other CoI members' contributions who were motivated to search for and upload in CoICode external links to interactive maps depicting the consequences of climate change or portraying different aspects of it (e.g., the relation between industrialization and greenhouse gas emissions):

Kostas (environmental education researcher), 27/4/2015: This is a very nice idea! Adventure and travelling appeal to kids of all ages [...] I believe that these interactive maps that depict the dimensions of climate change at several parts of the world will help us develop both the script and the widgets. What do you think? (attaches two links to interactive maps)

Angeliki (math education researcher) 29/4/2015: This map can be compared with this one (attaches a link to an interactive map with circles that depict global carbon footprints), so that we can pose questions like the following […]

It is noteworthy that Angeliki attempts to establish a common space of communication and exchange of ideas for the intersecting fields of Mathematics and Environmental Education by posting external links for others to comment upon. Searching for sources in a field other than her own, is for her a way to re-define her proper field and her CoI identity. This is done by getting connected with another field and trying to delineate how the former differs from the latter. Such a dialogical process of "othering" is a characteristic dimension of the *identification* mechanism in boundary crossing interactions.

Later on (13/5/2015), Irini picked up the idea of visualizing the quantity of CO_2 emissions and suggested the design of a widget instance, where the students are asked to draw circles or disks on a map, so to depict the carbon footprint of two main Greek cities. The widget instance was reified by another CoI member, Dimitris, a mathematician. Several elaborations of this widget instance took place, fueled by intense interactions between the CoI members until the final version was released and incorporated in the c-book unit (see, Fig. 4).

This episode shows how 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. 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, 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.

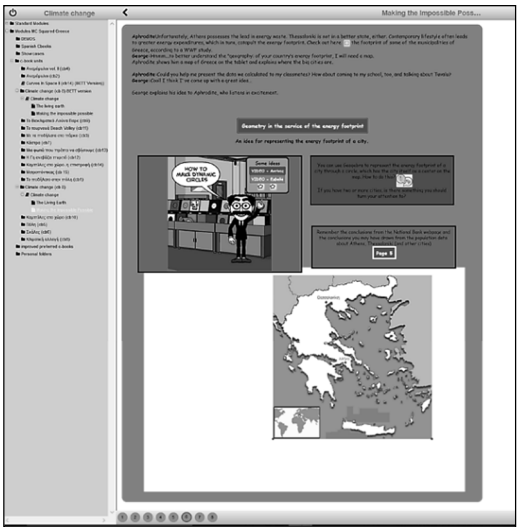

Figure 4: The final version of the produced "Carbon footprint" widget instance.

The 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 unit, but also because they enabled perspective-making and perspective-taking, managing this way to be transformed into 'creative' ideas and constructions.

4.2 Critical Episode 2: Narratives and Widget Instances Interweaved in the Design of the C-Book

The selection of the second critical episode was based on time series interaction data coupled with creativity scores calculated and provided by CoICode, helping us identify a segment of the discourse activity of the CoI quite dense in posting contributions, but also in putting forth and elaborating a number of highly creative ideas with regards to the narrative of the c-book. This episode started two months after the outset of the design process. It lasted for 18 days and all CoI members participated in it. At that time, a number of instances designed to afford mathematical creativity took the role of boundary objects while they were gradually evolving into more elaborated versions. These included, among others, constructing multiple representations of climate change dimensions (e.g., measuring the carbon footprint) and tinkering with 3D shapes. However, a decision on the narrative that would incorporate and join together all these elements was pending. The discussion (see, Fig. 5) begun with a suggestion on the outline of the script, based on an earlier idea about the main character, a backpacker who travels around the globe and comes across various consequences of climate change:

Sylvie (primary school teacher), 24/5/2015: […] By having a look at the discussion on the script, it came to me […] a story outline. Please send your feedback on the attached document.

Rea (environmental education researcher), 24/5/2015: […] in such a way we introduce a 'creative' character in the narrative. […] However, my idea was that our hero would travel and visit more places, so that we could get more glimpses of climate change as a global issue.

Eirini (mathematician), 26/5/2015: I don't understand this story. I can't realise how it connects with the widget instances already produced and the initial questions we posed for the design of this c-book. […] Whoever writes the story has to have a good understanding of the structure and the activities.

Kostas (environmental education researcher), 28/5/2015: […] trying to connect all the widget instances, I thought of starting writing a story based on a real incidence. Shall we go on this?

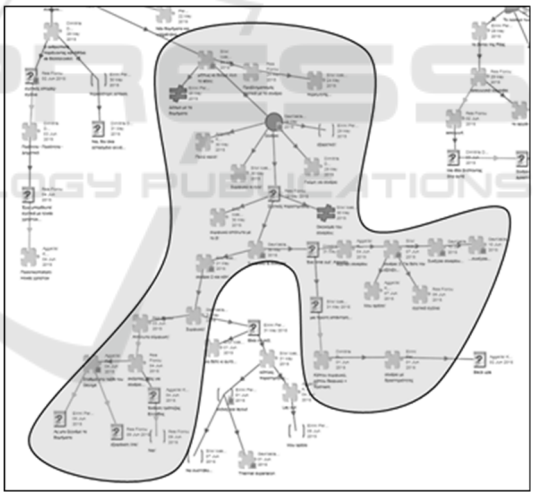

Figure 5: Excerpt from CoICode workspace depicting CoI members' interactions as described in critical episode 2.

This last idea turned yet into another boundary object, since it was unanimously accepted as novel and intriguing narrative with the potential to incorporate all the previously suggested widgets instances. Several refined versions of the narrative followed as a result of the exchange between the CoI members in CoICode. The flexibility of the scenario allowed its customization to earlier and newer ideas on the didactical design. And vice versa: it allowed the modification of the widget instances that had

already been produced, or inspired the design of new ones.

A communicative connection was established around the narrative as an evolving artifact bridging diverse perspectives. Continuity and effortless movement between these perspectives became the norm of interaction, and boundary permeability was enhanced, since mathematicians got involved into the construction of the narrative, while environmentalists connected dimensions of the climate change issue with ideas about mathematical widget instances. Perspective-making and perspective-taking were essential for the interweavement of widget instances with the narrative into a concise whole. Social creativity exemplified in the generation of a 'creative' script idea, was thus facilitated by the boundary-crossing exchanges that led to the transformation of the initial idea into some more 'tangible' products.

5 DISCUSSION

Our research employs the Boundary Crossing perspective as a framework to identify and study social creativity in the design of c-books by educational designers/ teachers. The findings suggest that this kind of 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, allowing for the meshing of narratives with dynamic constructionist artefacts-widgets, were at the center of these interactions, facilitating the continuous collaborative versioning of the various constituent parts of the c-book.

Moreover, our approach values the engagement of teachers in the design of digital educational resources. It acknowledges them as active creators of educational resources in participative cultures (Fischer, 2011) and not as just 'consuming' practitioners involved in top-down integrations of technology in the classroom as suggested by other frameworks, such as TPaCK (Mishra and Koehler, 2006). Socio-technical environments, like the one employed in this study, can serve as settings to deploy and study the teachers' collaborative design of resources and act as a driving force for classroom innovations (Kynigos, 2015b).

Regarding the CoI's involvement in boundary crossing interactions, four mechanisms seem to have played a role as depicted in the two critical episodes reported here: *identification*, through which new hybrid ideas come up in the course of the CoI's discussion of an idea-theme; *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 finally, *reflection* and *transformation*, as two important processes at the core of social creativity processes, 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 about the narrative into a better elaborated idea or new widget instance.

The design process of the "Climate Change" c-book was mainly focused on interweaving the widget instances with the narratives into a concise whole, a creative and definitely demanding endeavor, representing a focal characteristic of a new generation of digital educational resources. Integrating the various constituent parts of such an 'object' to bring it into existence in a complete and creative form is 'wicked' and thus a genuine design problem. As such, social creativity in the context of socio-cultural environments is identified as a necessary asset to invest on, since it can multiply the impetus for appropriately addressing issues of this kind. Solving dilemmas emerging while designing c-books (or any other types of new mediations with properties and functionalities which have never existed before, at least in the all-brought-together form), involves firstly articulating and posing these dilemmas, if we allow ourselves to think with the analogy of problem-posing and problem-solving. This is a task which is inherently creative and, in order to be facilitated and boosted, it needs to be situated in appropriately designed contexts, where designers collaboratively think and design not only *about* new technologies but also *with* these technologies.

Finally, 'climate change' worked well as a theme that inspired and enabled creative boundary transcendences from the part of all CoI members, and boosted the collaborative construction of new perspectives in teaching and learning about traditionally mono-disciplinary and normal science subjects, such as mathematics. This can be the case with other current sustainability issues, all sharing the characteristics of 'ill-structured' problems, by thus allowing for creative thinking processes to take place.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 610467 - project "M C Squared", http://mc2-project.eu. The c-book technology is based on the widely used Freudenthal Institute's DME portal and is being developed by a consortium of nine partner organisations, led by CTIandPress 'Diophantus'.

REFERENCES

Akkerman, S. F. and Bakker, A. (2011). Boundary Crossing and Boundary Objects. *Review of Educational Research*, *81*(2), 132-169.

Bakker, A. and Akkerman, S. F. (2014). A boundary-crossing approach to support students' integration of statistical and work-related knowledge. *Educational Studies in Mathematics*, *86*(2), 223-237.

Bonifacio, M. and Molani, A. (2003). The richness of diversity in knowledge creation: an interdisciplinary overview. *Journal of Universal Computer Science*, *9*(6), 491-500.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: Harper Collins.

Daskolia, M. and Kynigos, C. (2012). Applying a Constructionist Frame to Learning about Sustainability. *Creative Education*, *3*, 818-823.

Emin-Martínez, V., Hansen, C., Rodríguez-Triana, M. J., Wasson, B., Mor, Y., Dascalu, M., Ferguson, R. and Pernin, J.-P. (2014). *Towards teacher-led design inquiry of learning*. eLearning Papers. Retrieved March 6, 2015, from http://openeducationeuropa.eu/en/article/Towards-Teacher-led-Design-Inquiryof-Learning?paper=134810.

Engeström, Y., Engeström, R. and Kärkkäinen, M. (1995). Polycontextuality and boundary crossing in expert cognition: Learning and problem solving in complex work activities. *Learning and instruction*, *5*(4), 319-336.

Fischer, G. (1999). Symmetry of ignorance, social creativity and meta-design. In *Proceedings of the 3rd conference on Creativity and cognition* (pp. 116-123). New York: ACM.

Fischer, G. (2000). Shared Understanding, Informed Participation, and Social Creativity - Objectives for the Next Generation of Collaborative Systems. In R. Dieng, A. Giboin, L. Karsenty and G. De Michelis (Eds.), *Designing Cooperative Systems, The Use of Theories and Models* (pp. 3-16). Amsterdam, the Netherlands: IOS Press. Retrieved May 23, 2015, from http://l3d.cs.colorado.edu/~gerhard/papers/coop2000.pdf.

Fischer, G. (2001). *Communities of interest: Learning through the interaction of multiple Knowledge Systems*. Paper presented at 24th Annual Information Systems Research Seminar in Scandinavia, Ulvik, Norway.

Fischer, G. (2004). Social creativity: Turning barriers into opportunities for collaborative design. In A. Clement and P. Van den Besselaar (Eds.), *Proceedings of the eighth conference on Participatory design: Artful integration: interweaving media, materials and practices* (Vol. 1, pp. 152-161). New York: ASM.

Fischer, G. (2005). Social Creativity: Making All Voices Heard. In *Proceedings of the HCI International Conference (HCII)*, (published on CD). Retrieved May 23, 2015, from http://l3d.cs.colorado.edu/~gerhard/papers/social-creativity-hcii-2005.pdf.

Fischer, G. (2011). Social Creativity: Exploiting the Power of Cultures of Participation. In SKG2011: *The 7th International Conference on Semantics, Knowledge and Grids* (pp. 1-8). Los Alamitos, Washington, Tokyo: IEEE.

Fischer, G., Giaccardi, E., Eden, H., Sugimoto, M. and Ye, Y. (2005). Beyond Binary Choices: Integrating Individual and Social Creativity. *International Journal of Human-Computer Studies (IJHCS) Special Issue on Computer Support for Creativity (E.A. Edmonds and L. Candy, Eds.), 63*(4-5), pp. 482-512. Retrieved May 23, 2015, from http://l3d.cs.colorado.edu/~gerhard/papers/ind-social-creativity-05.pdf.

Fischer, G. and Ostwald, J. (2005). Knowledge communication in design communities. In R. Bromme, F. W. Hesse and H. Spada (Eds.), *Barriers and Biases in computer-mediated knowledge communication – and how they may be overcome* (pp. 213-242). Dordrecht, the Netherlands: Kluwer Academic Publishers.

Intergovernmental Panel on Climate Change (2015). *Climate Change 2014: Mitigation of Climate Change* (Vol. 3). New York: Cambridge University Press.

Kynigos, C. (2007). Half-Baked Logo Microworlds as Boundary Objects in Integrated Design. *Informatics in Education, 6*(2), 335–358, Institute of Mathematics and Informatics, Vilnius.

Kynigos, C. (2015a). Designing Constructionist E-Books: New Mediations for Creative Mathematical Thinking?. *Constructivist Foundations, 10*(3), 305–313.

Kynigos, C. (2015b). Constructionism: Theory of Learning or Theory of Design? In S. J. Cho (Ed.), *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 417- 438). Heidelberg New York, Dordrecht, London, Switzerland: Springer International Publishing,

Kynigos, C. and Daskolia, M. (2014). Supporting creative design processes for the support of creative mathematical thinking. Capitalising on cultivating synergies between Math Education and Environmental Education. *Proceedings of the 6th International Conference on Computer Supported Education (CSEDU 2014)*, Barcelona, Spain, 1-3 April (Paper #256, pp. 342-347). doi:10.5220/0004965603420347.

Laurillard, D. (2012). *Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology*. London: Routledge.

Lave, J. and Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lotz-Sisitka, H., Wals, A. E., Kronlid, D. and McGarry, D. (2015). Transformative, transgressive social learning: rethinking higher education pedagogy in times of systemic global dysfunction. *Current Opinion in Environmental Sustainability*, *16*, 73-80.

Mishra, P. and Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for integrating technology in teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.

Rittel, H. and Webber, M. (1973). Dilemmas in a general theory of planning, *Policy Sciences, 4*(2), 155-169.

Star, S. L. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, Technology and Human Values, 35*(5), 601-617.

Star, S. L. and Griesemer, J. R. (1989). Institutional ecology, 'translations' and boundary objects: amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-1939. *Social Studies of Science*, *19*, 387-420.

Wenger, E. (1998). *Communities of Practice: Learning, Meaning, Identity*. New York: Cambridge University Press.