Factors impacting on the collaborative design of digital resources

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In order to identify mechanisms that can support mediation, this paper analyses the decision making process in a collaborative design of a digital learning resource by two different Communities of Interest (CoI). It focuses especially on the influence of both the CoI context and socio-technical environment. We begin by describing the context of the "M C Squared" European project in the framework of which this research has been carried out, followed by the presentation of the conceptual and technical tools used in this project to ease and document social interactions in the design of innovative learning resources promoting Creative Mathematical Thinking in the users. We focus on two main forces: tools and culture, which supported the collaborative design work between two CoIs.

Keywords: Community of Interest, Context, Socio-technical Environment, Collaborative Task Design, Creative Mathematical Thinking.

Introduction

This paper focuses on the analysis of the collaborative design of an innovative kind of digital educational resources for teaching and learning mathematics by different teams of designers. This research took place in the frame of the European Research and Development project called "M C Squared (MC2)" (http://mc2-project.eu/) where innovative digital resources have been produced to promote creative mathematical thinking (CMT). These resources have been designed by four Communities of Interest (CoI) (Fisher, 2001) constituted within the project: the English, French, Greek and Spanish CoIs. One of the objectives of the project was studying the processes of social creativity occurring during the design of resources and uncovering factors fostering it. Moreover, as the design was carried out in four different countries, the question of the influence of the cultural and institutional context on the design choices, as well as on the processes of social creativity, was raised naturally.

In this paper, we focus on the design process that involved a collaboration between two CoIs, the inter-CoIs interaction being considered as a window on contextual issues impacting the design. We report the case of a resource called "Limits" that was initially designed by the French CoI members, redesigned by the Spanish CoI, and finally redesigned again in the cross-CoI collaboration of the two CoIs. In this framework of a collaborative design of a resource, we explore the influence of the context and of the conceptual and technical tools on the design process. In other words, we are particularly interested in *how the CoI context influences the design process in a given socio-technical environment* and *which tools and mechanisms support the collaboration between different teams of designers in the process of task design?*

The paper starts by presenting the context within which this research was carried out and its theoretical and methodological background. The design of the "Limits" resource is then described and analysed and the findings are discussed bringing to the fore elements of answers to the research questions.

Context and socio-technical environment of the CoI

Communities of Interest (CoIs) and their context

According to Fischer (2001), Communities of Interest "*bring together stakeholders from different CoPs* [Communities of Practice] *(Wenger 1998) to solve a particular (design) problem of common concern*". Four CoIs were constituted in the MC2 project gathering together, around a digital resource design, math teachers, teacher educators, researches in math education, educational software designers, artists, etc.

The French and the Spanish CoI, whose experience is reported in this paper, present different compositions and characteristics, we consider these as contextual aspects. The French CoI consists of 13 members with varied professional background, including researchers, school teachers, teacher educators, and educational technology developers. They share a socio-constructivist approach to mathematics learning rooted in the French didactical tradition of teaching and learning mathematics (CFEM, 2016). This approach has shaped the CoI representation of creative mathematical thinking (CMT) that manifests itself through (implicit) task design principles, such as designing tasks aiming at revealing specific misconceptions, using multiple representations to help conceptualisation of math notions, fostering social aspects through collaboration and affective aspects through challenging problems and games, or focusing on tasks enabling generalisation. The Spanish CoI, composed of about 20 members, integrates people from different communities of practice, including researchers in and out of mathematics education, secondary and university school teachers and publishers. Most of the resources designed by the Spanish CoI present many design principles that are especially important for mathematical modelling, such as proposing real questions to students in order to face linking mathematics with other disciplines (social sciences, history, etc.), articulating questions posed and mathematical tools to engage students in modelling progresses, enhancing the exploration or the contrast and validation of mathematical tools and models.

The socio-technical environment and collaborative design

The design of resources took place within a specific socio-technical environment developed in the MC2 project, called C-Book technology (http://mc2dme.appspot.com/mcs/). It integrates two main tools: i) an authoring environment enabling to create digital resources, called c-books ("c" for creative), which consist from pages including texts, pictures, hyperlinks, dynamic interactive widgets, and allowing to record successive versions of the c-book units; ii) a tool, named CoICode that provides a workspace to organize and enhance the interactions among designers. CoICode enables each designer to post various kinds of ideas ("contributory", "alternative", "objection", "off task" and "task organization"), each of them having a specific icon. When a designer posts an idea, the system captures several details: author's name, date, title of the idea, comments, attached resources, hyperlinks, etc. The CoICode system is integrated in the C-Book in the form of workspaces that a CoI or a CoI-pair (two CoIs collaborating), can create, providing designers with a space for the collaborative design in which the discussions can be visualised in form of threaded forum or in a mind-map view (see Figure 1), where nodes are ideas, comments, and branches of a tree model the evolutions of an idea. The reports of the system as a graph provide the basis of the Social Creativity data gathered for this study. A voting system has been implemented in the CoICode allowing designers to evaluate in terms of creativity any idea posted by someone else. Such evaluation follows a "*middle c*" perspective of creativity (Moran, 2010), that views creativity as a competence developed through interaction between members of a community and through their participation in situations where they creatively display their intentions and negotiate new alternatives for the interpretation of actions in situated activity systems.

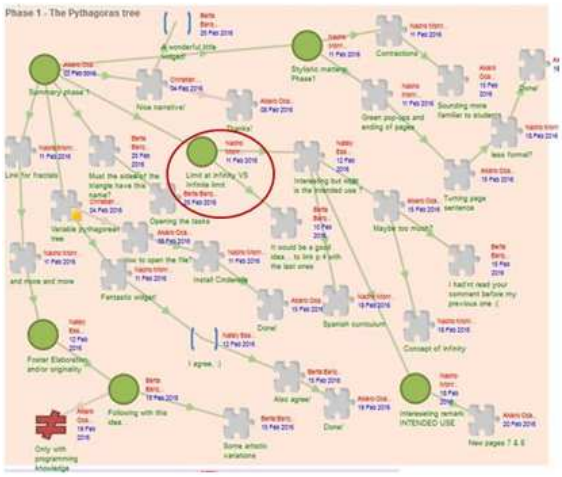

Figure 1. Excerpt of a CoICode workspace in the mind-map view.

The cross-CoI collaboration on the design of the "Limits" c-book took place in five phases, as follows: (1) a part of the French CoI designed a first version of the c-book, acting as the primary designers; (2) a part of the Spanish CoI (two secondary school teachers, one researcher in mathematics education and one researcher in Calculus) evaluated the CMT potential of the c-book; (3) this four members of the Spanish CoI redesigned the c-book according to their own approach, which constituted the first phase of the redesign; (4) a second redesign phase was carried out by the CoI-pair comprising this sub-CoI and two members of the French CoI (one researcher in mathematics education and one secondary teacher), called a CoI-pair; and (5) four new members (two of both CoIs not involved in the redesign) evaluated the CMT potential of the redesigned c-book.

Theoretical and methodological background

Our focus on the genesis of the resource leads us to adopt the *Documentational Approach (DA)* (Gueudet & Trouche, 2009) considering the design of this resource as a documentational genesis. In DA resources and resources' versions enables to look at the development of mathematics knowledge, CMT representation and culture. In addition, the CoI-pair infers different contexts and can be view as various worlds, activity systems. The *Boundary Crossing approach* (Akkerman & Bakker, 2011) is able to enlighten the interactions between these contexts. It allows to highlight discontinuities, i.e. boundaries. The "boundary objects" (Star & Griesemer, 1989) support the communication and the understanding between and within the CoIs, they can be in our case ideas posted in CoICode, the c-book versions, widgets, etc., they allow to build new norms. In addition, the mechanisms which are identification (consciousness of discontinuities), coordination (creation of continuities between domains), reflection (perspective making, perspective taking) and transformations (confrontation, recognition of a shared problem space, hybridization of ideas, crystallization) help us to decode the design process.

Grid for the evaluation of tasks features to foster CMT

The evaluation of the potential or affordances that a c-book has to foster CMT has been a central task in the MC2 project. Facing the necessity of CMT cross-evaluating a need emerged of agreeing on and sharing common criteria, tools and methodologies, which had been developed independently in the first cycles of c-book production. A common CMT evaluation grid, which combines design criteria or principles proposed by the four CoIs involved in the project, has been elaborated by the researchers. This grid could be adapted by each CoI or CoI-pair to better fit its context, by adding specific criteria.

The CMT evaluation grid is a questionnaire composed of three sections. The first and the widest section focuses on the evaluation up to what degree different dimensions of mathematical activity considered crucial for fostering CMT, such as conjecturing, questioning, evaluating, and establishing connections, are taken into account in the c-book design. With a total of 14 items expressing the indicators of different dimensions, evaluators of a c-book grade (from 1-4) their agreement on the items and explain their response according to the design being evaluated. For instance, the dimension of establishing connections is evaluated through the item: "The c-book provides users with opportunities to establish connections between various representations of the mathematical concepts at stake", or the validation dimension through the item: "The c-book stimulates to think about, reflect, summarize and evaluate the mathematical work already developed". The second section addresses social aspects through items like: "The c-book stimulates user's collaboration / cooperation / interaction with other users". Finally, the third section focuses on affective aspects via items like: "The c-book actively promotes engagement by generating a perception of usefulness of mathematics, either in everyday life, or inside the mathematical context". These grids, filled in for each c-book, provide the basis of the CMT study and development.

CoICode analytics features

In the MC2 project, a creative idea is defined as: (1) *novel* (original, unusual or new for the CoI member), (2) *appropriate*, that is it conforms to the characteristics and functions of the c-book units, including their CMT affordances, bind to the CoI context during particular phases of the design process, and (3) *usable*, that is ready and available to be used in the design of the c-book according to the designers' (the CoI members') estimation (Daskolia, 2015). CoICode voting mechanism allows any CoI member to express his/her opinion about the three attributes of any idea posted by any other CoI member. The expressed opinions are aggregated into the creative score of an idea defined as follows: "creative score of the idea i (CRi) = 0.5 x number of 'novel' votes + 0.25 x number of 'appropriate' votes + 0.25 x number of 'usable' votes, if the number of 'novel' votes is at least a half of the number of CoI members involved in the c-book design, otherwise CRi = 0". This definition reflects the fact that novelty is the sine qua non condition for an idea to be deemed creative, this is why the corresponding weight is the highest (0.5). On the other hand, the "middle c" perspective of creativity leads to considering an idea creative if the majority of the CoI members share this opinion. Thus, the interactions recorded in CoICode allow tracking the communication among the designers during the design process and getting automatically the ranking of the ideas according to their creativity score (see Table 1).

USER	DATE	ID	TITLE	NOVEL	APPROP	USABLE	SC SCORE
CM	04/02/2016 11:03:51	45675	Variable pythagorean tree	4	4	4	4
NE	12/02/2016 11:01:13	45901	EpsilonChat to foster social aspects	3	3	3	3

Table 1. Quantitative measurement to identify creative ideas

Data collection and observables for each phase

The ideas and their organisation in CoICode workspaces, the creativity score of ideas obtained automatically from CoICode, the CMT grids filled in by the evaluators of the c-book and the successive versions of the c-book help us to observe, analyse and understand the contexts, the cultural evolutions, the design decisions taken and the role of the tools.

c-book design process in the cross-CoI collaboration and its analysis

We focus on analysing some of the main aspects of the cross-CoI collaboration on the redesign of the c-book "Limits" that went through the five phases of cross-collaboration described above. In particular, we have chosen two moments of the redesign process, which were especially important with respect to our research questions. On the one hand, the transition between phases (1) and (2), when the Spanish CoI adopted the c-book designed by the French CoI and proceeded to evaluate its affordances to foster CMT. We consider this transition especially important to analyse how the process of exchanging, adopting and evaluating an external resource, leads the secondary-designers' CoI to decontextualize this resource and recontextualize it according to its own context. On the other hand, we are particularly interested in phase (4) when the CoI-pair worked collaboratively on agreeing and conceptualizing the last changes of the redesigned c-book. This phase shows how a new CoI-pair context was created, breaking boundaries between both CoIs who look for agreeing some shared design principles, and to evaluate the usability of some tools which support their collaboration and task design decision making.

Adopting the c-book and de- and re-contextualizing its design

The initial version of the c-book "Limits", designed by the French CoI, covered the notion of infinity through its meaning in solving equations, constructing the Pythagorean tree, analysing geometric sequence, comparing growth of functions, and calculating limits of real functions. The CMT representation of the French CoI members shaped the design of the c-book. In particular, it led the designers to embed tasks that enable intra-mathematical connections, generalisation, competition and challenge as levers for the CMT development. Following these principles, they proposed tasks offering various representations of the mathematical notions at stake (limits and infinity), by using algebraic, calculus, and geometrical settings, with the aim to provide students with alternative ways to make sense of these difficult notions in calculus and to generalise some properties. Moreover, the educational technology developers, involved in the CoI, enabled the development of specific widgets with features deemed as important to foster CMT, such as relevant feedback, written collaboration and discussions (a chat tool), and a framework for designing playful activities affording students' self-assessment.

When the cross-CoI collaboration began, the "Limits" c-book was adopted by the Spanish CoI. Four members from this CoI started by evaluating the CMT affordances of the c-book using the CMT evaluation grid briefly described in section 3 that appeared as an external resource. In relation to this evaluation, the Spanish CoI reviewers appreciated some important characteristics to be maintained, which can be considered as the common design criteria according to both CoIs contexts. For instance, they valued positively the *connections* between several representations (numerical, geometrical, algebraic ones) of limits; however they found the unit improvable regarding the connections that could be established with other disciplines or with other mathematical topics. With respect to *validation,* they recognised the potential of the new widgets to simulate functions, sequences, limits, etc. and their practical use in activities focusing on evaluating students' work and progress. On the contrary, they detected several traits to further improve the c-book redesign, some of them were central for their CMT representation; for example, they missed situations and questions that give sense and utility to the mathematical notions at stake (infinity, limits, etc.) – *questioning* or *problematization*. Also, they missed a global *articulation* of some of the activities dealing with a more general narrative and questions to focus on. This can explain why the redesigned c-book urged students to investigate questions like the ones about fractals constructions and properties (guiding part 1 of the new c-book unit), or the one about a cell phone password as the problem of the 9 points (guiding part 2), and to engage students in recognizing patterns in the process of mathematization of a problem, and in using the corresponding mathematical relations to check the validity of a conjecture.

As soon as phase (3) started, when the Spanish CoI began with the redesign of the c-book, they structured the workspace dedicated to intra-CoI redesign work according to the results of their CMT evaluation. They explicitly placed the eight design criteria or indicators, they consider as crucial to be prompted (validation, connections, articulation, problematization ...) according to their CMT approach to facilitate the further discussion (see Figure 2). Thus, the Spanish CoI instrumentalized CoICode, with the strong purpose of proposing tasks to enhance the c-book potential to foster CMT in students.

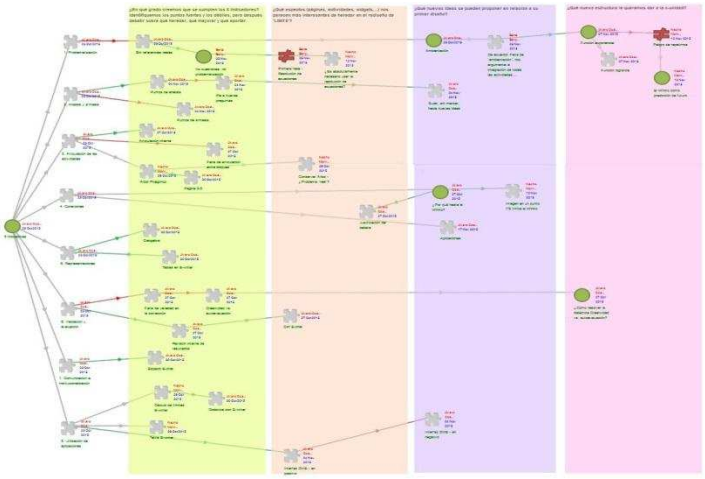

Figure 2. The workspace created for the intra-CoI redesign work and its four adornment zones (the four colored zones on the figure)

The CoI-pair collaboration in the "Limits" c-book redesign

When the Spanish CoI had the first complete version of the redesign of the c-book, it was translated into English and shared with the members from the French CoI participating in the cross-CoI collaboration. A new workspace was created to facilitate this collaboration. To organise this communication, the workspace was structured according to the four main sections of the c-book constituting four adornment zones, and a summary of the main aims and changes introduced in each section was added to facilitate the understanding of the Spanish design purposes by the French CoI members; indeed it helped the French team to compare the new version of the c-book with its original design. This phase was especially important because it was at that time that some design principles of both CoIs were recognized and discussed to progressively become shared by both CoI, such as the importance of including tasks calling for conjectures, simulation, communication of results, and validation. Other design choices were positively accepted by the primary designers of the c-book, such as the extra-mathematical connections included in the c-book or the new way of structuring and articulating activities in terms of chains of interrelated questions with increasing complexity. Moreover, new members could evaluate new tasks and helped improving the way they appeared.

Besides the importance that this phase had on creating a new and common CoI-pair design context, the role that the CoICode (specially with its mind-map view) played in structuring the discussion may be underlined; it constituted a key meditation support to agree on which ideas to accept (or not) by most of the designers and how fruitful they were for the design process itself. Furthermore, the quantitative information provided by the CoICode data analytics, in particular, in terms of creative scores of ideas (see Table 1) appeared as a powerful tool to identify ideas worth to be further developed in the CoI-pair collaboration.

More concretely, the two ideas that obtained the highest creativity scores were two comments that the members of the French CoI made after analysing the c-book redesigned by the Spanish CoI. In

particular, related to the first part of the c-book devoted to the study of fractals properties and the appearance of the notion of limit at infinity, a French CoI member provided a link to a widget from Cinderella to simulate fractals and predict their tendency in the infinity (idea n°45675, see Table 1). The widget was subsequently integrated at the end of this first section with new questions that CoI-pair members suggested. Another improvement suggested by another French CoI members concerned the possibilities embedded in chat tools, developed within the French CoI, to foster social aspects (idea n°45901, see Table 1), which were then integrated in the design to enable students to communicate their results or to pose new questions.

Discussion and conclusion

The analysis of the "Limits" c-book collaborative design shows that different CMT representations that both CoIs held, influenced by each CoI own culture and traditions, has enriched the cross-CoI collaboration and has acted as a key mechanism for decisions making in the intra-CoI and cross-CoI design work (Barajas, 2016).

In the two phases of intra-CoI and cross-CoI work (phases 3 and 4), it appeared that redesigning does not mean a total transformation and complete re-contextualisation of the initial unit, neither of the empirical setting envisioned nor the academic approach (Barquero, Papadopoulos, Barajas & Kynigos, 2016) and it helped to give confidence and trust atmosphere. On the contrary, some design principles shared by the two CoIs were reinforced, such as connections between multiple representations, or making and investigating conjectures. Others, coming from only one CoI, were negotiated and became shared by both CoIs, such as extra-mathematical connections or interrelations between the c-book activities, others were abandoned. The CoI-pair created a new, wealthier design context thanks to two different cultures close enough to create some overlaps which enable to build understanding. The understanding and respect allowed to share design decisions with the help of mediation tools (CoICode, different versions of the c-book 'Limits', CMT grid, creative scores of ideas) enabling to explicit points of view and cross some boundaries (different CMT representations, school cultures, research approaches, distance collaboration). The mediation tools favoured the dialogue between the CoIs and sometimes facilitated decisions, in conjunction with common good practices CoI moderation strategies.

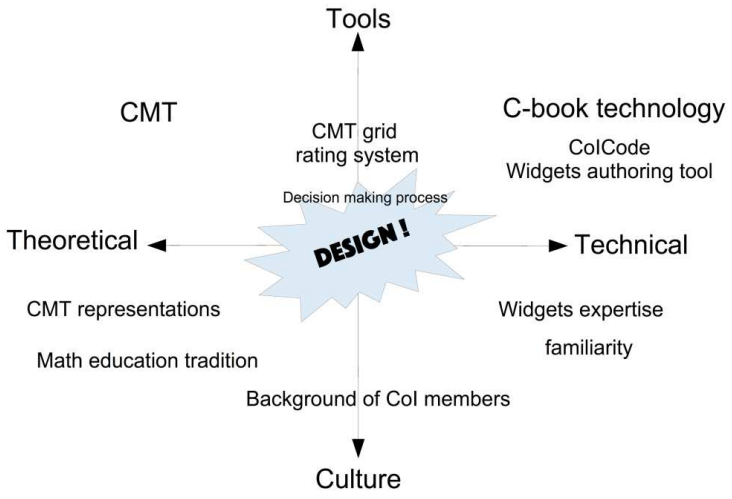

Figure 3. Main forces shaping the decision making in a c-book design process.

This study brings to the fore two main forces that shaped decision making in the design process: *tools* and *cultures* (Fig. 3). Both had either *theoretical* or *conceptual dimensions*, for example the CMT evaluation grid built on theoretical considerations about creativity, but they have as well

socio-technical aspects because the C-Book technology, comprising authoring tools, widget factories and CoICode, is the MC2 project social management main tool. The cultural context of the CoI includes mathematics education theoretical tradition, composition of the CoI, familiarity and expertise with the variety of widgets. The background of the designers impacts their attitude towards these tools, their CMT representations, their position in the collaborative decision making and the widgets they use. Eased by the proximity of collaborating cultures, the interplay of culture and tools in cross collaboration had enriched the scope of the designed tasks.

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