Half-baked mathematical microworlds as boundary objects in connected design

Chronis Kynigos, *kynigos@ppp.uoa.gr*
Educational Technology Lab, University of Athens and RACTI

Abstract

The paper addresses the problem of disparate theoretical frameworks, contexts and assumptions of the communities involved in the design of digital media for mathematical education. It draws on experience with international multi-organizational projects where design, development and use of digital media for mathematics education was promised as a collective collaborative activity. It discusses the notion of 'half-baked' mathematical microworlds as an improvable boundary object between communities engaged in collective design and on the process of design as an activity for intellectual growth for researchers, developers, teachers and students. The paper focuses on the kind of language emerging from such communities and discusses its potential value for integrated design.

Microworlds in a fragmented world

The term 'half-baked' microworlds is used to describe digital media designed to facilitate communication between researchers, technicians, teachers and students as they become engaged in changing them. This kind of connected design between diverse communities is important in addressing two kinds of problems. One is the failing infusion of microworld pedagogy and technology in schools. The other is the recently identified problem in the growth of our knowledge in the area of technology enhanced learning of mathematics due to the fragmentation of the emerging theoretical frameworks in the field. At the same time, connected design can be an activity of personal growth for the members of any of the above communities in different ways. In this paper some arguments in favor of connected design are outlined by suggesting the use of microworlds as boundary objects between these communities.

In the past 40 years of ICMI and ICME, microworlds have been vehicles through which the key ideas of generation of meanings through constructionist activity have been mediated within the field of instructional design for mathematics (Goldenberg, 1999). After 40 years, we have a lot of experience of how difficult it is to convey such meanings in education and more so, to have hopes for a progressive infusion of such practices in formal schooling (Kynigos, 2004). The demands for re-addressing epistemologies and personal pedagogies, changing roles and communicating about such changes, let alone the sheer logistics within the socio-systemic educational context, have been too big to see some serious scaling-up of educational practices based on the use of microworlds. At the same time, the production of microworlds and escorting materials has not scaled up either. It has been hard to convey the new kinds of pedagogy involved as well as the kinds of interaction with the technology envisaged in such educational environments. The process of designing educationally principled materials for microworlds requires integrated expertise which is hard to find. Many pieces of educational software and corresponding materials at large look more like products of fragmented views of the problem, emerging from traditional curriculum designers who miss the opportunity for added educational value, from technicians in the software industry perceiving design for education as just another field of application of generalized design processes, researchers who have little understanding of the pragmatics of education, students who inadvertently perceive their role as requiring memorization and response to tests.

Fragmentation also lies in the various theoretical frameworks for learning mathematics with the use of digital technologies, as elaborated by Artigue in a recent plenary lecture at ICMI study group 17 (Artigue, 2006). Around 10 theoretical frameworks and constructs were identified amongst the work of many researchers. Although the variety of frameworks was seen as a rich and necessary resource for addressing issues in the field there has been an explicit effort to figure out how to handle this complexity. As things stand, there is an incommensurability of perspectives and incompatible or contradictory results which in the long term may impede improvement of educational practices and discredit the research field (Arzarello et al, 2007). For example, the main theoretical constructs associated with microworlds have been those of 'constructionism' by Papert and his group (Kafai et al, 1996) and 'situated abstractions' by Noss and Hoyles (1996). At the time theories addressing the relationships between teachers and students in the classroom (for instance the Didactical Situations Theory, 'TDS', Brousseau, 1997) were at an earlier stage of development. Also, theories addressing the generation of mathematical meanings as a social phenomenon, such as Cobb and Yackel's 'socio-mathematical norms' was introduced at ICME 8 in Seville (Cobb & Yackel, 1996). Microworlds were thus seen as part of the 'constructionist – situated abstractions' theoretical framework and through the lens of the social interaction theories they were seen as vehicles for the development of individualistic theoretical frameworks. Both constructionist and situated abstraction theories however were built by discussing situations where interaction between students as they worked with microworlds was the key point of focus. The knowledge gained from these theories thus remained fragmented.

One of the ways of addressing the problem of fragmentation is networking and engagement in research carried out by wider and disparate communities. This is the experience currently gained though a group within the 'Kaleidoscope' European Network of Excellence, called 'TELMA', (Technology Enhanced Learning of Mathematics) which is carrying out a European R&D project called 'ReMath' (Representing Mathematics'). in this endeavour six disparate research teams are using their experience with development of digital media for mathematical learning and a cross- experimentation technique (each team carries out research with another's technology) in order to build a language rich in connections between theoretical frameworks.

What is needed is to develop a much more articulate language to convey the idea of connected design for reflection and for the generation of integrated expertise. Out of the communities mentioned, only technicians and maybe researchers perceive themselves as designers. Yet, design can be an activity which is tightly linked to 'socio-constructionism' for learners and to reflexive practice for teachers. Communal design can generate the need to be explicit, to reflect and to express meanings through argumentation. During a collaborative activity, a community works towards a common goal, which can be an ideal object to be created, or a specific *improvable* object (Bereiter &Scardamalia, 2003). This object is both the centre of the activity, and also functions as a communicational tool to shape a common language within the community. Cobb et. al. (2003) extend this notion by proposing the term "boundary objects", e.g. specific objects within different communities, which are «*relatively transparent means of conveying meaning among the members of the community who created them*». They can also be the centre around which community members organize their activities and can additionally operate as tools for communication among the members of the same community, and the members of other communities. Boundary objects will be interpreted differently by the different communities, and it is an acknowledgement and discussion of these differences that enables a shared understanding to be formed."Half-baked microworlds are meant to be *improvable boundary objects* and the process of changing them can be orchestrated to enhance integration in microworld design.

In recent years, analyses of the use of digital media have given rise to theories of use such as Rabardel's cognitive ergonomics theory of instrumentation (2001), i.e. the process by which a digital artifact (the object) becomes a mental scheme for each individual as they use it thought a process which he termed 'instrumentation'. Guin and Trouche (1999) discussed this theory further suggesting that we need a different term for the process by which instrumentation involves changes made to the artifact itself – 'instrumentalisation'. However, this theory, which is proving relevant at least within the field of mathematics education, seems to adopt a perspective that instrumentation and instrumentalisation are phenomena which inevitably happen when digital media are used. A particular characteristic of many Logo-based artifacts (to use Rabardel's term) is that they have been *designed* in order to be changed, i.e. *designed for instrumentalisation*. This characteristic however, in many cases remains implicit and is not really made use of in practice.

Half-baked microworlds are pieces of software explicitly designed so that their users would want to build on them, change them or de-compose parts of them in order to construct an artifact for themselves or one designed for instrumentation by others. They are meant to operate as starting points, as idea generators and as resources for building or de-composing pieces of software. This constructionist activity is seen as part of inquiry and argumentation leading to the generation of mathematical and scientific meaning. At the same time, half baked microworlds can be designed for teachers to engage in pedagogical or epistemological reflection as they de-construct or re-construct the microworlds in a context of designing tools for students. Half baked microworlds operate like diSessa's toolsets (diSessa, 1997) in that they are not built and presented as ready-made environments to be understood by the teachers and then used by students. Instead, the point is to change and customize them and thus to gain ownership of the techniques and the ideas behind microworld construction as outlined earlier.

Expressing meanings by changing the functionalities afforded by microworlds is something which has been happening through the years and reported at ICME conferences, the microworlds originally designed or used by one or more of these communities. However, they have not frequently been explicitly conveyed as media to be questioned and changed in themselves, but rather as tools to explore and construct with and possibly to extend. Moreover, the questioning of microworld functionalities and interface has seldom been perceived as an activity for people from such communities to interact with each other in order to acquire some shared perception of concepts, perspectives and goals.

A recent description of micro-worlds is that they are computational environments embedding a coherent set of scientific concepts and relations designed so that with an appropriate set of tasks and pedagogy, students can engage in exploration and construction activity rich in the generation of meaning. The first example of a microworld was 'Turtle Geometry' within the Logo programming language which generated a bulk of research on the construction of children's geometrical meanings (Laborde et al, 2006). Later research however, involved learning with the use of micro-worlds embedding a much narrower set of mathematical, scientific and other concepts, escorted by more focused theories on learning and pedagogy (Noss & Hoyles 1996, Edwards 1995, Clements & Sarama 1997, Sarama & Clements 2002).

In the early days, microworlds were seen as strictly programmable environments and their main characteristic was the ability to construct graphical models using a programming language. The semantics and rules of the language as well as the graphical representations were integrated with the concepts and relations of the domain characterizing the microworld. The key features of the students' activities enabled with such media were the ability to make constructions and change and extend the rules and relationships of the microworld itself. The highly editable nature of these media and their executable representations providing immediate and epistemologically succinct feedback (they can be characterized as conceptual mirrors) enabled exploration and bricolage and the kind of learning which took place was characterized by Papert and his team as a special kind of constructivist learning which they termed 'constructionism' (Kafai & Resnick et al, 1996). Seen in a wider context, microworlds were examples of the idea of 'deep structural access' (diSessa, 2000, Kynigos, 2004) to technologies for non-technical people, allowing for creativity, customization and personal construction of technological tools. This idea was used as an argument for the use of technologies to facilitate the growth of a technological culture rather than to inhibit creativity and expressivity with technologies.

Mathematics can be seen as an abstract domain of human thought, its objects being axioms, relations and mathematical proof. On the other hand it can also be seen as an applied science explaining various phenomena (economic, scientific, geometric, navigational, etc). Microworlds were seen to make mathematical representations useable and learnable and thus gave rise to some questioning about the learnability of traditional mathematical representations, such as formalization, providing alternative representations designed to facilitate meaning generation (Hoyles et al, 2002).

Engagement with working with half-baked microworlds involves the assumption that the overall goal is to design a learning environment which has good chances of providing some added educational value and which at the same time will be based on the use of these digital artifacts. However, both design for innovation and use of digital technologies have posed difficult challenges for education. These challenges have changed in essence during the past 40 years but not in magnitude.

Originally, this kind of technology was presented as a medium to challenge and bring about re-thinking of the educational paradigm of schooling and the epistemological approach of content domains such as mathematics. This rationale came about in the historical context of some bold attempts for curricular changes in the United States based on the problem-solving movement which focused on problem-solving methods rather than the understanding of mathematical concepts in themselves. Microworlds were seen as the ideal technological boost to the movement. Inevitably, they thus became victims of the educational innovation pendulum (Agalianos, 1997, Noss, 1992). They also became victims of the early stage in which they were created with respect to the spread of technology in the culture (Papert, 2002). Technologies were very hard to access, machines were slow and non-dependable, the internet had not arrived and people were not widely using digital technologies for something else. However, microworlds continued to be designed and used in design research initiatives providing evidence that when placed in the role of tools within a carefully designed and supported educational environment, they could greatly facilitate the generation of mathematical and scientific meanings in students. Furthermore, they appeared in contexts different to the one they originated from in countries such as Mexico, Kosta Rica, Greece and others (Blikstein&Cavallo, 2002, Kynigos, 2002). Recently there seems to be growing indication of a comeback of microworlds in a different role, that of digital artifacts for argumentation and inquiry learning in a digitally rich culture, which by itself will provide an external challenge to the schooling paradigm (Papert, 2002). At the moment, however, that culture is lagging greatly in integrating the use of digital media and reciprocally in evolving with respect to the traditional school-ish research paradigm. One of the reasons is that digital media are designed and developed by fragmented communities.

Microworlds have been perceived by the community at large as tools designed by researchers for radical innovation to be implemented in small scale situations. The era when this approach was valid and seductive to some communities outside our own seems to be ending. There is now demand for large scale initiatives and accreditation of new efforts before they have had the chance to become infused in educational curricula. The ideas behind the microworld culture are proving hard to grasp and accept not only by school systems but also by other stakeholders in education such as new computer science and telecommunication communities. This poses new challenges to the microworld community of finding methods and avenues for communicating these ideas to a wider audience in a language which is widely understood.

This kind of language can only emerge from experience of collaborating with such communities it is not something which can be defined at a theoretical level. The process will require being explicit about what happens when collaborative design and implementation is taking place. In this paper, we have an example of such an effort where different kinds of communities tried to find a common language to describe microworlds. This language may seem well understood and not very consequential to our own community. What's important however is that it seemed to be understood by others. Half-baked microworlds are tools designed to facilitate the production of such a language. They are *improvable boundary objects* in that they afford changes which operate as an ice-breaker between different communities. In discussing and implementing such changes people with different expertise, role and background negotiate and make themselves explicit. The results don't really matter, they can be one jointly agreed upon microworld or each community can go their own way and present alternatives. The importance is that in doing so, there is better understanding between them which often leads to the creation of hybrid actors (Kynigos, 2002), i.e. people with one expertise who understand enough about another so as to make sense and use it for joint design. In the next section I describe our own platforms for developing microworlds which were designed to address wider communities than our own. Subsequently, I provide an analytical description of a half baked microworld explaining how it was taken up and reformed though integrated design.

Projects

'ReMath' - Representing Mathematics with Digital Media FP6, IST-4, STREP 026751 (2005 – 2008).

'Greekworks': Interactive tools for presentation and study of Ancient Greek Technologies. Ministry of Development, General Secretariat for Research and Technology, R&D Consortia in sectors of national priority, Action 4.5.1., P1 (2003-2005)

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