Supporting Creative Design Processes for the Support of Creative Mathematical Thinking

Capitalising on Cultivating Synergies between Math Education and Environmental Education

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Abstract: Mathematical creativity is acknowledged as a backbone lifelong competence necessary to be fostered in all students. However, this is not an easy task to accomplish, due not only to a lack of appropriate technologies enabling the creative design of digital educational resources for creative mathematical thinking (CMT), but also to the absence of insightful methodologies to support creative design processes of this kind among professionals. The Mathematical Creativity Squared (MC^2) project aims to address this twofold problem in the following ways: (a) by designing and developing a new genre of technological environment for the design of CMT resources, 'the c-book' environment, and (b) by adopting and further developing a methodology based on the generation of Communities of Interest (CoI) as a social milieu which will facilitate the creative design of CMT resources in collectives of educational designers stemming from diverse professional and educational domains. Especially with regards to the latter, the rationale is that CoIs will support synergies among designers with a math education background with others carrying a more socially-relevant educational orientation, such as environmental educators and educators for sustainable development, both on epistemological and pedagogical level, with the aim that their 'boundary crossing' interactions will positively effect social creativity in the design process for digital resources for CMT.

1 INTRODUCTION

1.1 On Creativity and Mathematical Creativity

Creativity is perceived as the backbone of the skills required for new jobs and as an essential ability to be developed in the context of lifelong learning (EC, 2008; 2011). It is recognised as a transversal skill needed to foster each of the eight key lifelong competences identified by the European Commission (EC, 2008) as particularly necessary for personal fulfilment and development, social inclusion, active citizenship and employment. Mathematical competence is among these core life-long competences identified by the European Commission, comprising the ability to develop and apply mathematical thinking to solve a range of problems in everyday situations and the application of this knowledge and methodology in response to perceived human wants or needs (EC, 2006). Developing students' creative potential in mathematical thinking has been also ranked among the most needed skills to develop for the 21st century in the States (National Academies of Science, 2007).

Nevertheless, although creativity is deemed as a tool for succeeding personal development and social empowerment and as an impetus for achieving professional innovation and economic change (Banaji et al., 2006), it still remains an elusive target to attain and a largely under-researched topic, especially in terms of whether and how it can be enhanced. The wide array of theories and perspectives on 'creativity' (e.g., Runco, 2007), coupled with the inherent vagueness of the concept (e.g., Kampylis and Valtanen, 2010), its context-specificity (Amabile, 1983; Csikszentmihalyi, 1996), and the inadequacy of most traditional educational

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systems and processes, set several burdens in the fostering of creativity.

This is particularly true with mathematical creativity. The lack of an accepted definition among researchers and practitioners (Mann, 2006) on the one hand, and educational reality which systematically deemphasize creative math problem-solving ability on the other cannot but hinder any concerted activity in the field (Mann, 2009; Sriraman, 2005). Even though almost any academic perspective on math education has been promoting mathematical creativity (Menghini et al., 2008), well-meant intentions are not enough for developing math learning through creativity and vice versa. Endeavours of this kind are acknowledged to be closely associated with putting forth changes in educational systems, processes and outcomes; taking full advantage of the potential of information and communication technologies; and working towards materialising creative ideas into concrete, new and more effective, products and services (EC, 2008; Ferrari et al., 2009).

1.2 Fostering Mathematical Creativity through Digital Technologies

In terms of technologies, twenty or more years ago, emergent approaches to how digital media could be used to foster mathematical thinking were almost exclusively visionary and about using technology as an expressive medium for cutting edge pedagogy involving engagement with mathematical thinking and meaning making (Hoyles and Noss, 2003). Despite the existence of some excellent digital tools affording dynamic manipulation, interconnected representations (including mathematical formalism), simulations of phenomena and situations embedding mathematical rules, visualisations of data representations and handling of probability, their uses in education were frequently instrumented to a large extent towards contexts of traditional lecturing and demonstration of exercise-type activities (Hennessy et al., 2005; Ruthven, 2008). Some technological advances of the past few years have even further skewed attention back to uses of digital media to support traditional routine learning of mathematics through the assistance of learning management systems, portals, video and intelligence in tutoring systems to that effect (e.g., the Kahn Academy).

However, especially during the last decade there is a growing interest in Europe in the role and use of appropriate digital technologies as the necessary broad-based strategies to bring forth the envisioned shifts in terms of creativity and innovation in education (Ferrari et al., 2009). This rests to be explored with regards to the teaching and learning of any knowledge domain, including mathematics. Nevertheless, whether digital technologies can act as real enablers of creative mathematical thinking has to be combined with other processes, mechanisms and tools of school education, among which the design and use of appropriate educational resources.

1.3 Creativity in the Design of Educational Resources for CMT

This last point brings forth an inter-related and equally challenging issue, that of the design of appropriate educational resources for creative mathematical thinking (CMT), and its relation to creativity. Taking into consideration that any kind of design process is inseparably connected to creativity (Taura and Nagai, 2010), the task of designing educational resources for CMT becomes thus a 'squared' creativity issue.

Design creativity is recognised as a multidimensional concept, that can be identified, among others, in the processes or the outcomes of the design activity, or in the context within which such an activity is embedded (Gero, 2010). This is also the case with the design of educational resources (and instructional design in general), which although not overly acknowledged and studied as a design discipline compared to other domains (i.e., software design or architecture), creativity has recently also being acknowledged as a ‘built-in’ dimension of it (Clinton and Hokanson, 2012).

The 'social' component in various collectives of design professionals and its role in enhancing both the individuals' creativity and the creative capacity of the group in addressing complex design problems is also a relatively new focus of research. 'Social creativity' actually explores the social and technical environment within which participatory design processes take place (Fischer, 2001; 2011), when specialists from different domains coordinate their efforts to achieve a common design goal. Social creativity arises from the synthesis and synergy of the different perspectives towards a complex design task of shared interest.

Designing for digital educational resources for CMT can be therefore viewed as a squared creativity challenge, since it requires not only to define mathematical creativity but also to situate the design process itself within a socio-technical environment that can boost educational designers' creative potential. However, both challenges to be dealt with appropriately need some paradigm shifts in terms of thinking of, learning and designing pedagogical materials for mathematics, already represented in some debates in math education.

1.4 Boosting Math Creativity through Synergy with Other Domains: the Case of Environmental Education

For example, a key debate in the field is the one questioning the traditional paradigm of focusing exclusively on abstract mathematical concepts and problems as isolated from broader phenomena and social contexts in which they could become more relevant, and without highlighting the relevance and value of this knowledge to the students' life and society in general. Within this paradigm, math education seems to reproduce the false myth of an objective and value-free discipline, alienated from current reality. Criticisms of this genre are supported by evidence from many countries indicating that school curricula give preponderant emphasis on foundationalist approaches of learning about mathematics and on pedagogies advancing the transmission of dry knowledge, as if all students were being prepared to become the big mathematicians of tomorrow. However, there are serious doubts about whether such curricula can succeed to trigger in students any meaningfully creative engagements with maths.

A suggestion so that math education explores new creativity potentials and meaningfulness to a wider range of students is to 'bridge' it with educational domains which are more socially-oriented and centred to real-life problems, such is the case of Environmental Education (EE) and Education for Sustainable Development (ESD) (Kynigos et al., 2013). Although several scholars have stressed the opportunities for developing a beneficial relationship between science education and EE/ESD (such as Gough 2002, 2007; Sjøberg and Schreiner, 2005, etc), no relative bridging has been proposed to motivate students to get more actively involved with math concepts and processes by identifying the 'mathematics' hidden inside some of the most challenging current socio-scientific and sustainability issues.

Especially mathematical problem-posing and problem-solving which are indicated as appropriate learning formats to allow math creativity to emerge, are proposed to exemplify some characteristics with respect to the 'problematic situation'. For example, for a situation to be amenable to creative (mathematical) problem-posing and -solving (Torp and Sage, 2002) it:

- should be fairly ill-structured and messy
- may change with the addition of new information
- is not solved easily or with a specific formula
- does not result in one right answer.

These characteristics are directly applicable to most environmental and sustainability issues, which are by nature ill-defined, complex, controversial, value-laden and require the application of various perspectives to grasp them more thoroughly (Daskolia and Kynigos, 2012). However, it is this messiness and complexity that make them 'good' examples of creativity-triggering problems and amenable to be treated in learning situations that foster the students' creative thinking. It also turns them into "boundary objects" (Star and Griesemer, 1989), that is entities that can interpreted and employed by more that one groups or communities in ways that make sense to them.

At the same time, 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 and to expand the "boundaries" of their knowing of and being in the world both inside and across the realms of their discipline (Daskolia and Kynigos, ibid). This is what some would also identify as a creative appropriation of subject-matter and pedagogical knowledge.

2 THE PROJECT RATIONALE

For mathematical creativity to be fuelled new designs are needed, new ways of thinking and learning about mathematics through synergy with other educational domains, such as those of EE and ESD, and the support of learners' engagement with creative mathematical thinking in collectives using dynamic digital media. Designers of educational digital resources (either professionals or teachers) have therefore to look for and benefit from new designs that would assist them to explore, identify and creatively produce new educational resources and tools with a potential to stimulate creative ways of mathematical thinking.

This is not an easy task to accomplish, due not only to a lack of appropriate technologies enabling the creative design of digital educational resources for creative mathematical thinking (CMT), but also to the absence of insightful methodologies to support creative design processes of this kind. The MC^2

project aims to address this twofold problem in the following ways: (a) by designing and developing a new genre of technological environment for the design of CMT resources, that is an authorable e-book we call **'the c-book'** (c for creative), and (b) by adopting and further developing a particular methodology based on the generation of **Communities of Interest** (CoI) (Fischer, 2001; 2011) as a social environment that would facilitate the creative design of CMT resources in collectives of professionals. The rationale is that by providing educational designers with an appropriate socio-technical environment, they will have more opportunities for richer creative design processes.

The objective of the MC^2 project is thus to build both a technology and a social milieu that will jointly and interactively enhance creativity among educational designers in the design of digital educational resources fostering creative mathematical thinking in learners. Our approach addresses *social creativity in design* through specially formed Communities of Interest (CoIs) which will act as agents of potential cultures of participation among professional designers and teachers from different/ diverse educational domains (not only from the math education sector but also from environmental education) and will lead to the development of innovative frames of addressing the design of educational resources for creative mathematical thinking.

The MC^2 project places at the centre of its concerted action the design and development of ***the c-book,*** an integrated and beyond the state-of-the-art digital system which will facilitate all foreseen creative design processes and practices *and* will provide support for creative mathematical thinking. The main characteristics of this system will be:

- an authorable data-analytics engine and a graphical interface providing professionals from diverse creative industries involved in the design of digital resources for CMT (publishers, developers, researchers, school educators from diverse educational domains) with the ability of customizing the kinds of information they need for assessing end-user creativity and the kinds of automated reactions they wish the tool to provide to end-users' activity.
- an authorable dynamic e-book infrastructure to be used by pedagogical design professionals for collaborative design of CMT resources and by students to create their personalized versions of such resources.
- a set of dynamic, exploratory and constructionist digital tools integrated in the e-book infrastructure designed to foster creativity in students' mathematical expression, investigation and meaning generation.

The design of the c-book environment will require advancements not only in terms of technology but also in the design processes. MC^2 project will develop, operationalize and document methods for the emergence of creativity in the design process based on **'middle c'** social creativity in CoI embedding diverse actors and norms (Moran, 2010; Hämäläinen and Vähäsantanen, 2011; Sonnenburg, 2004). In effect, it will address and promote the creativity that emerges when communities share common goals and well-designed tools. The project partners have the capacity and experience to act as catalysts for systemic change in cultures characterizing current school and workplace practices. By situating the CoI in large-scale systemic national initiatives MC^2 will test how the process and productions of collaborative creative design for CMT can empower professionals (and teachers) from diverse (disciplinary and/or educational) domains to collaborate and create new educational designs. At the scientific level, the project will contribute to our knowledge of methods and processes in using digital media to enhance creativity in interdisciplinary CoIs. The emergence of creativity is perceived as 'a system' involving 'collectives with tools' characterized as 'cultures of participation' (Fischer, 2011). This project will advance our knowledge by integrating two constructs to generate and support such cultures for professional design, 'documentational approach' (Gueudet and Trouche, 2012) and the 'boundary crossing with digital media as boundary objects' approach (Akkerman and Bakker, 2011; Kynigos & Kalogeria, 2012). The technology will play a fundamental role by transforming an otherwise costly endeavour to an efficient knowledge co-construction process through both the collaborative and authoring features of the c-book which will be useable in the six languages of the partnership. This will provide stakeholders with the means to both advance and share creative intelligent mathematical artifacts and by thus to enable a broader reach. Accordingly, the impact of MC^2 will be long-lasting as the malleability of the creative widgets and the authorable intelligent feedback will create the foundations for subsequent evidence-based creative designs beyond the life of the project.

3 NEXT STEPS

Our position is that digital media designed to support practices and productions of added pedagogical value fall short of target if they address only the conceptual/ cognitive/ performance aspects of the learning process. There is a need to consider how to directly support future citizens in their social and work capacity. Mathematical creativity is viewed as a backbone ability and disposition for students, which can be cultivated and taught as a social phenomenon per se but also through teaching and learning about more socially-related and focused issues (i.e., current environmental and sustainability issues) and be widened up to all students. Social creativity amongst designers of educational materials with an explicit aim to support such a creative potential in learners is a core competence which nevertheless needs some appropriate frames to be identified, studied and boosted. Technologies supporting the design and deployment of educational materials and digital media for enhancing the students' creative mathematical thinking have so far been too much influenced by more traditional paradigms of thinking where such media have the role of unquestionably accredited tools to be employed by the students. New genres of technologies, such as the proposed c-book system, will help the questioning and development of the process of design and the kinds of media and accompanying paradigms which may become available to students in the future. Within this rationale, a c-book unit can be a medium containing questionable artifacts, statements, arguments for students to change, improve, negotiate over, re-construct; something for the students to re-draft, to shape or make on their own. They are viewed as objects for students to argue over and to collectively 're-write'. How does this will consequently change the designers' perspectives, methodologies and ways of thinking, collaborating and working? Our proposed c-book technology and supporting methodology aim to re-address how to design educational resources for creative mathematical thinking by turning into a creative learning asset the crossing of various pre-established boundaries across many inter-related or not until recently related fields.

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