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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 contexts and the socio-technical environment. This research was carried out within the framework of the "M C Squared" European project aiming at studying social creativity in the resource design. Specific conceptual and technical tools were 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 a 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-CoI 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 between 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, mathematics teachers, teacher educators, researches in mathematics 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 students' misconceptions, using multiple representations to enhance conceptualisation of mathematical notions, fostering social aspects through collaboration between students and affective aspects through challenging problems and games, or focusing on tasks calling for generalisation. The Spanish CoI, composed of about 20 members, involves people from different communities of practice, including researchers in and out of mathematics education, secondary school and university 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 processes, 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 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 provides designers from a CoI or a CoI-pair (two collaborating CoIs) with a space for collaborative design. In CoICode, the discussions can be visualised in form of threaded forum or in a mind-map view (Fig. 1), where nodes are ideas, and branches of the tree model

the evolutions of an idea. The reports in the form of a graph provided by the system are the main data gathered for the study of social creativity. 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 competency developed through interactions between members of a community and through their participation in situations where they display their intentions and negotiate new alternatives for the interpretation of actions in situated activity systems.

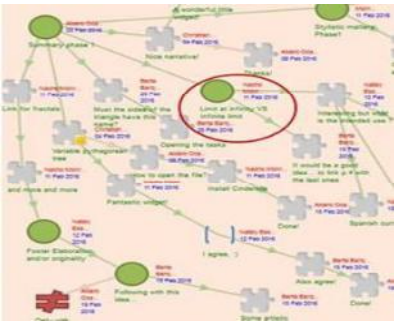

Figure 1. Excerpt of a CoICode workspace in the mind-map view.

The cross-CoI collaboration on the re-design of the "Limits" c-book was organized in the following five phases: (1) a part of the French CoI, acting as the primary designers, designed a first version of the c-book; (2) four members 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) these 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 Spanish sub-CoI and two members of the French CoI (one researcher in mathematics education and one secondary school teacher); and (5) four new members (two from each CoI not involved in the redesign) evaluated the CMT potential of the redesigned c-book.

Theoretical and methodological background

Documentational and boundary crossing approaches

Our focus on the genesis of the c-book resource leads us to adopt the *Documentational Approach to Didactics (DA)* (Gueudet&Trouche, 2009) and thus consider the design of this resource as a documentational genesis. The analysis of resources coming into play in this genesis and of their successive versions unveils designers' mathematics knowledge, CMT representations and culture. In addition, considering the collaboration between two CoIs, which can be viewed as two different activity systems, allows inferring the influence of the contexts on the design choices.

The *Boundary Crossing approach* (Akkerman& Bakker, 2011) enables enlightening the interactions between these contexts. It allows to highlight discontinuities, i.e. boundaries. Boundary objects (Star & Griesemer, 1989) and brokers support the communication and the understanding between and within the CoIs, allow to build new norms and a common frame of reference. Moreover, highlighting the mechanisms of *identification* (i.e., consciousness of discontinuities, awareness of multifold cultural background, which allows pointing out differences), *coordination* (i.e., creation of continuities between domains and bridges between cultures, which enables the construction of a common frame of reference), *reflection* (i.e., perspective making, perspective taking on the problem

at stake, which supports divergent thinking), and *transformation* (i.e., confrontation, recognition of a shared problem space, hybridization or combining ideas, and crystallizationor keeping a perspective, an idea) helps us to better understand the design process.

Grid for the evaluation of c-book features fostering CMT

The evaluation of the potential or affordances of a c-book to foster CMT was a central task in the MC2 project. Facing the necessity of CMT cross-evaluation, a need emerged for 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, and played a crucial role in the construction of a common frame of reference for all four CoIs.

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". This grid, filled in for each c-book, provides 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 members), (2) *appropriate*, that is it conforms to the characteristics and functions of the c-books, including their CMT affordances, bind to the CoI context, and (3) *usable*, that is available and ready 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 communication among the designers during the design process and getting automatically the ranking of the ideas expressed according to their creativity score (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 constitute the main data we analyse in order to highlight the impact of context, and cultural evolutions on the design decisions taken, as well as the role of the tools in the design process.

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

Our analysis focuses on two out of the five phases of the redesign of the c-book "Limits" (see above), namely phase (3), when the Spanish CoI redesigned the c-book and the phase (4) when the CoI-pair worked collaboratively on agreeing upon and conceptualizing the last changes of the redesigned c-book. We have chosen these two phases of the redesign process as they appear especially important with respect to our research questions.

Adopting the c-book and de- and re-contextualizing its design: mechanisms of coordination and reflection

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 sequences, 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. Hence, the involvement of software developers in the designers' team impacted the c-book design by creating new widgets in line with the French CoI culture. They also worked in close collaboration with the C-book technology developers, thus playing the role of technical brokers within the CoI.

As soon as the phase (3) started, the Spanish CoI began with the redesign of the c-book.The designers structured the workspace dedicated to the intra-CoI redesign work according to the results of their CMT evaluation with the grid (see section 3). For instance, they found the c-book improvable

regarding the connections that could be established with other disciplines or with other mathematical topics. They appreciated some characteristics of the c-book such as *connections* between several representations (numerical, geometric, and algebraic) of limits or 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. The decision to maintain these features can be interpreted as the agreement on the underpinning design criteria by both CoIs. They also detected several traits to further improve the c-book redesign, some of them being central for their own 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 *problematisation*. Likewise, they missed a global *articulation* of some of the activities dealing with a more general narrative and questions to focus on. This led the designers to organize the CoICode workspace around the eight design criteria or indicators they considered as crucial to be prompted (validation, connections, articulation, problematisation ...) according to their CMT approach (Fig. 2, first column on the left) to orient further discussion. Therefore, the redesigned c-book urged students to investigate questions like the ones about fractal constructions and properties (guiding part 1 of the redesigned c-book), 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.

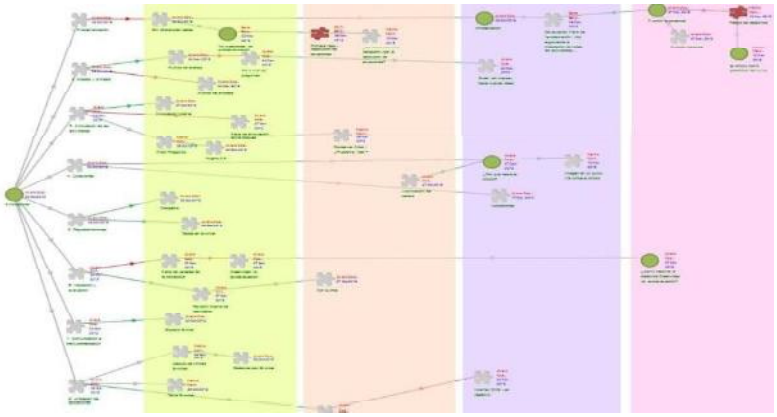

Figure 2. Excerpt of the workspace created for the intra-CoI redesign.

In this episode, we can identify a mechanism of coordination initiated by the CMT evaluation which supported the subsequent mechanism of reflexion sustained by the structure given to the workspace. We note that the Spanish CoI instrumentalized CoICode, with a strong purpose of enhancing the c-book potential to foster CMT in students in line with their culture. Hence the mechanism of reflexion enabled to open new perspectives, related to the Spanish context, by adding tasks on fractals, the problem of 9 points and the mathematization of another problem.

The CoI-pair collaboration in the c-book redesign: mechanism of transformation

The cross-CoI collaboration (phase 4), started with the translation of the redesigned c-book into English and the creation of a new workspace common to both CoIs. In order to organise and facilitate the communication between the two CoIs, the workspace was structured according to the four main sections of the c-book, and a summary of the main aims and changes introduced by the Spanish CoI in each section was added; the French team could thus compare the new version of the c-book with

its original design. During the CoI collaborative work, some design principles stemming from both CoIs were recognized and discussed to progressively become shared by both CoIs (confrontation and crystallisation of principles), such as the importance of tasks calling for conjectures, simulation, communication of results, and validation. Other design choices issued from the Spanish CoI were 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. 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. The two ideas that obtained the highest creativity scores came from two comments made by two members of the French CoI while analysing the c-book redesigned by the Spanish CoI. The first idea was related to the first part of the c-book devoted to the study of fractal properties and the appearance of the notion of limit at infinity. A French CoI member provided a link to a widget he designed with Cinderella dynamic geometry system to simulate fractals and predict their tendency in the infinity (Table 1, idea n°45675). The widget was subsequently integrated at the end of this first section with new questions that CoI-pair members suggested. The other idea was suggested by another French CoI member concerning the possibilities embedded in chat tools, developed within the French CoI, to foster social aspects (Table 1, idea n°45901).Chat tools were subsequently integrated in the c-book to enable students to communicate their results or to pose new questions. These episodes can be interpreted as hybridisation and elaboration of ideas.

Besides the importance that this phase had on creating a new and common CoI-pair design context, our analysis shows that the CMT grid, the CoICode workspace the creative scores of ideas and the c-book versions used as boundary objects between the two CoIs constituted key meditation supports to enable the designers to agree on which ideas to accept (or not) and on the ways of further elaboration of some of these ideas, thus sustaining the mechanisms of coordination, reflection and transformation.

Discussion and conclusion

The analysis of the c-book "Limits" collaborative design shows that different CMT representations that both CoIs held, influenced by each CoI own culture and traditions, enriched the cross-CoI collaboration, acted as a boundary object and participated in the key mechanism of coordination 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 either of the initial unit, of the empirical setting envisioned or of the academic approach (Barquero, Papadopoulos, Barajas & Kynigos, 2016), but rather an improvement of some aspects, and it helped to establish confidence and trust atmosphere. On the contrary, some design principles shared by the two CoIs were reinforced, crystallised through the mechanism of transformation, 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, yet others were abandoned. The CoI-pair created a new, wealthier design context thanks to two different cultures close enough to create some overlaps yielding a common frame of reference, which enabled to build understanding and fostered the mechanism of

coordination. The understanding and respect allowed to share design decisions with the help of mediation tools used as boundary objects (different versions of the c-book, CMT grid, creative scores of ideas) and to cross some boundaries (different CMT representations, school cultures, research approaches, distance collaboration). The mediation tools favoured the dialogue between the CoIs and facilitated decisions, in conjunction with common good practices and CoI moderation strategies. The workspaces in CoICode used as meditational artefact were instrumentalized to support reflection, enabling to make points of view explicit (perspective making) and to enrich ideas (hybridisation). The boundary objects, the structure of the workspaces and the moderation strategy played a major role in the mechanism of coordination, reflection and transformation.

This study brings to the fore two main forces that shaped decision making in the design process: *tools* and *cultures* (Fig. 3).

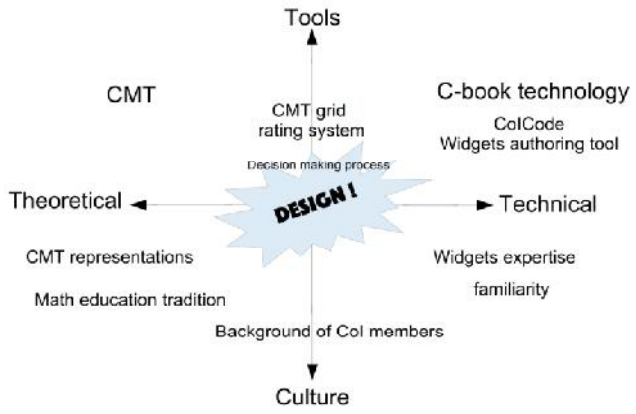

Figure 3. Main forces shaping the decision making in a c-book design process.

Both had either *theoretical* or *conceptual dimensions*, for example the CMT evaluation grid built on theoretical considerations about creativity, but they have *socio-technical aspects* as well 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-CoI collaboration had enriched the scope of the designed tasks.

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