learning patterns

for the design and deployment of mathematical games

kaleidoscope

Authors' Note

The project **Learning patterns for the design and deployment of mathematical games** is a collaboration between the Universities of Athens, Dublin, Göteborg, London, Utrecht and Warwick and Il Consiglio Nazionale delle Ricerche, and is funded by the Kaleidoscope Network of Excellence. The overarching aim of the project is to investigate game design and use in mathematics education so as to inform the practice of game designers, developers, researchers and teachers. The project investigates the mathematical dimension of game design and aims to foster knowledge integration from the varied communities involved through the promotion of a culture of design grounded in practice and practice informed by design.

To address these issues, we have adopted a two-pronged approach. One strand of the project is focused on the design process with respect to mathematical games, while the other is focused on their deployment in real-world classroom environments. Each strand mutually informs the other.

As a result, this literature review is divided into three parts. Part One examines the literature with respect to the game design. Part Two focuses on the deployment of mathematical games in real world settings. Part Three is the list of references combined from the two reviews.

Part 1
Literature Review: Design Strand

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Preface

"*Good design begins with honesty, asks tough questions, comes from collaboration and from trusting your intuition*." – Freeman Thomas.

Design is of central importance in the process of developing any learning resource. This is particularly so when considering game development. However, the design process is difficult: in order to develop pedagogically sound and innovative games, expertise is required from many different participants including researchers, teachers, students and game developers.

This literature review is intended as an introduction to the issues that arise when trying to capture the process of designing and developing mathematical games. It offers a perspective on the range of approaches available. Design patterns are suggested as an enabling tool for good practice, by facilitating pattern-specific communication and knowledge sharing between participants. These patterns are termed *learning patterns*, and they will be available as an outcome of this project.

Our research is divided into two strands: design and deployment. Thus, this review is accompanied by the review produced by the deployment strand. Taken together, they survey the wide-ranging research fields involved in the design *and* deployment of mathematical games and, as such, should be seen as companion pieces. Both are downloadable from: http://lp.noe-kaleidoscope.org, where you can also leave any feedback you many have. We look forward to hearing from you.

Niall Winters.

Niall Winters

Director, Design Strand

February 2006

Executive Summary

The goals of this literature review are to:

- Summarise the current state-of-the-art in design approaches to learning
- Delineate these approaches in relation to the design of mathematical games
- Detail past and current use of commercially and academically developed games for mathematics education
- Explain what a design pattern is
- Discuss the use of design patterns for learning
- Highlight the development of game design patterns and provide examples
- Provide a motivation for the creation of learning patterns for mathematical games

We provide a detailed account of the development of mathematical games and the wide range of design approaches taken to address this issue. Specifically, we promote the use of a design patterns approach in order to facilitate good learning design practice. This is characterised as a process of developing *learning patterns*, which will form one of the outputs of this project. We discuss the benefits of the patterns approach generally, but moreover, detail the pedagogical facets of software design patterns, the extension and adaptation of game design patterns and the relationship between design patterns and didactic functionalities.

This forms the basis for our belief in the potential for the design patterns approach (through learning patterns) to enable the development of pedagogically sound and innovative mathematical games.

1. Introduction

At the European level, mathematics education in schools, with some notable exceptions, has been characterised by traditional, abstract formulation that seems readily understood by only a small fraction of students. This is leading to '*poor experiences of science and engineering education among students generally*' (Roberts, 2002) and is impacting on the uptake of these subjects. For example, in the UK the number of students studying science and mathematics at A-level has dropped, in the case of mathematics, by 8.5% between 1990/1 and 1999/00. Similarly in 2004, a Swedish government report stressed making maths more available to students through less formal approaches. However, although traditional approaches still dominate, there have been attempts to make effective use of learning technologies for mathematics. In recent years, an interesting avenue of exploration has been the design and use computer games as tools for supporting mathematics education (diSessa & Abelson, 1986; Kafai, 1995; Hancock & Osterweil, 1996; Resnick et al, 1996; Klawe, 1998; Elliott & Bruckman, 2002; Jonker & van Galen, 2004; Good & Robertson, 2004; Mor et al, 2004; Simpson et al, 2005; Kahn, 1996). While there have been many worthy achievements, the design and deployment of pedagogically sound mathematics games with a wide appeal has proved illusive. There are many potential reasons for this but it is generally agreed that the process of designing a game for mathematical learning is a difficult task.

The EU-funded research project *Learning patterns for the design and deployment of mathematical games,* (a part of the Kaleidoscope Network of Excellence) over-arching aim is to investigate this problem. We work from the premise that designing games for mathematical learning is a difficult task because it requires the assimilation and integration of deep knowledge from diverse domains of expertise including mathematics, games development, software engineering, learning and teaching. Understanding how the developed games can be used in educational settings also entails familiarity with the pragmatic constraints of these settings. We see all these aspects of knowledge as various facets of *design knowledge*. The mathematical dimension of game design pertains to the question of selecting and connecting mathematical content – a question of designing mathematical structures. The question of pedagogy is a question of designing instructional structures, and so on. While each party may have expertise in several of the associated knowledge domains, no single party has expertise in all of them (see Figure 1).

Furthermore, the complexity of each of the various bodies of knowledge means that it is often hard to communicate concepts and ideas between parties. Worse yet, each community has developed its own lore and jargon. When a software engineer speaks of 'encapsulation' they mean something completely different to what an educational researcher would when using the same term. The result of this fragmentation of knowledge is that most games emerge from a particular, often restricted viewpoint. For example, a game that embodies deep mathematical can be poorly designed in terms of the gaming experience, whereas a sleek and entertaining game may be simplistic in its pedagogical intent. At one extreme we have commercial games, which often emphasize conformity with curricular policy and at the other extreme, we find academically develeoped games of outstanding mathematical beauty, but with minimal attention to visual design and pragmatics of classroom situations. (see Figure 2).

In summary, the two main issues are as follows:

- Knowledge integration from multiple disciplines
- Communication of ideas and concepts between parties

We claim that these issues can begin to be addressed through the development of design knowledge by participants in the design and development process. However, it would seem that the options to achieve this are very costly: create multi-party design and development teams, which will include experts in every related field or train 'super-designers' who are well informed in all domains. Ideally, we would like to see mathematical games developed by organizations that encapsulate all these diverse strands of knowledge. Unfortunately, creating such an environment is outside the scope of expertise of most organisations.

Therefore, we propose what we believe to be a viable alternative tool: *learning patterns*. These patterns will be designed as an enabling tool for the open and distributed sharing of design knowledge. They will be a major output of this project and will be fully detailed in the final report. For now, we focus on their conceptualisation as a development of design patterns.

1.1. Design patterns

Design patterns (Alexander, 1978; 1979) were conceived as a means of encapsulating expert knowledge in an accessible form, so as to empower non-experts to actively participate in the design processes. A pattern language for the design of mathematical games would have to afford expression of knowledge from all related domains, and its calibration. Such a language would facilitate a culture of communication among the different communities without necessitating costly organizational structures. Such a culture has emerged over the last decades in what is arguable the most complex and intense area of design activity: the construction of large software systems. In this domain the use of design patterns has been very successful. In their seminal book Gamma et al (1995) argue:

> One thing expert designers know *not* to do is solve every problem from first principles. Rather, they reuse solutions that have worked for them in the past. ... Consequently, you'll find recurring patterns of classes and communicating objects in many object-oriented systems. These patterns solve specific design problems and make ... designs more flexible, elegant, and ultimately reusable. They help designers reuse successful designs by basing new designs on prior experience. A designer who is familiar with such patterns can apply them immediately to design problems without having to rediscover them. (Gamma et al, 1995)

Appropriating the ideas of Christopher Alexander, they provided a standard template for software design patterns and taxonomy of 26 patterns. Since then, numerous pattern books, conferences and web sites have proliferated and spread into every aspect of software related design and production. These patterns and pattern languages enable designers to share discuss and aggregate their knowledge across wide, distributed and diverse communities.

Recently, the concept of design patterns has made its first strides in educational domains. One such domain is that of educationally oriented software systems, such as e-learning systems (Derntl & Motschnig-Pitrik, 2004); another is the design of computer science courses (Bergin, 2000). Our project aims to extend this paradigm to the domain of designing mathematical games. We see the design patterns approach as a potential answer to the complexity and intricacy of the issues inherent to this domain. We also hope that it can foster new practices and cultures of using games in education. Rather than relying on huge investments, extensive research, and long development cycles, we wish to facilitate a shift to lightweight iterations, where conception, design and development of mathematical games are driven by classroom needs. A culture in which games are familiar resources, constructed, adapted and modulated by practitioners to meet immediate objectives, much in the same way as a book or a whiteboard diagram would be used. A design pattern used in this way will be referred to as a *learning pattern*.

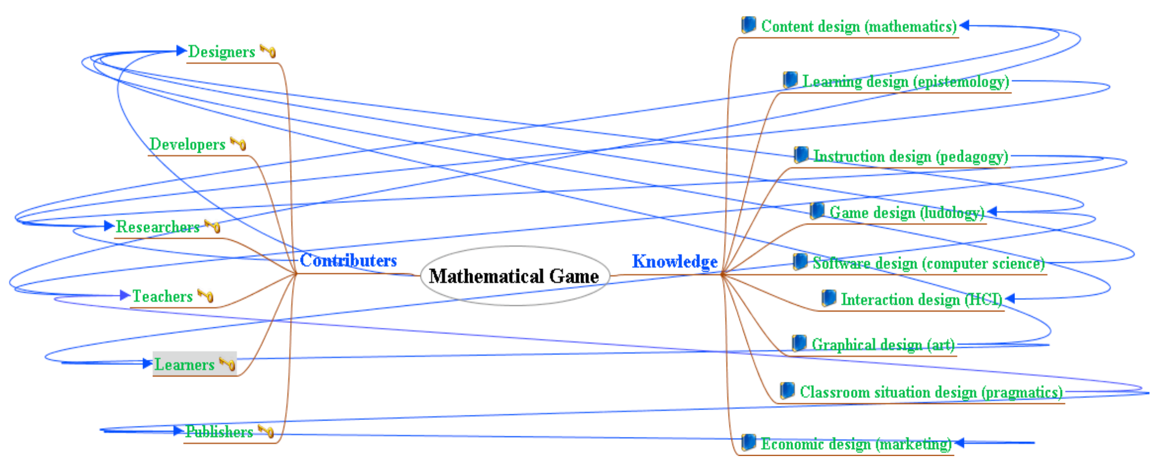

Figure 1: Contributing parties and knowledge domains involved in mathematical games

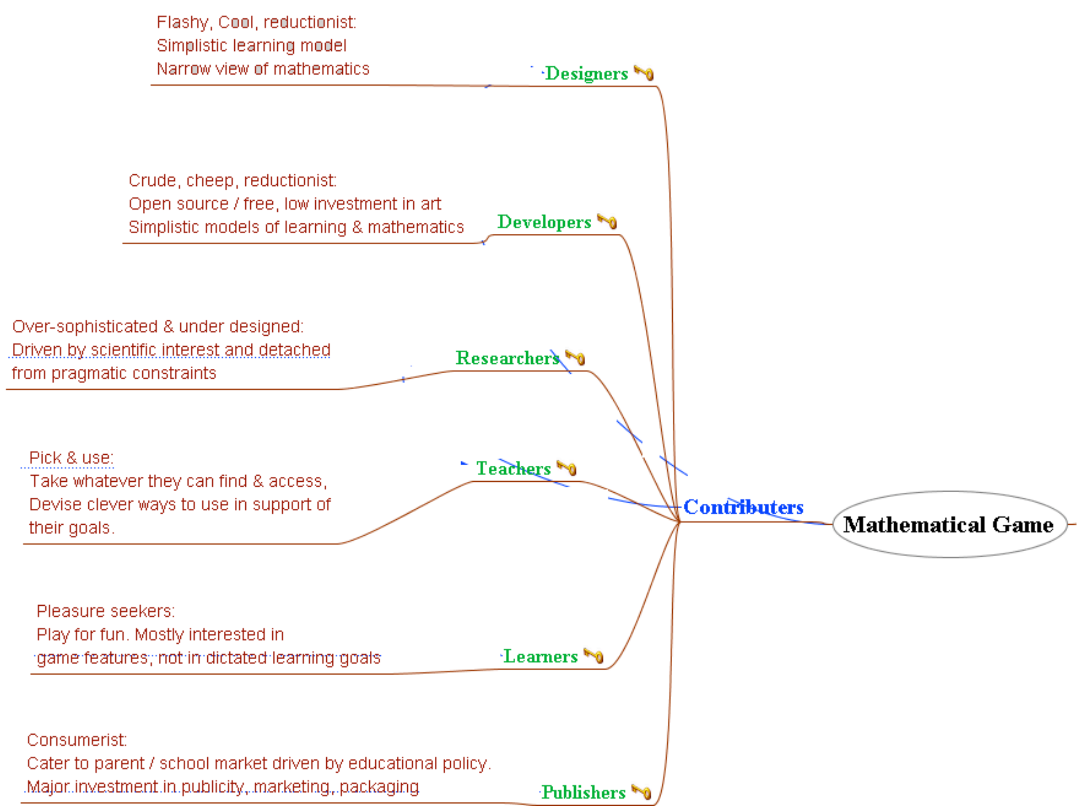

Figure 2: Possible outcomes of a 'worst-case' single-perspective game design

1.2. Computer games and learning

Computer games are a popular form of activity. In 2004, the US market alone was worth $9.9 billion (NPD Group, 2005), and in the UK in 2002 the market was worth approximately £2 billion (ELSPA, 2005). As such, games are playing a more central role in peoples' lives than ever before and are becoming a topic of serious research interest.

Over the years, games have been studied from many different perspectives by researchers, but two distinct categories can be identified. The first, which is older and still most common, regards games as a research tool or only studies aspects of games that are also found in what typically is a subject within a specific research discipline such as philosophy (Wittgenstein, 1973; Bauersfeld, 1995), culture (Huizinga, 1971), economics (von Neumann and Morgenstern, 2004), or literature[1] (Aarseth, 1997). The second category, which placed games and gameplay as the central topic of the new research discipline of ludology, is in contrast young. The field's first peer-reviewed journal was launched in 2001 (Aarseth, 2001) but already a collection of books (Salen and Zimmerman, 2003; Juul, 2005) and anthologies (Salen and Zimmerman, 2006; Wolf and Perron, 2003) show the extent of research produced. However, little of this has been focused towards the design of games but rather towards game studies, studies of players, or studies of games in relation to other media.

There are examples in both categories regarding research in educational use of games. Within the first category studies include the role of all types of games and play in child development (Sutton-Smith, 2001) and video games in particular (Jenkins and Squire, 2004; Gee, 2003) as well as games within the field of edutainment (Egenfeldt-Nielsen, 2006), to which we will return in Section 3.2. An example, within the discipline of ludology, is Kafai who stresses "making games for learning instead of playing games for learning" (Kafai, 2006) and thereby indicates an importance of understanding what games are so that one can create games with specific design goals. These design goals have to co-exist with characteristics that have been identified as being essential for activities to be pleasurable (Csikszentmihalyi, 1991), which in a game context translated to providing good gameplay (Järvinen, 2002). In turn, they continue a traditional characterisation of engaging gaming experiences (Malone, 1980). These characteristics, which can be seen as general design goals of games with respect to enjoyment, are (Järvinen, 2002):

- *A challenging activity that requires skill*: Enjoyment will arise when the action required of the player matches their skill level. The player's skill will develop in relation to their ability to learn the fundamentals of the gameplay.
- *The merging of action and awareness*: Players become so involved in the game

[1] It should be noted that Aarseth since then has become one of the leading voice in claiming ludology as a research field in itself, e.g. by being instrumental in the creation of the Game Studies online journal as noted below.

that self-awareness ceases; they cannot separate themselves from their actions. Gamers often refer to this experience as being ‘in the zone’.

- *Clear goals and feedback*: Players should be provided with clear goals and receive immediate feedback on their actions so that they feel they are in direct interaction when playing the game.
- *Concentration on the task at hand*: The game should be designed so as all of its component elements support the players immersion in, and concentration on, the game. If any component is ill conceived, badly designed or badly executed this will falsify the experience, thus breaking the players concentration on the task.
- *The paradox of control*: The ability of the player to be able to exercise control over the game world is dependent upon the means they are provided with to do so.
- *The loss of self-consciousness*: This refers to the ability of games to enable players to *expand* their concept of self through opportunities (i.e. flow experiences) to forget temporarily the constraints of who they are (Csikszentmihalyi, 1991).
- *The transformation of time*: The author sets the temporal structure of a game, and the relationships between particular events. In this way, a player’s enjoyment of a game transforms their concept of time. Unlike some traditional forms of media, for example, events may not play out in a linear fashion.

Kirriemuir and McFarlane (2004) undertook a literature review of games and learning for the National Endowment for Science, Technology and the Arts (NESTA) in the UK. An overview of the main developments in research into gaming and the educational relevance of video games illustrated that although the use of ‘mainstream’ games in schools is rare, parents and teachers increasingly recognise the potential of games to support valuable skills development, such as “strategic thinking, planning, communication, the application of numbers, negotiating skills, group decision-making and data-handling”. Significantly they also highlight the fact that educational games often fail to realise players’ expectations because the games are often too simplistic or repetitive with respect to commercial computer and video games, and are often poorly designed with little support for active learning to achieve understanding.

In 2002, the British Educational Communications and Technology Agency (BECTA) undertook a small-scale pilot study (BECTA, 2002) investigating the use of six computer games in a school setting. In summary, they found some promising potential for future work by researchers, teachers and games developers based on initial, tentative findings that games can support student's ICT skills, increase their motivation, encourage collaborative working and can have positive side effects such as increased library use. However, they also noted some potentially considerable negative affects of gaming. These include the fact that playing commercial games can be time consuming and they are often too complex for the classroom context, resulting in educational focus being lost. In addition, although girls are a fast growing segment of 'gamers', they may be disaffected.

While both of the above studies make a valuable contribution to the rationale for employing games in learning, they view the potential at a high level (e.g. increased motivation, support planning). In a more focused study of commercial game use in the classroom (McFarlane et al, 2002), the views of parents, teachers and pupils views were sought. A number of features of games were seen as important when integrating them into formal classroom practice, and should be taken into account by designers. These features included: record what players have done, show clear progression, make the difficultly level adaptable to students of varying abilities, if repeating, make sure the repeats are not identical, embed the ability to save the exact point at which the player finished and provide suitable stopping periods for complex games which require multiple class sessions to complete.

2. The design and use of games for mathematics education

In this section, we primarily focus on the design and use of games specifically in mathematics education. We provide examples of the approaches taken by researchers in the field and highlight the key concepts and ideas used. Technology use in mathematics education

Before going on to deal specifically with the use of games in mathematics education, we provide a background of the use of technology in mathematics education by tracing the milestones of its evolution, illustrating the main historical research strands.

Throughout the history of the use of technology in education we find a line of evolution on the basis for the different metaphors used to describe (and design) the relationship and interactions, between the human, the employed technology, and knowledge. Such perspective is relevant because it highlights the position of the different theoretical frameworks with respect to knowledge, pupils, teachers, community culture and the relationships among them. Comprehensive descriptions of such evolution of educational approaches are given by (Bottino, 2001), and (Bottino and Chiappini, 2002). By drawing on their work we will point out those aspects that we consider to be relevant to for our study. Three main metaphors will be used as a lens through which to view this progress: the transmission metaphor, the user-centred metaphor and the participation metaphor.

The transmission metaphor is based on the idea that knowledge can be transferred from one person to another, and where technology is concerned, from a person to an object, and from an object to a person. The cultural context is that of behaviourism which, in fact, influenced the first ways in which the computer had been used for educational purposes. Learning was seen as the "induction of a required behaviour according to the well-known model stimulus response"" (Bottino, 2001, pp. 13). The reference to such a model led to the design of systems such as those usually referred as to drill-and-practice programs and tutoring systems.

Drill-and-practice programs consist mainly of automated ways to submit exercises to pupils, users are faced with questions to answer, and usually get feedback on the correctness of the answers. As Bottino observes, “they usually employ some form of questioning strategy and often use some gaming techniques for encouraging participation and motivation” (ibid., pp. 13).

Tutoring systems, as distinct from drill-and-practice programs, are often based on an information processing approach to learning. Their design ascribes importance to reinforcing memorisation, presenting objectives, specifying prerequisites, eliciting and assessing performance. Given a topic, they include related content instruction, and present questions that, to be answered, require the user to employ concepts or rules covered in the instructional sequences. The given feedback is mainly diagnostic, aiming at identifying processing errors and prompting remediation or recasting of the instructions. Such systems are conceived as “‘stand alone’ systems, designed as a single learner's private tutor” and “their use in classroom practice is limited since they are often perceived more as replacements of teachers than as tools to help them in their work” (ibid., pp. 13).

According to Bottino, both kinds of computer programs were severely limited: they do not substantially change the way their users interact with a given object of knowledge, and do not contribute to furnishing a learner with new ways to give meanings to related concepts. The system is conceived as an “environment where knowledge is transmitted in order to be acquired by the user” (ibid., pp. 13-14).

However, despite its limited educational advantages, the transmission metaphor has been particularly successful in the sense that most of the commercial games for mathematical learning are based on this approach, probably because of the simplicity of the games developed within this strand. Moreover, despite, and because of, its limited educational advantages, the transmission metaphor played a key role in the evolution of educational research, as Bottino and Chiappini observe:

"One of the major forces driving change has been the assumption that meanings are lost if learning is simply the transmission of information".

([Bottino and Chiappini, 2002, pp. 758).

Such a driving force gave birth to the user-centred metaphor, which objected to the assumption (which characterised the transmission metaphor) that the user of a given educational technological artefact is mainly a receptor, and the artefact itself is in charge to transmit knowledge. Thus, within this paradigm, the study of the artefact itself has great relevance because it has, to some extent, to contain some knowledge and be able to transmit it. Such an imbalance of focus was reversed when the interest on constructivist theories increased, leading to a shift of attention from the artefact to the user, to the internal aspects of the learner (Bottino, 2001, pp. 14).

Many authors use expressions such as 'learner-centred systems'[2] and 'problem-based learning', and, in general, view learning as based on active exploration. The learner has to be in some way immersed in the topic and also be involved in problem solving activities relevant to the topic. Such involvement is supposed to motivate the learner in seeking new knowledge and acquire new abilities (ibid., pp. 14; Bottino and Chiappini, 2002, pp. 758).

Given a topic, one may think of creating an environment with artefacts or objects that have some relationship with the topic and where learning may occur by exploring the environment. Such an idea is at the core of the concept of the Microworld, introduced by (Minsky and Papert, 1971) This is an environment that is built around a given domain, which has to be explored by interacting with the program. A detailed history of the concept of microworlds can be found in (Noss & Hoyles, 1996).

In a microworld, a crucial role is played by the objects that are made available to use through the interface: "Papert defined them as a transitional computational objects, that is objects which are in between the concrete and directly manipulated, and the symbolic and the abstract" (Bottino, 2001, pp. 15). Thus, for educational purposes, it is important to consider the epistemology of the transitional objects in order to evaluate microworlds and "distinguish between potentially powerful environments and environments less appropriate for exploration" (ibid., pp. 15).

However, if on the one hand, epistemology played a crucial role in the design and choice of microworlds; on the other hand, as far as learning situations and educational research

[2] As distinct from Learner-Centered Design, which will be detailed in Section 1.3.1

are concerned, great attention was given to learner behaviour. The objective was to design and analyse learning situations, which favoured the emerging of knowledge from the interaction between the student and the environment.

If we now take a games perspective on this, the focus was both on the games and on the learners, their roles are different, but both are crucial for the design and implementation of educational activities. Within such a framework, significant results have been produced by years of research, but their impact on school practice was far less than expected. This was mainly because changes in classroom practices did not occur to adequately enable exploitation of the new technological artefacts (i.e. ICT-based tools):

"high expectations regarding ICT-based tools potential to drive change and innovation at school remain largely unfulfilled. One of the main reasons for this […] is that technology has often been introduced as an addition on to an existing, unchanged classroom setting"

(Bottino, 2001, pp. 15).

The previously described paradigms focused mainly on the technology-user pairing, and on the relationship and interactions between them. This turned out to be too limiting for the purpose of education. Moreover, technology itself turned out to not to have the power of giving greater meaning to educational activities. Research showed a need to extend the focus: where a tool is concerned, its pedagogical significance cannot be defined by taking into consideration only its characteristics, but rather must consider aspects that are external to the tool itself (Bottino and Chiappini, 2002, pp. 758-759). There is then a need to develop, together with new technology (games in our case), specific educational paradigms aimed at exploiting the new resources for the improvement of teaching and learning activities. However, we cannot work on the assumption that tool use will lead to educational improvements as such a simplistic approach has been shown to lead to disillusionment. This issue, in recent years, has represented a major topic in the debate conducted by researchers. The ongoing discussion shifted the focus from cognitive theories to other perspectives, less focussed on the individual, and more oriented to highlighting the *social nature of cognition and meaning production* (for example, Activity theory, Situated Action Models and Distributed Cognition; see (Nardi, 1996)). Within these theoretical frameworks, practice is viewed as interlaced with learning, and meaning is interpreted as interlaced with the practices and the contexts in which it is negotiated (Bottino, 2001, pp. 16).

These theoretical viewpoints had a major influence on the design and use of technology: it was no longer conceived merely as a means for the development of specific abilities and/or the accomplishment of particular tasks. Instead, a holistic approach was required: the context of teaching and learning activities had to be taken into account, included the long term processes that are needed to develop complex articulated knowledge. This can hardly be analysed considering only the student-artefact unit. The idea is that of interpreting learning not only as an individual construction developed during the interaction with the artefact, but also as a social construction developed within the whole learning environment.

2.1. The use of games in mathematical learning

The first historical document showing explicit use of games in mathematics is an educational text book written between 735 and 804 by Alcuino from York: 'Propositiones ad Acuendos Juvenes' (Franci 2002). The text presents a set of problems that can be classified as belonging to recreational mathematics: the aim of solving them is only to get intellectual pleasure (ibid pg. 168). Moving on to computer games specifically, we find that there has been a long history of the use of games specifically for mathematical learning. In part, we will use Egenfeldt-Nielsen's overview of the educational use of computer games as an initial basis to detail this history (Egenfeldt-Nielsen, 2005). Furthermore, we will delineate the main strands of research with the field of mathematical games for education.

The first games developed were focused on simple drill-and-practice techniques that did not utilise the powerful computational and interaction potential of computing technology Klawe (1999). One of the first strands was the development of games to aid with understanding everyday mathematics (Egenfeldt-Nielsen, 2005). In the early 1980s with the widespread use of pocket calculators, Levin (1981) determined that there was a need for mental estimation techniques to verify the reasonableness of computations. Inspired by the 'Darts' game (Dugdale & Kibbey, 1975), Levin (1981) developed two computer games, 'Harpoon' and 'Sonar' to aid children in developing an "intuitive feel" for numbers by successively estimating closer approximations to the answer. Both games were tested with ten year old children, who found them challenging and motivating (Levin, 1981). Levin goes on to argue that students should be provided “with a wide variety of approaches for computation, rather than any one canonical technique [and rather] than reacting to the new technology for calculation as a threat, we should consider it a valuable opportunity to reconsider the assumptions underlying the mathematics curriculum”. We agree with the sentiment but in our case, 25 years later, the new technology is computer and video games but the motivation is similar.

More recently, the Electronics Games for Education in Math and Science (EGEMS) was a collaborative project investigating the design and use of computer games in enhancing mathematics education specifically for students aged 9-14 (Klawe, 1999). In particular, prototyping educational computer games and conducting focused quantitative and qualitative studies to evaluate the effectiveness of various design and use options was a priority. The project findings suggest that computer games can be highly effective in increasing children’s learning and enjoyment of mathematics when children actively “think about and value the mathematics embedded in the computer game [with] three factors to be particularly important in focusing students’ attention on the mathematics: teacher attitudes, supporting activities and collaborative play”. (Klawe, 1999). However, when this doesn’t happen almost no mathematical learning results from playing the game.

The relationship between mathematics and gaming has been often used as a means for motivating pupils. Other researchers employ games directly as means for motivating pupils and increasing their participation. Bednarz et al (2001) studied how games can be employed so as to foster a positive attitude in pupils with respect to mathematics and to learning in general. The study focused on the case of underprivileged pupils who were provided with a set of competitive games involving mathematical reasoning. The students’ learning happened as they participated in the games, including their changing/discussing the rules of the games and discussing the strategies developed. Engagement in game play can thus provide a meaningful context for students to study mathematics. In some case, this engagement is motivated through a second learning experience. For example, Novotna et al. (2001) describe examples of experiences where mathematical games are played using a language that has to be learnt. In this specific case, it is not clear how much the learning of mathematics is explicit, or how much it comes as a side effect of the overall activity. However, this example highlights research focused on the idea of mathematical learning as a 'side effect' of game play.

Another approach is to design games that cannot be completed without players performing some mathematical operations. This is often the case with classic drill-and-practice games, but in the literature one can find more complex extensions of this concept. The 'Interactive Instructors of Mathematical Entertainers', is one such example aimed at the collaborative learning of mathematical concepts through an online learning environment, where student communicate via instant messaging (López et al., 2001). Another example, within this strand, is that provided by (Holzinger et al., 2001). In their approach learners train a virtual quiz player, and then help the player in participating in a competitive mathematics quiz. The authors speak of the "Tamagotchi effect", of students taking responsibility for their virtual player by getting particularly involved and motivated in training the virtual player and helping it to win the virtual quiz. The underlying idea is that students may enhance their learning of the mathematics by solving the mathematics, which the virtual player has to be trained in. In a sense the learner is also a teacher bring to mind the old adage that 'if you want to learn something, try and teach it'! We may probably ascribe to this strand also the theory of "transfer" described by Evans (1999).

The strands we have described so far refer to quite generic ways to employ games in order to motivate, provide meaningful contexts, increase learning, but they do not refer explicitly to fundamental mathematical concepts. Employing games as a way for learners to engage with specific mathematical concepts (i.e. rules, strategies, etc.) is one of the most popular ways in which games are used in mathematics education. This strand includes the games described by Bednarz et al (2001). The key idea here is that playing games may involve adapting to rules, discussing rules, formulating strategies and dealing with specific mathematical concepts. An interesting example is provided by the 'Guess my Something' strand of games, as reported by Carraher et al. (2003) and as employed by Italian National Research Council and the London Knowledge Lab in the Weblabs project (Mor et al, 2004).

A final strand worth mentioning is games concerned with learners developing and validating strategies. For example, some authors provided pupils with ‘logic games’ under the assumption that learning happens in terms of the development and validation of strategies. Masoon et al (2002) provide such as case but however they do caution that students may tend to validate their strategies by playing rather then by “proving” them.

The issue of developing, discussing and validating strategies is addressed by Chevallard et al. (1997) who introduce the *Theory of Didactic Situation* basing the definition of “a didactic situation” on the relationship between the formal game and strategies development. The authors describe the theory by providing an example based on a game (“Carrera del 20” or “Race of 20”): to begin students play the game in pairs, then they play in teams and formulate strategies. Finally the class attempts to validate the strategies developed by the team: each team has to propose a winning strategy and can critic the other team’s strategies, try to show that they are false, and oblige other teams to play using a given strategy.

Finally, we would like to include within this strand research that involves students in the development process by employing them as “researchers”. Thus they are not only playing the games, but critically are also reflecting on the games (Klawe et al. 1995). This research is related to participatory design, as detailed in Section 3. In some cases there is also the presence of a virtual tutor (Zhao 2002), which may substitute the teacher.

The main strands on the use of games in education are summarised in Table 1.

• Drill and practice • Games and linguistics • Games as attractors, to motivate and involve pupils • Games as meaningful contexts for pupils to develop mathematical contexts	• Mathematical learning as a side effect of playing games • Games and concepts, strategies or rules • Games as contexts to experience researcher's activities

Table 1. The main strand of research we have identified on the use of games in mathematics education

2.2. From games to gaming situations

In Section 2.1, we showed how the evolution of the idea of a learning environment, led to the inclusion of the whole learning situation. This focus on the holistic teaching/learning context leads to attention being put not only on game design, but also on how the game can be used for specific educational purposes, as reported by Bottino for the case of computational technology:

"Consequently there is an increasing interest in aspects related not only to software design but also in the definition of ways of use suitable for exploiting software features in order to accomplish meaningful teaching and learning activities." (Bottino, 2001, pp. 17).

We observed an evolution in the literature from the point of view of the unit of analysis considered, and of the roles played by the technological artefacts and by its users. Researchers started out by considering only the couple user-artefact, and ended in enlarging the unit to the whole learning context within the participation metaphor approaches. Concerning games, at first the 'main actor' was the game itself. Then, under the influence of constructivism, the user played the 'main actor' role, and the design and use of learning environments was conceived to adapt to the user and serve the user development in some way. In recent years, as a holistic approach to the learning situation was considered, we witnessed the inclusion of other important elements in the ‘gaming situation’, for example, the teacher or other gamers.

Within the transmission metaphor, knowledge was assumed to be learnt by pupils simply thanks to transmission of contents, while within the user-centred approach, knowledge is assumed to be recreated/reconstructed (thus learnt) by pupils by playing games within specially designed environments or microworlds. The latter is a constructivist principle that proved its validity, but that showed also some weakness. A crucial point, here, is the coherence of the knowledge built by pupils with the knowledge the teacher is trying to teach. If only the system user-game is considered, then such coherence can be ascribed only to the user and to the nature of the game and the interactions with it. Accurate epistemological studies of the system (even during the design phase), may point out some kind of knowledge that in some way is embedded in the game. Nevertheless, the user may not necessarily learn such knowledge: it may happen that users do not relate the gaming activity to what they are supposed to learn. This was shown in the case of Computer Algebra Systems (Guin and Trouche, 1999), highlighting a key question regarding the use of games in mathematics education: *when playing games how can learning outcomes be produced that are coherent with a given mathematics educational goal*? Such a question has been partially addressed in the domain of technology in mathematics education. Cerulli (2004) stated that coherence could be achieved through an evolution of the learning outcomes, under the guidance of the teacher, by means of particular communicative strategies. Such approaches rely on the Vygotskian notion of semiotic mediation (Mariotti 2002; Mariotti and Bartolini Bussi 1998; Cerulli 2004).

2.3. Didactical functionalities

In this section, we detail a construct which will allows us to analyse, compare and classify, the different approaches to the use of games in mathematics education. We term this construct a *Didactical Functionality* (Cerulli et al, 2005). It was developed by the TELMA European Research Team (ERT), within the Kaleidoscope Network of Excellence, of which a number of researchers in this project are involved. The goal is to determine critical concerns that characterise the educational uses of information technology in mathematics education. Once such concerns are identified, it is then possible to compare how different research approaches, or theoretical frameworks address the concerns. In the case of information technology used for education, the key concerns identified are:

1. There exists, at the very least, *a tool* and *an educational goal*.
2. The tool is employed *as a means* to achieving the educational goal.

This then identifies three key concerns: the tool, the goal and the means of achieving the goal using the tool. The latter is also referred to as a 'modality of employment'. In turn, these form the starting point to develop *didactical functionalities*, defined as (Cerulli et al, 2005):

... those properties of an ICT tool and its modalities of employment, which may enhance teaching/learning processes, according to a specific educational goal.

Notice that, according to this definition, issues such as context, pedagogical strategies, etc., are addressed in terms of "modalities of employing" the tool. This flexibility was deliberate: it does not state *a priori* what aspects of the modalities of employing a tool must or must not be addressed. The idea is behind this is that such detail depends on the specific theoretical frameworks assumed for each approach. Thus, a comparison between different approaches can be done only in terms of the details provided – in the definition of didactical functionalities – for the employed tools. On the negative side, there is a risk that this could lead to a proliferation of details (provided as a description of the modalities of employment of a tool) within a given approach, making it difficult to compare different approaches. However, such complexity can be reduced by adopting a *necessity principle*: "not all the details of the experiments needed to be given, but only those that the team believed to be necessary conditions for the experiment to be successful according to the team's theoretical assumptions" (Artigue et al, 2006). In other words, if specific details are not believed to be crucial for the achievement of the stated educational goal, then such details should not be considered as characteristic of the modalities of employment.

Potentially, there are two main ways of using the didactic functionalities: a) For a given tool one can identifying an educational goal, and defining the ways in which the tool is to be employed (in the teaching/learning practice) in order to achieve the goal; b) One can start by having a modality of employment and then identify an educational goal to be addressed, and only later build the tool. The first situation is probably the most common one, but there are also examples of the second kind. Cerulli (2004) wanted to develop a new tool. He began by using an *existing* tool in order to examine the current practice in introducing pupils to geometry theory. He then extracted the ways in which that tool was being employed to achieve such goal, and only after that, identified the educational goal: introduce pupils to algebra as a theory. He then developed a symbolic manipulator to achieve the educational goal using the *new* tool.

The concept of a didactical functionality is in a sense "fair" because it does not place particular attention on any one element. In principle, the same importance can be given to each of the elements (tool, goal, means). We may thus find fact some researchers focusing mainly on the hard characteristics of tool, some researchers that focus mainly on the educational goal, and researchers that focus mainly on the modalities of employment. This is sometimes not simply a difference of focus, but also a difference of theoretical frameworks: the TELMA experience showed for instance that researchers referring to the "Theory of Didactis Situations" place much more importance to the hard characteristics of the tool, as compared to researchers using Vygotskian theories, who placed more importance on modalities of employing the tool. (Cerulli et al. 2005).

A partial example of a *didactical functionality* defined and used, assuming a socio-constructivist perspective, is provided in Table 2.

Tool characteristics	Educational goal	Modalities of employment of the tool
• Provided feedback • Allow users to leave boxes unfilled • Construction of trees of expressions	Understanding key concepts of fractions.	**Setting:** pupils work in pairs; the teacher interacts with students in order to question/validate their strategies and to stimulate/support their production; the teacher orchestrates class discussions. **Typologies of activities**: open ended activities; verbalization of activities; class discussions highlighting and discussing the emerged strategies. **General educational strategy**: to enable pupils to explore open ended problems and to try out solutions to be verbalized, validated and institutionalized.

Table 2. An example of didactical functionality, for the algebra software Aplusix, defined and experimented by the I.T.D. team within the TELMA activities, assuming a socio-constructivist perspective. Each element described in the modalities of employment column is to be considered as a necessary condition for this didactical functionality to be effective.

3. Design approaches

In Section 1,we argued that the production and use of mathematical games in educational settings involves a wide range of design problems: mathematical content design; pedagogical and epistemological design; game and software design; graphical and interaction design. From a research perspective we see three paradigms that relate to design: design as an object of study; design as an outcome of study and design as a method of study.

The first theme engenders questions regarding the suitability of design to purpose, and the guidelines for achieving better design. Following the dimensions of designing mathematical games, such questions can lead to foundational research in instructional design, human-computer interaction, and game design. Once these foundations are established, a second wave of studies will appear, building on the theories developed in the first, producing and evaluating concrete designs. Every few years, this process will iterate with the emergence of a new overarching paradigm.

Traditional research would segregate the design of policies, practices or artefacts from their evaluation. The former was the role of policy makers, practitioners or publishers. The researchers' role was to observe, passively and objectively. The recent decades have seen an increasing breach of this divide. Researchers began to use their own designs, to demonstrate, validate – and even develop their theories. Gradually, this trend grew into an established methodology of design research. This blurring and reconfiguration of roles provoked an even more radical breakdown of structure: if researchers can partake in the design process, why not teachers, and for that matter – why not learners themselves?

For many researchers, design had become a ubiquitous activity. Consequently, they came to see a strong connection between design and learning. On one hand, the process of design is by necessity a site of learning. On the other hand, users of technology are confronted with a constant demand to learn new tools and new practices. Several researchers, coming from various traditions, had begun to explore ways of enhancing and directing the learning potential of design, either by engaging learners in design processes or by building scaffolding for learning into artefacts.

The breadth of research along these themes is overwhelming, even if we restrict ourselves to studies that relate to mathematics or games. We will limit ourselves to the strands that shall inform our work.

3.1. The Learner vis-à-vis design

Druin (2002) offers an extensive and insightful review of the evolving role of children in the design of technology. Nesset and Large (2004) provide a broad and lucid taxonomy of the main theoretical trends. We refer the reader to these sources for further reading.

Druin (2002) argued that for a long time, even when users are consulted in the design or evaluation of educational technologies, these are predominantly teachers or parents, and rarely the learners themselves. The interest in children as users of computer technology, once sporadic and limited to educationalist (mainly from the constructionist tradition), has expanded recently to a wider community of Human—Computer Interaction (HCI) and Technology-enhanced Learning (TEL) researchers. With this expansion comes a shift, from questions focusing on the educational impact of technology on children to the impact of children's psychology on technology design. Interestingly, she notes that the first paper discussing children and HCI issues was focused on analysing children's use of games (Malone, 1982).

Druin (2002) states that there are four main roles which children can play in the technology design process: user, tester, informant, and design partner. These roles are concentric - an effective tester needs to be a competent user and so forth. As users, children's contribution to the design process is passive - through observations, video recordings, usage logs, and post-usage evaluation. The level of involvement grows from one role to the next, where as design partners, children are considered equal contributors and stakeholders, in accordance with their capabilities and the constraints of the process.

The degree of impact children have on design is defined by their role in two dimensions. Obviously, the closer the children are to a partner role, the broader and deeper their input to the design process. Yet there is also a temporal dimension: the closer children are to the user end of the spectrum, the latter they are engaged with the design process. Thus, as users, they are presented with a completed product, and the observations made by researchers will only feed into the design of other products. As testers, their contribution may affect subsequence versions, whereas as partners they can influence the process from its early conceptual phases.

The earliest attempts to observe the child as user where in line with the general convention of their time, that the user does not have the expertise to understand her own needs. The methods included, as an example, one-sided mirrors. The researcher would take note of the learners' actions, and interpret them without actually interacting with her 'subject'. The concept of child as tester only emerged in the late 1980s. The notable exception is the constructionist tradition (discussed in Section 2.1), which, from its beginnings in the 1960s at the MIT AI laboratory, engaged learners as testers. This was no coincidence, as the active role of children was at the core of the constructionist philosophy. Furthermore, the learning activities focused on construction of digital artefacts. In fact, one of the first reported projects challenges students to write a game-playing program (Papert and Solomon, 1970). Yet in terms of responsibilities, the segregation between children and adults was maintained. Adults worked according to a plan, motivated by deep epistemological ideas, directing children's learning. Children played, and learned, carelessly within the microworlds provided by adults. This distinction was not explicit, but more a matter of instinct. In fact, the role of children in the design process wasn't questioned – it was assumed.

In wasn't until 1997 when Scaife et al (1997) initiated a critical discussion regarding the role of children in the design process, and offered the distinction of 'informant design'. At about the same time, child-as-partner approaches emerged, influenced by the Scandinavian participatory design movement of the 1970s. Participatory design is "a set of theories, practices, and studies related to end users as full participants in activities leading to software and hardware computer products and computer-based activities" (Muller, 2002). From this perspective, Béguin (2003) points at the tight relationship between design and learning. He suggests that the effective design should be constructed as a process of mutual learning involving users and designers. In the beginning, stakeholders have partial views of the designed artefact. Referring to socio-cultural theories of instrumental genesis (Vérillon & Rabardel, 1995) and semiotic mediation (Vygotsky, 1978; Wertsch, 1995), Béguin argues that the products only reach their final form through use, and that this should be reflected in an iterative design process which allows the users and designers to collaboratively shape their concept of the product and its actual form simultaneously. Such an approach, if sometimes not explicitly stated in these terms, led to the emergence of methodologies, which utilizes the participatory design of tools and artefacts as a central element in the learning process.

Caroll et al. (2000) describe a long-term participatory process of designing a virtual learning environment, and argue that apart from driving success in the development of the educational technology, this process was a source of empowerment and personal development for its participants. Vavoula et al (2003) refine the concept successfully in the domain of mobile learning, proposing a model they call the future technology workshop. Kaptelinin, Danielsson and Hedestig (Kaptelinin et al, 2004; Danielsson 2004) situate their analysis in the Vygotskian tradition, and argue that participatory design methods promote a trajectory form user to learner to contributing participant.

The Participatory design approach would appear to be close to the constructionist one. The first promotes learning by engaging students with the design of (predominantly) digital artefacts, whereas the later does so by engaging them with the construction of (predominantly) digital artefacts. Surprisingly there has been little interaction between the communities. A possible explanation for this is cultural: the participatory design approach descends from a tradition of research in software engineering and interface design (see (Kensing and Bloomberg, 1998; Asaro, 2000) for a political and historical background of the Participatory Design movement), whereas the constructionist approach is derived from a Piagetian developmental tradition of epistemology. The primary concern of participatory design was in deriving better designs for useful systems, tuned to the needs of their users. The educational value of the process was only acknowledged in retrospect. By contrast, the constructionist agenda focuses on the learning process and the construction of meaning. Any artefact used or created on the way is a disposable by-product. Consequently, participatory design, as a methodology, seeks to structure and formalize the design process so as to facilitate synergy best, while constructionism often (albeit not necessarily) strives to leave as much of the activity open and unplanned to allow for tinkering or bricolage (Papert and Harel, 1991).

A notable exception is the Druin's cooperative inquiry method (Druin, 1999). This method is specifically tuned to children participants, and stresses the learning facets of the design process. It is grounded in the Logo and SmallTalk traditions, stemming from the seminal work of the 1970 at MIT and Stanford. Yet it explicitly promotes an egalitarian relationship between children and researchers, while acknowledging children's unique characteristics as technology users and design partners. The unique challenge of this approach, as testified by Druin, is that neither party is in full control of the design (and learning) process. Decisions need to be honestly negotiated and outcomes are unexpected. Not many adults are willing to enter such a relationship with children. From a research point of view, this blurring of boundaries poses a methodological challenge: how can one provide valid and credible accounts of situations where the researcher-observer is deeply immersed as a participant, and some of the observations are conducted by the children. Yet the rewards are overwhelming, in terms of the children's learning experience, in terms of the adults' learning experience and in terms of the innovative and surprising products generated by the process.

A related strand of research was initiated by Soloway, Guzdial and Hay (1994). Blending socio-cultural and constructivist theories with the popular user-centred approach to interaction design, they proposed a theory of Learner-centred design. Learner-centred design is based on the premises that a user of technology constantly changes, through learning, and that her needs from the technology change in the process. In particular, the user learns through using the technology, and the design of the technology needs to account for that learning. Soloway et al begin by questioning the dichotomy between learning and work. Drawing on the *learning organization* model, they claim that in modern organizations workers are required to constantly learn. In fact, they claim, learning is most effective when done *on the job* and *by action*. They challenge the HCI community to address three questions:

1. Why support learners and learning?
2. How might the interface support learners and learning?
3. What are the issues involved in providing such support?

They then call on Piaget (1954), Vygostky (1962) and Papert (1993) to suggest that students learn through an active, social process of meaning construction; understanding is built up through the acts of conversing with others, constructing artefacts, and reflecting on those conversations and artefacts. Drawing on (Rogoff, 1990) they see *scaffolding* as the main role of teachers in constructivist learning, and propose that this should be the role of the interface in technology-rich environments. They propose a specific model for embedding such scaffolding in technology, and some principles that emerge from it.

This model is elaborated in (Guzdail et al, 1995; Quintana et al, 2005) among many others. Quintana et al propose a framework for designing scaffolding structures. Position this framework in the context of inquiry-based learning. Consequently, organize the framework around three processes: 'sense making', which involves the basic operations of testing hypotheses and interpreting data; 'process management', which involves the strategic decisions involved in controlling the inquiry process; and articulation and 'reflection', which is the process of constructing, evaluating, and articulating what has been learned. From these principles, they derive a framework which includes several elements:

- The task model, the constituents of activity derived from the inquiry based learning literature.
- Obstacles encountered by learners.
- Scaffolding guidelines provide principles for designing scaffolds to help learners overcome the obstacles.
- Scaffolding strategies, more specific implementation approaches
- Examples

In spirit, this approach converges on the idea of design patterns. However, the scaffolding strategies are too laconic to be useful as an immediate design tool, for example: 'Restrict a complex task by setting useful boundaries for learners'. The details of how to do so are provided implicitly, through a set of examples and their lengthily discussion.

Another restriction of this approach is that it strives for non-intrusiveness. The focus on continuous workplace learning means that learners' primary attention is given to concrete job tasks – not to the learning experience. While valuable in that context, one has to be careful when extending this approach to situations where learning, exploration or pleasure is the declared aim. In a workplace environment, there is no teacher present and the whole learning experience needs to be embedded in the software. Any learning method that assumes human interaction needs to be excluded. Exploratory activities are also out of the question, since the work is expected to be focused on concrete tasks.

Following on from Druin (1999), we believe it is time to revisit the gap between the traditions of constructionism and participatory design, and ask how they can inform each other. What can constructionist learning design gain from awareness of participatory design practices? How can participatory design accommodate more exploratory and open-ended activities? What modes of participation will balance the quest for partnership with classroom constraints? Most of the research focuses on students – how can we integrate teachers as design partners? Finally, how can the intersection and juxtaposition of these two paradigms inform our theory of the role of games in learning? Here too we see potential value in the use of design patterns, as a means of communication between teachers, researchers and software developers.

3.2. Game design

Computer games are a multi-billion euro industry. Given this, it may appear somewhat surprising that professional game designers have raised explicit concerns that a developed design discipline for digital games is lacking, and specifically that a language to discuss gameplay is needed (Spector, 1999; Costikyan, 2005). Several potential solutions to this problem have been proposed by the industry itself. Writing to a designer audience, (Church, 1999) introduced formal abstract design tools (FADTs) as a way to reach a shared design vocabulary. These FADTs are, despite an emphasis on formalism and abstraction from specific examples, one-sentence descriptions; the first FADTs given is in its whole “INTENTION: Making an implementable plan of one's own creation in response to the current situation in the game world and one's understanding of the game play options.” Barwood and Falstein (Falstein, 2002) suggested a more formalized method with the 400 Rules Project, which collects proven game design rules and techniques, stating these as instructions. An example of a rule from the 400 rules project:

> **The Rule:** Provide Parallel Challenges with Mutual Assistance
>
> When presenting the player with a challenge – a monster to kill, a puzzle to solve, a city to capture – provide several such challenges and set it up so accomplishing one challenge makes it a little easier to accomplish the others (that’s the mutual assistance component). It is also effective to set up these parallel challenges on many levels of scale of the game, from the ultimate goal down to the small short-term steps. This eliminates bottlenecks and makes the game accessible to a wider range of players.
>
> **The Rule’s Domain**
>
> This is a basic rule of game design, and applies to all games directly.
>
> **Rules that it trumps**

There are as yet no rules in our database that this one trumps.

Rules it is trumped by

This is trumped by "Provide Clear Short-Term Goals", our rule from last month's column, in that it is important not to let parallel challenges confuse the player about what must be accomplished. But the two rules can easily co-exist in harmony if the parallel challenges are clear steps necessary for a larger goal. In Small Soldiers: Squad Commander from Dreamworks Interactive, we broke the single goal of freeing an ally into two sub-goals of "free his feet" and "free his hands", each of which became an entire mission that could be accomplished in either order.

Examples from games

This rule is used effectively in many classic, successful games. Sid Meier's Civilization series of games is practically a case study of extensive use of this rule, nested recursively on many levels. On the highest level, the objective is to win the game – but this can be done in the original game by conquering all the other civilizations in the world, or by being the first to send a Starship to Alpha Centauri. If a player focuses on conquest, it still can help to pay attention to building technology that leads to the Starship victory, as this technology provides advantages in conquest as well. And if the player focuses on the Starship victory, limited conquest of neighbouring civilizations can provide the resources needed to achieve it. The most recent Civilization adds various parallel diplomatic and cultural avenues to win the game. But deeper down in the game, the rule is applied even more directly. At any point there are challenges of improving individual cities, building the military, accumulating wealth, engaging in diplomacy, and researching new technology. Moreover, success in any of these can make it easier to achieve the others.

Diablo II is another fine example. Unlike many other less successful games, you are never left with a single bottleneck challenge that must be surpassed by the frustration of repeated vain attempts. Completing one of several available quests makes your character incrementally stronger by gaining a new level, or

> wins better armor or magic, making the other quests slightly easier. Even the apparent bottlenecks of tough boss monsters at the end of each act of the game are really parallel challenges with mutual assistance. You are required to fight the boss to progress forward – but you can always go back and repeat earlier quests, allowing you to face the boss with a higher level, better prepared character. This was effective in making Diablo II into a multi-million unit seller because this structure has made the game accessible to a wide range of skill levels. A very experienced player can zoom through and fight Andariel, the first act-end boss, with a character that has only achieved level 15 and accordingly must be handled masterfully, providing a tough and exciting challenge. A novice player can stay in their "comfort zone", taking their time to reach Andariel, raising their character to level 20 or higher and gaining new weapons and armor. For them, Andariel will still be an exciting challenge that they'll vanquish only after a satisfying fight, despite their more modest game playing skills.

As can be seen from Falstein's section titles, ("Imperative Statement," "Domain of Application," "Dominated Rules," "Dominating Rules," and "Examples"), the rules are intended for practical game design and are less suitable for analytic studies. Both FADTs and the 400 rules project have been promoted within the game industry but have suffered from not being finished into complete collections.

Several books dealing with game design have been written by professional game designers (Crawford 2003, Rollings and Adams 2003, Koster 2004). Although used both within the industry and educations these books are based upon personal experiences and anecdotes without a framing in design or pedagogical theories. One of the few examples of game design textbooks written by educators is *Game Design Workshop* (Fullerton et al, 2004) which advocated methods typically found within interaction design (see (Preece et al, 2002) and (Shneiderman and Plaisant, 2004) for comparative examples), e.g. iterative design cycles, end-user testing, and low fidelity prototyping.

3.3. Game design as learning

We believe that the first reference to *constructing* a computer game as an explicit approach to learning is (Papert and Salomon, 1970). Since this time, and especially in the last 15 years, a growing number of projects have explored the educational impact of engaging children in the design and production of computer games. Pelletier (2005; 2005b) approaches this issue from a media studies perspective, seeing gaming as a new literacy, and arguing that students understanding of the medium can be enhanced from taking an active role in game authoring. Good & Robertson (2005) note the value of making games in promoting students' traditional literacy skills, including narrative structure and creativity, while providing significant benefits in terms of motivation, team work and self esteem.

In the domain of mathematics education, Kafai (1998; 2006) makes a distinction between instructionist and constructionist use of games. The instructionist form is the predominant one – using games as given, unchangeable resources, as a starting point for a planned instruction sequence. The constructionist paradigm asserts that there are mathematical ideas which can be accessed in depth through the construction of games. Such an approach is the premises of projects such as Playground and WebLabs (Mor et al., 2004; Simpson, Hoyles & Noss, 2005; Mor et al, in press); these are projects in which the authors of this review have been involved, and which inform the current study. It also stands in the core of the philosophy behind the design of educational programming languages such as ToonTalk (Kahn, 1996; 1999) Boxer (diSessa & Abelson, 1986) and Squeak (Kay et al, 1997; Ingalls et al, 1997; Masuch & Rüger, 2005), as well as the construction kits idea (Resnick et al, 1996; Eisenberg et al, 2002).

Drawing on an impressive array of sources from design theory, artificial intelligence, architecture and education, Kafai (1995) argues for a convergence of theory of design and theory of learning. Starting from Simon's broad definition of design, she highlights the common themes: problem solving, interleaved construction of knowledge and artefacts, sensitivity to context and representation. She notes that while several design theories acknowledge the idea that every process of design is a process of learning – both on part of the learner and on part of its recipients – the focus has been on the product and not on the process. In a way, educational theory had suffered from a similar flaw – engaging with educational artefacts (methods, curricula, textbooks) as products for consumption by learners, and neglecting the potential of learning in the process of designing or creating such artefacts. In the Game design project, Kafai worked with a group of 16 fourth grade children, on a daily basis, for 6 months. The children's task was to design and construct a game that would help younger children learn about fractions. This prospect proved valuable in terms of motivation and engagement. However, as Kafai herself notes elsewhere "While students significantly increased their understanding of fractions, one of the problematic aspects in Kafai's study was the integration of fraction content and game ideas. With the exception of one game designer, all students developed games with extrinsic fraction integration." (Kafai et al, 1998, p 153).

In the Playground project (Goldstein and Pratt 2001; Hoyles et al, 2001; Adamson et al, 2002), young children manipulated and restructured the code of computer games written in ToonTalk. By changing the rules of the game, children developed an understanding of rule-based reasoning and formal languages, a fundamental component of mathematical thinking. A similar observation was made by Pelletier (personal communication) in the context of the making games project. Although her perspective is derived from media and literacy studies, she notes that students evolving understanding of the construction of rules led them to approach rule-based reasoning and analysis as an available resource when approaching novel problems.

One of the activities in the WebLabs project was based on the well-known Lunar Lander game (Simpson et al, in press). In this case, the game's main contribution was in providing a familiar and attractive context for the activity. Although students did program their versions of the game, this was not the main focus of research.

Other examples of constructionist activities with games exist. Nevertheless, it is evident that these are not widespread and appear mainly in research settings. Furthermore, most of these activities follow the "tinkering" tradition – bypassing the issue of game design. We believe that the failure of such activities to penetrate the educational mainstream can be attributed, in part, to the high demands they impose on teachers and the vagueness in terms of educational gains. On one hand, in order to support students in game design and construction the teacher needs to poses significant knowledge of programming, gaming and design; Knowledge that is not part of the teacher training canon. On the other hand, the benefits of such activities are stated in highly abstract terms – which are difficult to map to concrete curricular requirements.

We see the design pattern approach, through our development of learning patterns, as offering a potential answer to these issues. Having a description of game design and construction activities in an pedagogical pattern language summarizes the prerequisite knowledge and expected gains in a compact format, such that a busy teacher can consult and evaluate for her needs.

3.4. Design based research

In recent years, design-based approaches have become popular as methods of educational research (Brown, 1992; Collins, 1992; Reeves, 2000; Edelson, 2002; Collins and Bielaczyc, 2004; Barab and Squire, 2004; Cobb et al, 2003; Gorard et al, 2004). Often referred to as design experiments, iterative design or design research. In these methods, the researcher conducts a series of teaching experiments. These experiments are run at a small scale, to allow elaborate interpretation. This interpretation then feeds into the next round of design. Thus, at the next iteration, the design is refined and at the same time the interpretation is validated. The immediate products of the design process – tools, practices and methods – are often seen as transient and discarded between iterations. The settings in a design experiment are idiosyncratic: the subjects are often a small selected group, the researcher is highly involved in the experiment in all its stages, and her knowledge advances as it proceeds. Thus, it is reasonable to expect the results to not necessarily be representative. Quantitative methods have little validity under such conditions. Most of the analysis is done by qualitative means.

Cobb et al (2003) identify five characteristics of design experiments:

- The purpose of design experimentation is to develop a class of theories about both the process of learning and the means that are designed to support that learning.
- It is a highly interventionist method of study. The researcher is a participant observer with flexible control of many of the research parameters.
- Design experiments always have two faces: prospective and reflective. On the prospective side, designs are implemented with a hypothesized learning process and the means of supporting it in mind in order to expose the details of that

process to scrutiny. On the reflective side, design experiments are conjecture-driven tests, often at several levels of analysis.

- Together, the prospective and reflective aspects of design experiments result in iterative design. As conjectures are generated and perhaps refuted, new conjectures are developed and subjected to test.
- Theories developed during the process of experiment are humble not merely in the sense that they are concerned with domain-specific learning processes, but also because they are accountable to the activity of design.

Ann Brown (1992) puts forth the two main arguments in favour of design-based educational research. The first argument is methodological. The complexity of classroom situations does not lend itself to the procedures of laboratory research. Strict control of experiments and isolated variables are unattainable. Under these circumstances, Brown (1992) suggests we adopt the procedures of design sciences such as aeronautics and artificial intelligence.

The second argument is ideological, perhaps even ethical. It questions the fundamental goals of educational research. To what extent are we driven by a pure quest for knowledge, and to what extent are we committed to influencing educational practice? If we see contribution to good practice as a primary goal, then the outputs of our research should have direct bearing on it.

Critics of this approach would argue mainly with the first, questioning the scientific value and lack of “evidence” of inherently irreproducible experiments. The response to this critique is twofold: first, we must modestly accept the limitations of our approach. But then, it is debateable whether seemingly scientific methods can offer any greater validity. At the same time, we need to be as stringent and self-critical when analysing our data – precisely because we do not enjoy the protection of standardized statistical tests.

A more subtle criticism of the design-based approach scrutinizes it on its own turf: does this approach live up to its commitment to offer a contribution to educational practice? On one hand, the conditions of most design experiments do not resemble those of a normal classroom, if only due to the presence of a dedicated, highly informed researcher in the class. As argued by Alan Collins:

> Typically the experiments are carried out by the people who designed some technological innovation, so that they have a vested interest in seeing that it works. They typically look only for significant effects (which can be very small effects) and test only one design, rather than trying to compare the size of effects for different designs or innovations. Further more such experiments are so variable in their design and implementation that it is difficult to draw conclusions about the design process by comparing different experiments. Finally they are carried out without any underlying theory and so these results are for the most part uninterpretable with respect to constructing a design theory of technological innovation. (Collins, 1992, p. 24 in Issroff and Scanlon, 2002)

On the other hand, the reported data and analysis typical includes case-studies and theoretical generalizations derived from them. The former are too specific to inform practicing teachers, whereas the later are too abstract. Furthermore, there is a fundamental difference in the nature of knowledge produced by design experiments. Whereas traditional methods of social science strive to establish beyond doubt the *existence* of phenomena, design research aims to *explain* phenomena, while maintaining a cautious stance on the determinism of their appearance. In the words of Ann Brown "*a 'Hawthorne effect' is what I want: improved cognitive productivity under the control of the learners, eventually with minimal expense, and with a theoretical rationale for why things work*" (Brown, 1992, p 167).

Perhaps the most substantial remarks on design studies in education come from two of its foremost proponents and promoters. DiSessa & Cobb (2004) warn against the drift of design research away from theory. They argue that theory is critical, both from a research perspective and from a practice one. Furthermore, they claim that design studies can – and should - make significant theoretical contributions by addressing the gap between theory and practice. First, they describe four categories of theory: *Grand Theory*, *Orienting Frameworks*, *Frameworks for action* and *Domain specific instructional theories*. All of these are important for educational design, but cannot be applied readily to concrete situations. In the words of the authors, it is fine to say one should build on students' contributions, but totally unclear how to do this. They answer by suggesting that design research may offer *Ontological innovations* – new linguistic constructs for describing and discussing educational phenomena.

We claim that the design patterns approach, through our development of learning patterns, offers the potential to fill the gap highlighted by diSessa & Cobb (2004). Such patterns encapsulate the researchers' knowledge is a form that is transferable and applicable to classroom situations, and is accessible to practitioners as a pragmatic resource.

The design element in a design study may refer to the pedagogy, the activity or the tools used. In some cases, the researchers will focus on iterative refinement of the educational design while keeping the tools fixed, in others they may highlight the tools, applying a free-flowing approach to the activities, in yet others they will aspire to achieve a coherent and comprehensive design of the activity system as a whole.

Finally, the constructionist paradigm (Papert, 1981; Papert & Harel, 1991; Kafai & Resnick, 1996) lends itself readily to the design research framework. It promotes investigation by design of microworlds – compact and coherent systems of computer-supported educational tools and activities – and observing students' actions, products and articulations within these systems.

4. Design patterns

Our interest in games for mathematical learning is both practical and theoretical. We strive to enhance the fundamental understanding of this topic, and at the same time contribute realistic recipes for classroom practices. With these goals in mind, we see our research as predominantly concerned with design questions. We find the *design patterns* approach valuable, both in the theoretical and in the practical aspects of our work.

Theorists within design such as Jones (Jones, 1992) have differentiated between traditional and modern design, pointing to several fundamental differences that require designers to rethink their methods. Specially, Jones states modern design demands more consideration due to the increased complexity in technology available as well as better understanding of the diversity and interrelationships within the society in which a product will be used. The increased demands will typically enlarge the circle of people involved in the actual design process; either other designers or people with vested interests in the design results (e.g. financers, distributors, producers, retailers, end-users, service providers, government officials, interest organizations).

Although traditional methods of externalizing the design process, such as sketching, can allow designers to divide work time on a design to several different periods, these do not support explicit externalization of the process of designing but rather provide snapshots of specific potential designs. This may not be a problem within a well-developed design community if they have a well-developed *design language* where the implicit assumptions are embedded in the work process. Rheinfrank and Evenson (Rheinfrank and Evenson in Winograd, 1996) describe design languages as consisting of collections of elements, principles of organization, and qualifying situations and state that three distinct purposes of a design language: embed meaning into artefacts, allow artefacts to express meaning to people, and allow artefacts to be assimilated into peoples' lives. However, modern design may require involvement with people not fluent in a particular design language, e.g. designers from various specialities or stakeholders with no design background. Although these may understand the particular design language, as any user of a product must have, they may not be able to *express* themselves in the language.

The *Design patterns* paradigm (Alexander et al, 1977) was developed as a form of design language within architecture. This was done with the explicit aim of externalizing knowledge to allow accumulation and generalization of solutions and to allow all members of a community or design group to participate in discussion relating to the design. These patterns were organized into coherent systems called *pattern languages* where patterns are related to each other. Although the use of design patterns never achieved a large following among professional architects, the idea has been embraced in several other disciplines, starting with software engineering through the seminal "gang of four" book (Gamma et al, 1994). More recent examples of areas where design patterns collection have been created include hypermedia (c.f. German & Cowan 2000), interaction design (c.f. Erickson, 2000 and Borcher, 2001), mergers of cinema studies and computer science (Walldius 2001), and pedagogical settings (see next section).

The original definition of a design pattern positions it as a high-level specification of a method of solving a problem by design which specifies the context of discussion, the particulars of the problem, and how these can be addressed by the designated design instruments. In *Pattern Languages* Alexander writes:

> Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice. (Alexander, 1977)

And in *the Timeless Way of Buildings* he elaborates:

> Each pattern is a three-part rule, which expresses a relation between a certain context, a problem, and a solution.
>
> As an element in the world, each pattern is a relationship between a certain context, a certain system of forces which occurs repeatedly in that context, and a certain spatial configuration which allows these forces to resolve themselves.
>
> As an element of language, a pattern is an instruction, which shows how this spatial configuration can be used, over and over again, to resolve the given system of forces, wherever the context makes it relevant.
>
> The pattern is, in short, at the same time a thing, which happens in the world, and the rule which tells us how to create that thing, and when we must create it. It is both a process and a thing; both a description of a thing which is alive, and a description of the process which will generate that thing. (Alexander, 1979, p 247)

In other words, a pattern has three facets: descriptive, normative, and collaborative. It is an analytic form, used to describe design situations and solutions, a meta-design tool, used to highlight key issues and dictate a method of resolving them, and a communicative tool enabling different communities to discuss design issues and solutions. The tension between these three aspects is visible in Alexander's work, and in much of the literature that followed. We will touch on this issue shortly.

The original collection by Alexander et al (1977; 1979) can arguably be positioned on *normative* end of the scale, in the sense that a socio-political agenda can be interpreted from the collection. Pattern 8 in the book compels the town planner to:

> Do everything possible to enrich the cultures and subcultures of the city, by breaking the city, as far as possible, into a vast mosaic of small and different subcultures, each with its

> own spatial territory, and each with the power to create its own distinct life style. Make sure that the subcultures are small enough, so that each person has access to the full variety of life styles in the subcultures near his own. (Alexander, 1977)

While we may perhaps agree with this claim on a personal level, it is hard to take it as an objective observation. As Erickson puts it: “Alexander's Pattern Language is not value neutral” (Ericksson, 2000). On the other hand, Alexander’s Mexicalli project is taken as an emblem of participatory design, where patterns are used to facilitate design and empower users – who make their own choices (Dearden et al, 2002). In this case, patterns are predominantly a social tool allowing the expert to communicate knowledge to the families designing their own home. One could claim that there is a socio-political agenda here as well. The difference is that in this case it is made explicit, and given as the premises – not the conclusion.

Such pattern languages seem to be quite alien to the *descriptive* pattern languages, prevalent in software design. This contrast may stem from Alexander’s strong political convictions – which may not be shared by many software designers. On the other hand, they may be inherent to the nature of the different fields. While in urban planning and architecture it is clear that almost any decision has a political and ideological context, it is hard to see such context in the design of, for example, network routing protocols. However, this distinction needs to be made with great caution. Design is rarely as value-neutral as we perceive it. The designers’ personal, subliminal values are always in the background. Even the example we used has its political dimensions: are the protocols open or closed? Do they allow for encryption? Do they have ‘government backdoors’? Such decisions which are often made off-hand have extreme consequences in terms of civil liberties. The value dimension of patterns becomes more salient as we move from the core of a technological system (e.g. network protocols, data storage algorithms and database structures) towards the user. Interface and interaction design is laden with such implicit value decisions: does the interface empower the user, or harness her to organizational needs? Is it gender or culturally biased? Does it marginalize users with disabilities? Such questions are generally pushed aside. Perhaps the most notable exception was the Scandinavian participatory design movement in the 1970s, discussed above, which set forth out of a political design agenda of democratizing technology and empowering workers (Kensing & Blomberg, 1998 Asaro, 2000).

Obviously, the value dimension of technology cannot be avoided when we come to educational technology. After all, everything about education is inherently value-driven. Every bit of technology designed for education assumes – and therefore supports – a particular organizational structure and a specific prioritization of knowledge. Yet these assumptions are often left unmentioned. We can only conclude this discussion by saying that we hope our values are honestly displayed in the introduction of this paper.

We have explored two interrelated axes of design patterns: the functional axis (what are they used for) and the value axis. Finally, we mention the *subject* axis – or, what are the patterns *of*? Alexander's patterns are structural – they describe spatial configurations (Alexander, 1977). So are the 'Gang of Four' software design patterns, which describe ensembles of classes in object-oriented programming (Gamma et al, 1995). Other languages aim to design *Actions* (Ericksson) or *Activity Systems* (Guy, 2004). Digiano et al (2002), for example, interweave three levels on patterns in a language for collaboration design: whole activity patterns, which describe the dynamics of human interaction, data patterns, which describe the structure and relationships of the artefacts exchanged in the process, and support patterns, detailed patterns which enable higher-order patterns to flow smoothly. The next section discusses the use of pattern languages in educational contexts. Regrettably, it seems that most of the work in this area focuses on structure of digital artefacts, and neglects the dynamics of human activity.

4.1. Design patterns for learning

The computer science community has embraced the idea of design patterns, which originated in Architecture theory. It is not surprising that this is also where it had made the greatest impact with respect to education. The design patterns approach has manifested itself through three main trends. The first is the growing trend of *Pedagogical Design Patterns* (Anthony, 1996; Bergin 2000; Eckstein, Bargin & Sharp, 2002). The second is the development of software design patterns for educational technology (Dearden, Finlay, Allgar & Mcmanus, 2002; Avgeriou, Vogiatzis, Tzanavari and Retalis, 2004). The third is the search for patterns in related practices, such as evaluation and assessment (Barre, Chaquet & El-Kechaï, 2005). Nevertheless, it is important to note that the first reference to learning is made by Alexander himself, in his seminal book (Alexander et al, 1978), describes a pattern called “Network of Learning”. The premise of this pattern is that in a society that emphasises teaching, learners become passive and unable to think or act for themselves. He argues that creative, active individuals can only grow up in a society that focuses on learning instead of teaching. The solution he proposes is to replace the structures of compulsory schooling in a fixed place, with decentralised processed of learning which engage learners through contact with many places and people all over the city: workshops, teachers at home, professionals will to take on the young as helpers, older children, museums, youth groups, scholarly seminars, industrial workshops, old people, and so on. This argument resonates with Ilich's call for “deschooling society” (1971) and conviviality (1973). We find such arguments motivating in our search for alternative means of mathematical learning.

Pedagogical design patterns apply the concept of design patterns to pedagogical design. The fundamental claim behind this effort is that many experienced practitioners in education have tried and tested methods of solving recurring problems or addressing common needs. Among the pioneers in this field where Anthony (1995) and later the pedagogical patterns project (http://www.pedagogicalpatterns.org/), initiated by a group of experienced software engineering and computer science educators (Bergin, 2000; Eckstein, Bergin & Sharp, 2002). They proposed a set of patterns dealing with issues ranging from the design of a college course to specific principles of computer science instruction and to concrete problems and their solutions. As an example, consider Anthony's “Mix new and old” pattern:

> **Problem**: *Basic concepts must be reviewed over and over, but this gets boring for many students. New concepts must be introduced, but few can handle more than 10-15% new material.*
>
> ***Constraints and Forces***: *In addition, each student varies in their "learning style"; whether they learn better from doing something, seeing diagrams or demonstrations, or hearing explanations.*
>
> ***Solution***: *Iterate over a concept several times. Each time, present the material in a different variation on the learning styles. Each time, mix in some new material*

> *with the old. This both maintains students' interest through the review and helps them absorb the new material.*
>
> ***Related Patterns****: "Simulation Games" provide an alternative to exercises for the learning style that learns by doing. "Visible Checklist" provides an extra stimulus for the group that learns by seeing. "Colorful Analogy" provides a boost for the learn by hearing group.*

This pattern addresses a recurring problem in computer science instruction. Such a problem might baffle a novice teacher. Having this pattern at hand, the novice can anticipate the problem, and design a solution, before encountering it in class.

A second arena that has seen a proliferation of design patterns over the last years is web-based educational technologies. Notable examples in this field include the E-LEN project (http://www2.tisip.no/E-LEN/) and several initiatives within the IMS-LD framework (http://www.imsglobal.org). Most of the work in this area is focused on the engineering aspects of designing, developing, deploying and evaluating good technology for web-based instruction (Frizell & Hubscher, 2002; Hernández-Leo et al, 2006; Bailey et al, 2006)

This strain of work is done mainly in the context of developing large scale technological systems to support organizational and vocational learning or web-delivered higher and further education. Due to this context, much of the work is highly technical. Many of the valuable innovations have a strong engineering flavour to them (e.g. Bailey et al, 2006) which might deter teachers and educational researchers. Even the issue of uncovering design patterns can get embellished as structural analysis of XML documents (Brouns et al, 2005). The interaction between student and instructor is assumed to be mediated by this communication channel. Under such circumstances, most of the effort goes into designing the representation and organization of educational content and the mechanisms by which learners interact with it (Frizell & Hubscher, 2002). Design patterns are also situated in this context, with the engineer of educational technologies as the user in mind (Avgeriou et al, 2003; Garzotto et al, 2004; Kolås & Staupe, 2004).

Pedagogical issued are assumed, rather than discussed, for example:

> "Based on a study of current pedagogical models, Merrill (2003) summarized them as

> follows: "… the most effective learning products or environments are those that are problem-centred and involve the student in four distinct phases of learning: (1) activation of prior experience, (2) demonstration of skill, (3) application of skill and (4) integration of these skills into real-world activities". Instead of transferring facts to learners, the major focus should be on the attainment of complex skills and competencies in authentic task situations" (Koper & Olivier, 2004, pp 98)

While we may agree with this statement, under certain circumstances, we see it as an issue for debate and discussion – not as a trivial fact.

A noteworthy exception is (Goodyear, 2004). In an attempt to distance himself from the dominant approaches in e-learning, Goodyear focuses on what he calls networked learning, where technology is used to promote connections between learners and foster communities which make efficient use of their resources. In this context, Goodyear emphasises patterns as a means of empowering practitioners to utilize accumulated design knowledge. His patterns are succinct and written in plain language.

Another study oriented towards educators is (Dearden, Finlay, Allgar & Mcmanus, 2002; 2002b). Dearden at al. point to the strong ideological and methodological parallels between Alexander's original vision of pattern language and the paradigm of participatory design. Pattern languages were conceived as a means of making expert knowledge accessible to naive planners, and enable educated and informed designers to work with naive users in collaboration. By contrast, in practice many pattern languages have taken a highly specialized form, and have become part of a professional jargon. As an alternative, Dearden et al propose the 'facilitation' model developed by Alexander et al (1985) in the Mexicali project. In that project, an 'Architect-builder' worked with a family to enable them to design and build their own house. Very significantly, the pattern language *was shared by the designer and the family, and used to present and discuss design problems and solutions*. The family could refer to the pattern even when choosing an alternative design.

One of the studies Dearden at al. report uses Bergin's language pedagogical patterns to support the participatory design of an elearning web-site. The design was produced by a group of students and practicing teachers and facilitated by an experiences designer. They report that using this approach empowered the practitioners and enabled them to produce quality designs. This approach also enabled the facilitator to structure the design process and communicate complex issues. On the cautionary side, practitioners reported initial difficulties and even stress associated with learning such a new approach. They also tended not to question the patterns, relying on them as given truths. These issues place extra responsibility in the role of the facilitator.

We see such an approach as very promising in the context of designing pedagogical practices for the mathematical classroom. In such a model, researchers and designers contribute their specialist knowledge, while teachers bring their practical experience and awareness of real-world constraints. Using a suitable pattern language can enable such a diverse community to pool knowledge and collaboratively design innovative, effective and realistic educational practices.

Finally, design patterns have recently been used in the context of assessment, evaluation and analysis of learning and learning systems (Gibert-Darras et al, 2005). The aim of this work is to offer a pattern language for assessing students' problem solving abilities, in the context of a basic Java course. The standard Alexandrian argument holds here as well: assessing student performance is a hard job, where a lot of research has been done and a lot of practitioners have accumulated insights through experience. Patterns allow us to offer this knowledge in a useful form to novice teachers.

To conclude, with the exception of Dearden et al (2002a, 2002b), Goodyear (2004) and Bergin et al (2000, 2002) most studies which utelize design patterns in education are concerned with the hard issues of creating good educational technology and authoring content within technological systems. Such work is extremely important, and informs our work in many ways. Nevertheless, we see a need for research which would address the needs of educators in schools. Furthermore, we see a challenge in communicating the ideas and tools developed in the technology-oriented research to the pedagogy and epistemology research communities. The challenge goes in the reverse direction as well: much of the technology-oriented research reflects a shallow and narrow pedagogical discussion. Design patterns have the potential to bridge betweens these disparate research and practice communities, and allow each one to enjoy the fruits of the other's efforts. In order to materialize this potential, pattern languages need to avoid jargon, and at the same time make space for higher theoretical discussion.

Alexander's architectural design patterns are informed by theories of construction, engineering, and human psychology. In much the same way, Pedagogical patterns should be based on a theoretical layer concerning pedagogy and epistemology. Whereas for example a software design pattern may need to include justification in terms of computational efficiency and robustness, a pedagogical design pattern should include its epistemological, psychological or social dynamic rational. Unfortunately, this is rarely the case. Since most pedagogical patterns are developed by skilled practitioners (or software engineers), who have their formal grounding in computer science rather than educational sciences, they are informed by solid intuitions but lack in educational theory.

4.2. Games design patterns

The idea of applying the design patterns approach to produce game design patterns was first described by a practitioner within the game industry (Kreimeier, 2002). Although some patterns were presented in this work, a complete collection was first produced (Björk and Holopainen, 2004) by researchers. This collection was created with a different framing (Björk et al., 2003) that shifted the focus of a pattern from being *problem-solving* to being *feature-descriptive*. The change can be described through four observations, two explicitly based upon the use of design pattern in the context of games and two on general observation of design patterns. The first observation is that the typical context of creating games does not start with a real-world problem. This means that game designers do not need to restrict themselves to functional requirements to the same degree as other design fields, but more typically start from wanting to add a feature that is perceived as being advantageous for the design. The second observation was that the effect of introducing, removing or modifying a game feature easily affects many different aspects of the gameplay to the point that it would be difficult to state one specific problem that was addressed by one design solution. The third observation was the design patterns had the potential for support analyzing existing designs, but this potential was difficult to realize as a noticed design feature not necessarily could easily be matched to a pattern described as a problem-solution pair. The fourth observation was that many professional game designers identified patterns with mechanically producing a solution, especially if they were presented as ways of solving specific problems. Based upon these observations game design patterns were defined as “semi-formal inter-dependent descriptions of commonly reoccurring parts of the design of a game that concern gameplay” (Björk and Holopainen, 2004).

These observations led to the development of a new pattern template which consists of three parts. The first part gives the name of the pattern, a one-line definition of it and a general description which examples. This general description does not make use of other patterns in order to allow readers to enter the collection at any point without knowledge of other patterns. Part two and three in the description are intended to support design and analysis respectively. The second part, using the pattern, describes alternatives and requirements that have to be considered when designing a game so that the pattern is present. The third part, consequences, describes what effects the presence of a pattern can have on other patterns, gameplay, and the game experience in general. The pattern description ends with a collection of the other patterns referred to in the two last parts.

The shift to feature-descriptive patterns changed the types of relationships a pattern could have. Rather than the parent and child relation introduced by Alexander and used subsequently five relation type were given: instantiates, instantiated-by, modulates, modulated-by, and potentially conflicting. The instantiates | instantiated-by relation indicate when the presence of a pattern is likely to automatically make another pattern present (e.g. the use of the Dice pattern makes the Randomness pattern likely to be present as well). The modulates | modulated-by pattern describes patterns that can change the design that another pattern describes but is optional and does not guarantee the second patterns presence (e.g. the Container pattern changes the design of what a Producer-Consumer pattern describes but the presence of the latter is not dependent on the former).

A typical example of a game design pattern, Producer-Consumer, is described below. It is part of a large collection (~300 patterns) and references to other patterns are noted through italics.

Producer-Consumer

Producer-Consumer determines the lifetime of game elements, usually

Resources, and thus governs the flow of gameplay.

Games usually have several overlapping and interconnected Producer-Consumers governing the flow of available game elements, especially resources. As Resources are used to determine the possible player actions, these Producer-Consumer networks also determine the actual flow of the gameplay. Producer-Consumers can operate recursively, that is, one Producer-Consumer might determine the lifetime of another. Producer-Consumers are often chained together to form more complex networks of Resource flows.

Example: In the computer game Civilization (reference), the units are produced in cities and consumed in battles against enemy units and cities. This kind of Producer-Consumer is also used in almost all real-time strategy games.

Example: In Asteroids, the rocks are produced at the start of each level and are consumed by the player shooting at them. The same principle applies to many other games where the level of progression is based on eliminating, that is, consuming, other game elements: the pills in Pac-Man, free space in Qix, and the aliens in Space Invaders.

Using the Pattern

As the name implies, *Producer-Consumer* is a compound pattern of *Producer* and *Consumer*; as such, this pattern governs how both are instantiated. Because the produced game element can be consumed in many different ways, the effect of producing and consuming *Resources* or *Units* often turns out to be several different pairs of *Producer-Consumers*. For example, the Units in a real-time strategy game such as the Age of Empires series can be eliminated in direct combat with enemy Units, when bombarded by indirect fire, and finally when their supply points are exhausted. The *Producer-Consumer* in this case consists of the *Producer* of the *Units* with three different *Consumers*.

Producer-Consumers are often, especially in *Resource Management* games, chained together with *Converters* and sometimes with *Containers*. These chains can in turn be used to create more complex networks. The *Converter* is used as the *Consumer* in the first *Producer-Consumer* and as the *Producer* in the second. In other words, the *Converter* takes the Resources iproduced by the first *Producer* and converts them to the *Resources* produced by the second *Producer*.

This kind of *Producer-Consumer* chain sometimes has a *Container* attached to the *Converter* to stockpile produced *Resources*. For example, in the real-time strategy game StarCraft, something is produced and taken to the converter and then converted to something else and stockpiled. Investments can be seen as *Converters* that are used to convert *Resources* into other forms of *Resources*, possibly abstract ones.

Consequences

As is the case with its main subpatterns *Producer* and *Consumer*, the *Producer-Consumer* pattern is quite abstract, although effects on the flow of the game are very concrete. Simply put, *Producer-Consumers* govern the whole flow of the games that have them, from games with a single *Producer-Consumer* to those with complex and many layered networks of *Producer-Consumers*.

The feeling of player control is increased when players are able to manipulate the *Producer*, the *Consumer*, or both; adding new *Producer-Consumers* over which the players have control gives them opportunities for more *Varied Gameplay*.. In more complex *Producer-Consumer* chains, however, where the effects of individual actions can become almost impossible to discern and the process no longer has *Predictable Consequences*, players can lose the *Illusion of Influence*. *Producer-Consumer* networks with *Converters* and *Containers* are used in *Resource Management* games to accomplish the *Right Level of Complexity*; the games usually start with simple *Producer-Consumers* and add new *Producer-Consumers* to the network to increase the complexity as they progress.

Relations

Instantiates: *Varied Gameplay*, *Resource Management*.

Modulates: *Resources*, *Right Level of Complexity*, *Investments*, *Units*.

Instantiated by: *Producers*, *Consumers*, *Converters*.

Modulated by: *Container*.

Potentially Conflicting: *Illusions of Influence*, *Predictable Consequences*.

5. Discussion

So far we have presented the literature contextualising the *learning patterns for the design and development of mathematical games* project. As the design strand, we have naturally placed a heavy emphasis on design and its relationship to the contextual development of mathematical games.

We now go on to discuss three important issues arising from our review:

- Pedagogical facets of software design patterns
- Extension and adaptation of game design patterns
- Didactical functionalities and design patterns

These delineate potential avenues of investigation on the road to our development of learning patterns, one of the key outcomes of the project.

5.1. Pedagogical facets of software design patterns

Some design patterns which have originally been conceived in response to pragmatic engineering issues may have potential pedagogical value, if put in the right context. In (Mor et al, in press) we discuss the potential epistemic benefits of using a software design pattern called *Streams* in learning about number sequences. This claim is stated in the context of constructionist programming activities, in which children generate and manipulate number sequences as dynamic programmes. Using the "streams" design pattern allowed students to mould their intuitions into a situated formalism with which they could explore quite complex ideas, and argue convincingly and with commitment for their hypotheses. The *guess my robot* game which followed these activities (Mor et al, 2004) build on this knowledge, and used number streams as game-pieces in a competitive game. The games of *guess my graph* (Simpson, Hoyles & Noss, in press) and *guess my garden* elaborated the same game design pattern, and at the same time made different uses of the Stream software design pattern.

Another example is the *model-view-controller* pattern (Krasner & Pope, 1988; Gamma et al, 1995). This pattern dissects the representation and manipulation of information from its structure and content. Perhaps one of the most powerful patterns in interface design, it also resonates the pedagogical discussion of representations (Balacheff and Kaput, 1996; Radford, 2000). Indeed, this pattern is utilized in the design of ToonTalk (Kahn, 1996). However, it needs to be explicitly communicated to educators involved in constructionist activity design for them to leverage the extensive body of computer science knowledge it embodies. Such an effort should contextualize this pattern in both worlds: that of software engineering and that of educational design.

If we wish to capitalize on the pedagogic and epistemic potential of such patterns, we need to augment – perhaps totally rephrase – the pattern structure. Instead of addressing an engineering problem and context, we now need to specify an educational one. The programming solution will also be modified, emphasising issues such as simplicity over computational efficiency.

5.2. Extension and adaptation of game design patterns

The idea of appropriating software design patterns to pedagogical contexts is applicable to game design patterns as well, if not more so. For example, the *Producer-Consumer* pattern described above (see Section 4.2) illuminates the design of *guess my X* type games mentioned in the previous sections. In these games, player B consumes mathematical objects, produced by player A. In this analysis, the derivative of the Producer-Consumer pattern takes on board pedagogical significance: as argued by Matos et al (2005), the fact that the mathematical objects of the game where produced by learners had a profound effect on participation and performance in the game.

As with software design patterns, the pedagogical implications of game design patterns need to be brought forward and the format of the patterns need to adapt to account for them. In the process of analysing patterns for their pedagogical value, the patterns themselves will inevitable evolve.

5.3. Didactical functionalities and design patterns

The construct of *didactical functionality* was born as a means for comparing researches, and it consisted of a first way to provide different researchers with a sharable language to talk about technology in mathematics education. Such language is based on three key concerns, three key "words", which for the case of games can be: *game*, *educational* *goal*, *modalities of employment* of the game to achieve the goal. In a similar way, assuming a design patterns perspective, we try to provide a sharable language to talk about, study, classify, and design games (with ways of using them) in mathematics education; such a language is based on the following key words: *problem*, *constrains and forces*, *solution*, and *related patterns*.

The concerns identified by the keywords of the two perspectives appear to be related but not identical, and at least partially complement each other. In particular, one may think of using design patterns as means to define new didactical functionalities or vice versa, one may think of using didactical functionalities as means to define new design patterns.

In the first case, given a design pattern, the signs found in its *solution* to the addressed *problem* can be used as starting points for the design of a didactical functionality for a tool to be employed *as means for solving the problem* addressed by the given design pattern. This could mean that the design pattern is used either to design the tool itself, and/or an educational goal, and/or the modalities of employing the tools (or even the three elements at the same time). Thus, a design pattern could provide principles to define any of the three elements of a didactical functionality. Notice that if the "problem" already contains both the tool to be used and the educational goal, then all that remains is to define the modalities of employment. For example, in the example of new tool development (Cerulli, 2004), the "problem" contained both the modalities of employment of the hypothetic tool and the educational goal. Significantly, the design principles used in designing the *new* tool were taken from studying student use of an *existing* tool. Therefore, potentially design patterns can be use to define a didactical functionality, when starting from a "problem" in a particular "context" (which define which of the three elements of the didactical functionalities are missing).

On the other hand, we may consider the inverse case, where we exploit didactical functionalities to define new design patterns. Firstly, suppose that we are given a tool (or a set of tools) for which we previously identified a didactical functionality with respect to a specific educational goal. Secondly, suppose that we have to define a design pattern starting from a *problem* that includes achieving the given educational goal; then we can refer to the given didactical functionalities of the given tool when defining the *solution* to the problem. Notice that in this case, it may happen that more than one didactical functionality of a tool is used, or that more then one tool is used, so in a sense a design pattern can exploit a set of didactical functionalities. It can also be the case that within a design pattern, the defined *solution* consists of achieving a set of goals, which can be addressed in terms of a set of didactical functionalities.

Within this perspective "didactical functionalities" and "design patterns" can be seen as complementary tools to be used as means for setting up fruitful teaching/learning processes when employ games, or technological tools more generally. We intend to investigate this complementarily as this project progresses.

5.4. The potential of learning patterns

In undertaking this literature review, a number of interesting gaps were identified. We believe that the development of learning patterns, and critically the approach we take in designing them, has the potential to address *some* of these gaps within the timeframe of the project. In what follows, we summarise this potential related to the identified gaps outlined in earlier Sections.

Primarily we believe that learning patterns can be written so as to be a mediating communication tool between learners, teachers, researchers and software developers. Using a suitable pattern language, this diverse community can pool knowledge and collaboratively design innovative and realistic educational practices. In particular, when thinking about mathematical games, a description of game design and construction activities in a learning pattern language summarizes the prerequisite knowledge and expected gains in a teacher friendly format.

With respect to design experiments, we believe that learning patterns might offer the potential to "managing the gap" (diSessa & Cobb, 2004) between theory and practice. For example, a learning pattern (or language thereof) could encapsulate a researchers' knowledge in a form that is transferable and applicable to classroom situations, and is accessible to practitioners as a pragmatic resource. However, such a development would require motivated input, along with empirical experiments, from all involved parties.

6. Conclusion

In this review we have detailed the literature on design approaches to learning environments, discussed design patterns and the relationship between game design and mathematics education. We noted that if these diverse fields are to inform the development of pedagogically sound and innovative mathematical games, communication and knowledge sharing between all the participants in the process is key.

We highlighted the problem of students' poor experiences of mathematics education across Europe and contrasted this with the explosion in the popularity of commercial computer and video games. We listed good design goals for games and highlighted their potential for engendering a player's engagement. We went onto to detail the development of educational computer games generally, and those aimed at mathematics education in particular. We stressed the need to move away from simply considering the tool (i.e. the game) itself when developing a learning environment and presented didactic functionalities as a method of moving toward the development of 'gaming situations'.

A significant part of the literature review was devoted to design approaches in education. In particular, we detailed: participatory design (including with children), game design, game design as learning (with a deep focus on mathematical games), and design-based research. However, we promoted the potential of *design patterns* in particular and we detailed *design patterns for learning* and *game design patterns*. These approaches were discussed as forming the basis of one of the major outcomes of this project: the development of *learning patterns* for mathematical games.

Part 2
Literature Review: Deployment Strand

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Executive summary

Deployment of mathematical games is largely concerned with what happens after a game is designed, and needs to take into account the attitudes and experience of the individual teacher, the classroom environment, and the motivation and prior learning of the students (that is, prior knowledge of the subject and prior knowledge of games). Games are located in a specific cultural milieu, which requires consideration in addition to the usual e-learning implementation. The literature has many example of the use of games in education, but these are mainly examples of commercial simulation games being reapplied to an educational context. Games for mathematics education are usually smaller games that have been specifically designed to teach mathematics. Both situations have found the value of games to be the increased motivation of students, and also promote the empowerment and autonomy of students over their learning, and support constructivist models of learning. Developments within the multiplayer online gaming may be able to be exploited in collaborative learning within education, but this is constrained by teachers' exposure to these forms of gaming.

1 Introduction

Initially, this document briefly reports on some theoretical frameworks concerning technology enhanced learning in mathematics which were analysed and elaborated on in another Kaleidoscope KJA, the TELMA European Research Team (www.itd.cnr.it/telma). This was seen as a potentially useful context to gain some understanding of the use of digital games for learning mathematics in educational settings. Taking into account the recent move within the mathematics education research community towards perceiving and studying learning as construction of knowledge within the social setting of classroom environments, the TELMA group emphasized two distinct theory strands, that of 'Didactical Situations' and that of 'Activity Theory'. Using these strands as a background, the group then went on to develop and refine a suggestion made earlier by researchers in the field that it would make sense to analyze and discuss the use of digital technologies within learning environments, i.e. their didactical functionalities (Cerrulli et al, in press).

The report then goes on to consider some key issues with respect to the process of learning with game technology emerging from general theories of learning with digital games and individualistic theories of learning mathematics with digital games. Finally, a brief outline of some quantitative data on the extent and the way games are being used in education systems.

2 Main theoretical frameworks

In mathematics education, there has been a move away from pure constructivist approaches towards socio-constructivist and socio-cultural approaches (Artigue, 2005, p. 18). The social dimension of the learning process points out the necessity that emerges for signifying the crucial role of the learning environment. In order to succinctly describe the social dimension of learning processes we consider two main approaches that are addressed by the TELMA research teams: theory of didactic situation (TDS) and activity theory (AT).

Up until now, the teams have identified three problematic issues of common interest between these approaches. These issues are: the notion of learning environment, relationships between teacher and learner in the learning process and the role of instruments in teaching and learning processes (op. cit. p. 10). We consider the main theoretical approaches mentioned above from the point of view of these three issues.

2.1 Notion of learning environment

Research in recent years has perceived learning as a social process and learning environment as something including the whole teaching and learning situation, considering the whole set of interactions established in a class over the course of time and how the activities evolve (op. cit. p. 10). From the point of view of collaboration within learning environment, the theory of didactic situations is more 'antagonistic' than the 'cooperative' activity theory.

TDS proposes that the teacher must create a situation for teaching a mathematical concept that would set up an antagonistic system for pupils. In this case knowledge emerges from the interaction and retroaction of the dialectic process between pupils and between pupils and the ICT tool. The role of the teacher is to construct the conditions under which the responsibility of the solution is entirely submitted to the student, as well as to institutionalise the acquired knowledge by the student.

From the activity theory point of view, "learning environment is constituted by the enactment of a teaching/learning activity oriented to an educational object, involving students, teachers and artefacts" (op. cit. p. 11). The teacher is a co-actor in the achievement of the educational aim of the activity and the crucial role of the instruments is to mediate the learning process. This cooperative environment dominates the division of labour, duties and obligations.

2.2 Relationships between teacher and learner in the learning processes

This issue regards the sharing of mathematical responsibilities between teachers and pupils, considering socio-constructivist approaches such as those proposed by Cobb and Yackel (Cobb and Yackel, 1996; Gravemeijer, 2000). In TDS, the relationships between teachers and students are called ‘didactical contract’, where the rules are interiorised through a process of accommodation and assimilation (p.13-14). In this learning process, knowledge emerges in a constructive way through contradictions and breakdowns (inaccurate estimation of students’ sufficiency).

The activity theory underlines the notion of the ‘division of labour’ in an extrinsic and an intrinsic way with regard to teachers and students. “In practice, the division of labour defines a system of reciprocal obligations that mediate the strategy by which community members, interpreting specific roles, interrelate for the social construction of the object of the activity” (p. 14).

In addition to these two approaches, socio-mathematical norms are related to the socioconstructive approach regarding the relationships between teachers and pupils. They are presented as distinct to another two approaches, the individualistic and the interactionist, where learning is respectively perceived as a solitary action of the learner and as an interaction between the learner and the teacher. The difference is that the students not only have to construct their knowledge through exploration and sharing or explaining their thoughts with the others, but also have to achieve a socially acceptable solution to the activity given. The role of the teacher is crucial in this process.

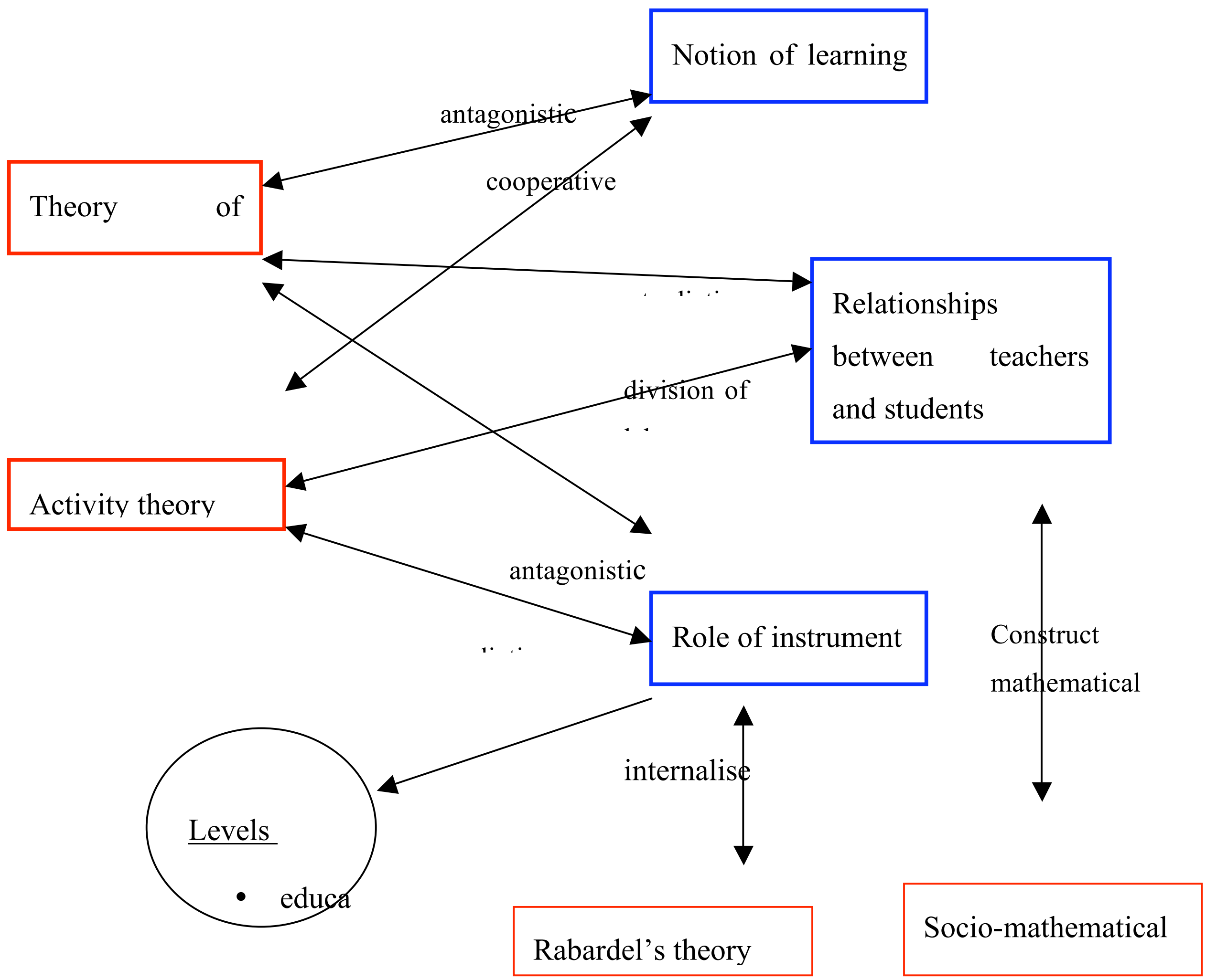
2.3 Role of instruments in teaching and learning processes

There are two concrete levels at which we could consider a specific ICT tool: the level of educational instruments and the practical level. Considering the TDS at the educational level, the instrument must be utilized by the teacher in a didactic situation where the tool facilitates the student to accomplish a specific educational goal. In the practical level, the instrument is considered as antagonistic to the student (learning through antagonistic interaction with the tool).

The activity theory considers the instrument as a medium of the learning process. If the teacher decides to employ the instrument at the educational level, there must be built an activity in which the tool mediates the process of achieving the educational goal by the student. In the practical level, the student must confront the tool as part of the learning environment, so as to facilitate the tool in a cooperative way.

The theoretical framework that Rabardel propose ascribes a crucial role to the instrument. In this theoretical framework, the tool through the process of instrumentation (at the practical level) offers the student the chance to internalise the schemes of use (Rabardel, 1995). As a result of that, the teacher can utilize this characteristic of the instrument (at the educational level) to accomplish the instruction of a mathematical technique.

The following figure represents the interconnections between the two main theories that we described above and the three issues that had been underlined by TELMA teams.



2.4 Didactical functionalities

The notion of didactical functionalities of an ICT tool proposed by TELMA teams for declaring the way an ICT tool is used for educational or for other purposes, as well as contrasting professional and educational ICT tools. Didactical functionalities are specified as:

> "Given an ICT tool, it is possible to identify its didactical functionalities: with didactical functionalities we mean these properties (or characteristics) of a given ICT, and their modalities of employment, which may favour or enhance teaching/learning processes according to a specific educational aim".

"The three key elements of the definition of the didactical functionality of an ICT tool are then:

1. a set of features / characteristics of the tool

2. an educational aim

3. modalities of employing the tool in a teaching/learning process referred to the chosen educational aim." (Artigue, 2005).

3 Learning

Much literature has focused on theories concerning learning processes, as well as defining the way students think and learn (Kafai, 1998). But it is complicated to define what exactly is learning, "what it means to learn and what forms of learning are valuable". (Kirriemuir and McFarlane, 2004, p.13). Although there are many models to view the learning process through learning theories of different areas, the research goal is not always to define what happens during the learning process. For example Prensky (Prensky, 2001) focuses on the object of learning and maintains that for choosing the way we define learning, we must define what there is to be learnt.

The object of learning is not always given priority, especially in areas such as mathematics. The question that emerges here is if we want students to learn and apply basic mathematical contents and operate a set of routines, or to develop basic skills such as problem – solving and mathematical thinking (Kafai, 1998; Gros, 2003). The first approach is closer to an instructional way of the learning process, while the second one approximates the contructionists' view. Despite these different approaches, the interest is not focused on the object of the learning process, but on the ability to develop learning. As Papert suggests: "The really basic skill today is the skill of learning" (Papert, 1998).

Individualistic theories of learning mathematics with digital technologies have centred on the notions of constructionism (Resnick et al, 1996) and situated abstractions (Noss and Hoyles, 1996). They have mainly considered learning as a process of constructing knowledge and enhancing the ability and strategies to learn, rather than as a process of receiving, digesting and reproducing rote knowledge delivered through prescribed curricula, which is the main underlying metaphor in many educational systems. Constructionism refers to the action of building things, whether these are tangible objects, computational models and representations or written descriptions or justifications of a learner produced theorem or conjecture. The notion is compatible to constructivism, yet different in that it emphasizes the process of learning through construction and bricolage. The notion of situated abstractions refers to student generated abstractions emerging directly from and bound to the learning situation at hand. These may well be mathematically partially correct or incorrect. What is important is that the student engages in a process of abstraction and perceives its power by being able to use it to resolve problems or construct more generalized digital tools and models. Both these notions are connected to the idea of microworlds, i.e. 'computational environments embedding a coherent set of mathematical 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 mathematical meaning' (Laborde et al, in press, see also Noss and Hoyles 1996, Edwards 1988, Gravemeijer, 2000, Sarama and Clements 2002).

Another aspect that emerges from the literature is that the content of the learning experience must be not abstracted from reality and the learner must have an active role on this (Calarneu, 2005). In an attempt to describe valuable and efficient learning, there has been introduced the term 'authentic learning': "By definition, the term 'authentic learning' means learning that uses real – world problems and projects and that allow students to explore and discuss these problems in ways that are relevant to them" (Carlson, 2002).

Many learning environments, especially computer – based have been created during the last decades to engage both teachers and learners in effective learning processes (Kafai, 1998). Regarding the area of technology enhanced learning in mathematics, the computer environment holds a crucial role in supporting learning. As a result of that, the question emerges of how we should apply the theoretical frameworks of learning in the design and deployment of learning environments. Additionally, there is an increased interest in the area of educational games and the ways we can use them to support learning in general and educational practice inside school. In the following sections, we attempt to specify how these areas could be combined to propose an introduction about how games can contribute to learning.

3.1 Learning with games

Computer games are an important part of most children's lives (Kirriemuir and McFarlane, 2004; McFarlane et al. 2004), so the best way to benefit from children's interest about games is to leverage their tendency to integrate them into education (Papert, 1998). The key areas of research in the field of supporting children's learning inside and out of school using games, have focused in pleasurable learning, learning through doing and learning through collaboration (Kirriemuir and McFarlane, 2004). All of these features seems to exist in learning environments where games are involved.

The question that emerges is 'why use games for learning?' Learning through the use of games could be efficient for many subject areas and in many ways. McFarlane et al. (2002) suggest that: "The nature of learning supported by games' use could be broadly divided in three types:

1. as a result of tasks simulated by the content of the games,
2. knowledge developed through the content of the game,
3. skills arising as a result of playing the game. This last one could be subdivided into direct and indirect learning." (McFarlane et al., 2004).

The distinction between the first and the second type of learning mentioned above is relative to the distinction between intrinsic and extrinsic integration of the content of the game (Kafai, 2001). Kafai (2001) suggested that there is a difference between "games to teach" and "games to learn" and the way that each educator uses games in classroom reflects the way he prescribe the learning process, in an instructionist (intrinsic content) or a constructionist (extrinsic) view.

Regarding the content of the game, this can be integrated into the game in an intrinsic or an extrinsic way (Kafai, 1998; Kafai, 2001; Malone and Lepper, 1987). In the case of intrinsic integration the game idea is integrated with the content of the game to be learnt. In other words, the educational and game components are inseparable (Klopfer, 2005). Most of these computer games contain school – like exercises and it is more like drill-and-practice educational games. As Galarneu maintains about these games "the content and teaching method are entirely unchanged from their non-game origins, so only the presentation style differs" (Galarneu, 2005).

In the case of extrinsic integration, there are two ways to consider the game content and the goal of using the game. The first way is to use a game for supporting student to develop knowledge and cognitive skills, regardless to the content of the game. In this case, the game idea and the content are separable. The second way to consider extrinsic integration differs at the goal and the way the game is used. From the constructionist's point of view, "the goal has been to provide students with greater opportunities to construct their own game and to construct new relationships with knowledge in the process" (Kafai, 2001). In that sense, the mathematical microworld idea has been used in the design of some games where students adopt several roles in using a game, i.e. that of player, that of designer of a game for someone else and that of changing the rules of the game and reflecting on the rules during the process (see publications from Playground and Weblabs, also one from the Learning Games project Kynigos and Latsi in press).

The distinction between extrinsic and intrinsic integration of the game content is seen by Sauvé (2005) as a way to categorise the game as 'educational' or 'didactical', regarding the purpose of using the game through the learning process. As he declares: "The purpose of an educational game is only implicitly centred on learning since it is hidden from the player and the notion of pleasure which it engenders is rather extrinsic whereas the purpose of a didactic game is clearly focused on the duty of learning and it is explicitly identified as such, appealing to the intrinsic pleasure of performance." (Sauvé et al., 2005).

Much of the literature has focused on the learning, cognitive and social skills (Prensky, 2001; Kafai, 2001; Gros, 2003; McFarlane et al., 2004; Kirriemuir and McFarlane, 2004; Mitchell and Savill-Smith, 2004) that children develop through the process of game playing. The following table summarises some of them. The distinction between them has been made by McFarlane et al. (2004).

Personal and social development	• interest and motivation to learn • attention and concentration • collaboration, communication, negotiation skills, group decision making, respect for peers • the learner can take charge of the process of learning • student acquire digital literacy informally • student increase strategies for parallel attention
Language and literacy	• encourage children to explain what is happening • use talk to organize, sequence and clarify thinking, ideas, feelings and events
Mathematical development	• use everyday words to describe position • problem – solving, deductive reasoning

	• learning through observation and hypothesis – testing • increase strategies for parallel attention • broaden the understanding of scientific simulations
Creative development	• respond in a variety of ways • use their imagination in art and design music, and stories
Knowledge and understanding of the world	• investigate direction and control • increase spatial and dynamic imagery, iconic representation (via the need for dividing attention across different locations on the screen)
Physical development	Fine motor control can be developed with the increased refinement in using a mouse for navigation and selecting objects

3.2 Educational games

There are currently two major theoretical approaches regarding the learning of mathematics; the constructivist approach and the activity theory. One of the research projects that uses these strands as background is the TELMA team (TELMA report, 2005). In this section, we attempt to integrate the theoretical framework proposed by TELMA regarding the methodological tool for the use of ICT tools, with elements that exist on games and have been underlined by literature in this area. The deduction of this integration would be the illustration of some issues about 'what elements there must be in a game to be considered as educational game'. These aspects concerned to be prominent as it is crucial to identify the educational characteristics of a game, in order to choose appropriate games to support the learning process.

The methodological tool that TELMA suggests is built on the three components of the notion of didactical functionality (Cerruli et al., 2005). For each of these components it is suggested to focus on specific 'concerns' that relay equally upon different theoretical frameworks regarding the area of mathematics. We endeavour to correlate some of these 'concerns' with the characteristics of educational games that we think as more important.

a) Tool analysis and identification of specific tool characteristics

- *Concerns regarding the characteristics of the possible interaction between student and mathematical knowledge*

  Games provide an environment that integrates reflection into the process of play (Paras and Bizzocchi, 2005) and the interactive environment that games are implemented, submit many learning opportunities to the learner.

- *Concerns regarding the characteristics of the implementation of mathematical objects and of the relationhsips between these objects*

  Mathematical objects can be either intrinsic or extrinsic integrated into the game content (Kafai, 1998; Kafai, 2001; Malone and Lepper, 1987).

- *Concerns regarding the possible action on mathematical objects*

  Mathematical objects can be directly manipulative (the case of drill-and-practice games) or indirectly (in the case of logic or puzzle games).

- *Concerns regarding semiotic representations*

  One of games' most significant characteristics is that sometimes educational games have features that are not relevant to the epistemic content, or are relevant in an irrelevant representational way. However, these features may detract from learning, they also motivate children (Kao et al., 2005).

b) Educational goals and associated potential of the tool

- *Epistemological concerns focusing on specific mathematical contents or specific mathematical practices*

  Specific mathematical contents are usually implemented through the use of drill-and-practice games. "In the area of mathematics two broad objectives were set: i) to familiarize the child with the basic structural skills and mathematical though, and, ii) to learn and apply basic mathematical contents, focusing on the areas of arithmetic and geometry" (Gros, 2003).

- *Cognitive concerns focusing on specific cognitive processes, or specific cognitive difficulties*

  Games can provide the opportunity to the learner to develop cognitive processes (McFarlane et.al, 2002; Gros, 2003; Mitchell and Savill-Smith, 2004).

- *Social concerns focusing on the social construction of knowledge, on collaborative work*

Although collaboration is difficult to support in a game context, (Manninen and Korva, 2005), is one of the most significant issues in the development of cognitive learning (Kearny, 2005).

- *Institutional concerns focusing on institutional expectations, or on the compatibility with the forms and contents valued by the educational institution*

Institutional expectations are rather different in the case of games, as most of them don't relate directly with school curricula and teachers' everyday practices (Kirriemuir and McFarlane, 2004; Can, 2003; Gros, 2003; McFarlane et al., 2002).

c) Modalities of use

- *Concerns regarding the tasks proposed to the students including their temporal organization and progression*

The key element in games' learning process is that they can take charge of the learning process (Papert, 1998).

- *Concerns regarding the functions given to the tool including the possible evolution of these*

Most of simulation games or collaborative online games are designed in a way that the learner can take charge the evolution of game's interface or environment.

- *Concerns regarding the social organization, and especially the interactions between the different actors, their respective roles and responsibilities*

Teachers play the role of facilitator or mediator, which is very important in explaining and augmenting the game (Mitchell and Savill-Smith, 2004).

- *Concerns regarding institutional issues and especially the relationships with curriculum expectations, values and norms, the distance with usual environments*

Issues about using games in classroom report in the following session.

4 Deployment of Games in Education

The development of computer and video games has developed remarkably in the last decades, yet the technology remains largely unexploited within education, for example, Squire (2003) notes that:

> "Video games, as one of the first, best developed, and most popular truly digital mediums (sic.) embody a wealth of knowledge about interface, aesthetic, and interactivity issues. Historically, video games have been on the technological cutting edge of technically of what is possible, whether it is building online communities on the Internet, creating rich worlds using 3D graphics cards, or allowing dynamic synchronous interaction play by streaming information over the Internet. Indeed, even a cursory glance at the latest games can leave the designer blown away by what is currently possible with technology and inspired by the sleek interface or production values games contain. In fact, the greatest benefit of studying games may not be as much in generating theoretical understandings of human experience in technology or guidelines for instructional design, but rather, in inspiring us to create new designs."

However, as Squire also notes:

> "Computer and video games are a maturing medium and industry and have caught the attention of scholars across a variety of disciplines. By and large, computer and video games have been ignored by educators. When educators have discussed games, they have focused on the social consequences of game play, ignoring important educational potentials of gaming."

Games can also be related to the curriculum in a variety of ways; one method for categorising them is as either endogenous or exogenous (Malone and Lepper 1987; cited in Halverson, 2005))

> "Exogenous games provide simple networks of generic, interactive strategies useful for organizing access to a wide variety of content. …Endogenous video games connect game design and domain content by integrating relevant practices of the learning environment into the structure of the game." (Halverson, 2005)

Halverson notes the importance of the teacher in designing the learning activity in which to include the game, stating:

> Integrating endogenous games into typical school settings highlights the role of teachers and leaders in designing learning environments. (Halverson, 2005)

Halverson defines these environments, relating them to the game Rise of Nations, a simulation game similar to Civilization, (discussed in section 4.2):

> *"Learner-centered environments* draw on the interests and motivation of learners to direct learning. Endogenous games are powerful learner-centered environments that scaffold learning content in terms of what students need to know and when they need to know it. Here learning designers must be able to mediate the learner-based features of game design with the content-based features of traditional curriculum design…
>
> *Assessment-centered environments* integrate authentic learning measures into the environment. Endogenous games provide opportunities for risk-taking and controlled failure that link player actions directly to consequences…
>
> *Knowledge-centered environments* organize content for appropriate use by learners. School knowledge, organized in terms of disciplines, often neglects to help students integrate what they know across disciplines. *Rise of Nations* provides a prime example of how different domains such as economics, politics, history, and warfare interact in a dynamic system. … Analyses of curriculum alignment may point to areas of program overlap ripe for multidisciplinary investigation to show where integrated lesson design could make the most sense." (Halverson, 2005)

In this section, we endeavour to identify some issues about the use of digital games in schools that *have* been focused upon in the literature, particularly how their use can efficiently enhance educational practice. Additionally, we indicate the perceptions of teachers about this new educational medium since their opinion is crucial for the integration of games into schools (Can, 2003).

This section then examines specific implementations of games, and the success or failure of these implementations, both for games for education in general and for games for mathematics education in particular.

4.1 Issues relating to the deployment of games in education

The deployment of games within education is facilitated, or held back by, a variety of different factors. These factors are not limited to the appropriateness of games to education, but they include both the attitudes of teachers to games, their experience of them, and teachers' ability to find ways to incorporate them into the curriculum.

4.1.1 Games and society

Gros (2003) notes that games are having an impact on society and on the way people interact with technology. The degree to which children are exposed to multimedia is developing their digital literacy, but is doing it informally through play. Not only are schools and universities failing to take advantage of this digital literacy, but the development of students' abilities and the change in the culture to which they are exposed is widening the gap between students' expectations and educational delivery. Video games are among the most direct means of access that children and young people have to the world of technology. The digital generation has an ever increasing capacity for parallel processing which involves a more diversified form of concentration, it is probably less focused, and less centred on a single aspect. If games form a part of the educational strategies used by teachers then these skills can be drawn upon, and education can adopt forms more familiar to students.

> In Fromme (2003) the author sees a role for parents to play together with their children: "Even children who are quite engaged, in terms of frequency and general interest in playing computer games, apparently do not give up other activities and interests like outdoor and sport activities. Our findings also do not suggest that electronic gaming leads to social isolation. In most cases it seems to be fully integrated into existing peer relationships. To be together with friends for the great majority of children remains the favoured leisure activity. The interactive qualities of computer technology are quite attractive in situations when children are alone, however…

In most cases, parents or other adults do not participate in children's gaming cultures in an active (or interactive) way. Playing computer games is not - maybe not yet - a common project of the family. On the one hand, this may be regarded as something that should be accepted or even supported, because children want and need to have their own spheres. On the other hand, it raises the question of whether or not media education (in a wide sense) should restrict itself to controlling media use from the outside. In my view, the pedagogical task remains to actively and also critically accompany the children's process of growing up and developing their relationship to the cultural world. And the task remains to secure a plurality of resources and challenges they can use to develop their cognitive, social, and physical abilities."

4.1.2 General educational value of games

The general agreement within the literature is both that there are educational benefits to the use of games and that educational principles are a key part of the construction of games. Gee (2003) states that there are:

"thirty-six important learning principles are built into good video games, principles strongly supported by current research on human learning in cognitive science, such as:

- how one forms an identity
- how one connects different sign systems such as words, symbols, artefacts and so on
- how one chooses between different ways of solving a problem
- how one learns form non-verbal cues
- how one transfers abilities learned while doing one task to doing another".

Gee (2004b) also adds to this list identifying the following elements of games that enable students to learn:

"empowered learners

- good learning requires that learners feel like active agents (producers), not just passive recipients (consumers)
- different styles of learning…

problem solving

- learning works best when new challenges are pleasantly frustrating in the sense of being felt by learners to be at the outer edge of, but within, their 'regime of competence' expertise is formed in any area by repeated cycles of learners practicing skills until they are nearly automatics, then having those skills fail in ways that cause the learners to have to think again and learn anew.
- Human beings are quite poor at using verbal information (i.e. words) when given lots of it out of context and before that can see how it applies in actual situations. They use verbal information best when it is given 'just in time' (when they can put it to use) and 'on demand' (when they feel they need it)
- Fish tank: In the real world, a fish tank can be a little simplified eco-system that clearly displays some critical variables and their interactions that are otherwise obscured in the highly complex eco-system in the real world. Using the term metaphorically, fish tanks are good for learning: if we create simplified systems, stressing a few key variables and their interactions, learners who would otherwise be overwhelmed by a complex system get to see some basic relationships at work and take the first steps towards their eventual mastery of the real system" (p. 19)

Gee's idea of semiotic domains are compared with 'situated cognition', 'new literacy studies' and 'connections' (2003, p8). Gee's idea of 'situated cognition' is very relevant to educational research. Gee connects playing games to the way a good and effective science classroom would function and relates these to learning theories, games and science. Gee's learning principles may be used to design 'wrappers'.

An even stronger line as to the value of games in education is taken by Begg et al (2005) in that education as a whole could be modified to include many of the positive aspects of gaming. Begg et al take issue with the relevance of incorporating games into the curriculum, merely as a supplement to learning; referring to this as g*ame-based learning*. *Game informed learning*, on the other hand, is the process of using the processes of game design to change the nature of education, since the role of the gamer is very similar to the role of a constructivist learner "users need to be suitably contextualised, need to feel consequential, and need to feel the experience of the game or game world to be consistent, coherent, and intrinsic to their expectations" (Begg et al, 2005). Similarly, gamer clans have many of the characteristics of learning communities, though perhaps with stronger commitment to the process (Gee, 2003; cited in Begg et al, 2005). The degree of social interaction in MUDs is also a salient example for educators in the degree of invention, collaboration and role-play that occur within them (Curtis 1992; Dibbell 1999; cited in Begg et al 2005).

From their trials conducted at the University of Edinburgh in which game informed learning activities were conducted, Begg et al conclude the following features of a learning activity are important:

> “The backstory gives an emotional "in" for context and character role.
> Intrinsic feedback enhances students' enjoyment and feeling of agency, increasing opportunities for learning by encouraging students' willingness to learn difficult material (Malone 1982).
>
> “The ability to act in an emotionally engaging simulated situation without the serious consequences that such action might have in the real world … allows for repetition and improved performance as well as more committed performance from students (Gee 2003).
>
> “Students assume identities within the application and perform accordingly. Students develop an emotional attachment to the character within the application that contributes to the learning experience by helping students to perceive the application as a real, situated experience (Ryan 2001).” (Begg et al, 2005)

4.1.3 Motivational factors of gaming

One of the most valuable of the factors that the use of games brings to the educational experience in the opinion of teachers (Begg et al, 2006) is the motivational aspect. Wishart (1990) identified motivational factors as “desire in the user to control the computer, the user responds to a perceived challenge from the computer, and the user wishes to explore the complexity of the computer software”. Bowman’s list extends this (1982; quoted in Egenfeldt-Nielsen, 2005) comparing the difference in experience in arcades and classrooms and noting that the games played in arcades provide “clarity of task, choice in problem-solving strategy, possibility for self-improvement, balance between skills and challenges, clear feedback, enjoyment while learning and lack of fear of failure” the implication being that the classroom does not provide this kind of learning environment.

Csikszentmihalyi (1990) gives a good analysis of the motivational factors of gaming in which flow is an important aspect of a good 'game'. These are:

> “Completely involved, focused, concentrating - with this either due to innate curiosity or as the result of training
> Sense of ecstasy - of being outside everyday reality
> Great inner clarity - knowing what needs to be done and how well it is going
> Knowing the activity is doable - that the skills are adequate, and neither anxious or bored
> Sense of serenity - no worries about self, feeling of growing beyond the boundaries of ego - afterwards feeling of transcending ego in ways not thought possible
> Timeliness - thoroughly focused on present, don't notice time passing
> Intrinsic motivation - whatever produces "flow" becomes its own reward”

Jenkins, H. (2002) also notes the value of the motivation that games can bring to the teaching of Newtonian physics.

> 'As this example suggests, our educational games are designed to exist in relation to a broader array of classroom activities. We don't think that games can make you a scientist or engineer any more than they can make you a school shooter, and we don't think they are an adequate substitute to real-world experiments. We see games as enhancing the capabilities of gifted teachers, not displacing them with impersonal machines. Yet, games do offer teachers enormous resources they can use to make their subject matter come alive for their students, motivating learning, offering rich and compelling problems, modelling the scientific process and the engineering context and enabling a more sophisticated assessment mechanisms.' (p. ***)

4.1.4 Teachers’ attitudes to the use of games in education

In a recent research (Becker and Jacobsen, 2005) 70% of the participant teachers answered that they had used games and simulations in class and most of them (53%), used games to support the learning process. Although the percentage is significantly high, “many inside the school institution are reluctant to introduce new media into their teaching” (Gross, 2003).

Teachers’ resistance is related mostly with the content of most educational games that is not directly relevant to school curricula and their everyday practices (Kirriemuir and McFarlane, 2004; Can, 2003; Gros, 2003; McFarlane et al., 2002). However, “tolerance of games with little content relevance is greater in primary schools than secondary”(McFarlane et al., 2002). In another research curried out by Can (2003) most of the teaching staff were willing to use games but with specific educational criteria that they propose. As Becker and Jonabsen argue “one possible interpretation for the results is that the more an application *sounds* like game, the less willing they were to try” (Becker and Jacobsen, 2005). Additionally, many educators ignore the educational potential of games, giving attention to possible negative social consequences of game play (Squire, 2003).

Another aspect that could be the reason for the resistance of teachers’ to use games is the limited experience that teachers have with computational environments such as games. The “competence of the manipulation of game hardware and software” is the notion that Pelletier suggests as ‘game literacy’ (Pelletier, 2005). This could be an obstacle for most teachers as they must familiarise themselves with games and manipulate their computational environment effectively to produce and design appropriate activities, for creating learning opportunities for their students (Klopfer, 2005).

Recent research indicates, however, that a new generation of teachers are entering the profession with a wider experience of gaming (Schrader et al, 2006). In a survey of pre-service teachers, it was found that:

> “The majority of preservice respondents had played games (76.4%), and of those individuals, most played at some point during each week (83.3%). The majority of these respondents played for less than one hour (45.8%) while nearly one fifth played for three or more hours per week (19.2%). Several (20.2%) respondents indicated that they had lost track of time while playing, while another 45.3% indicated that they had neglected other tasks in order to play.” (Schrader et al, 2006).

As stated previously, in their views of the applicability of gaming to education, it was the motivational aspects that the pre-service teachers focused upon, rather than the social aspects that are possible through online interactions of multiplayer games, preservice teachers valued games as a motivational tool (83.4%) rather than an important part of social life (51.3%) (Schrader et al, 2006). This could be that few of them experiences online multiplayer gaming

> “Although participants reported significant gaming frequency, most (89.8%) reported that they did not feel like they were part of a gaming community. Most

participants (77%) preferred single player games, and the massively multiplayer online role-playing game genre was the least popular genre—with only eight participants (1.1%) indicating that MMOGs were their favorite. This statistic is possibly explained by the participants' age and the fact that MMOGs have only recently become a part of contemporary popular culture.” (Schrader et al, 2006).

This omission is a particular concern in the light of research such as Eustace et al, (2004) which reveals some of the educational benefits of MMOGs.

Regarding teachers’ opinion about the learning benefits of games, the majority of them agree that playing computer games helps development of some useful knowledge and skills, stimulates curiosity in learning, helps motivating students and as a result it is possible to learn through play (Can, 2003; Gros, 2003). Additionally, they think that “computer games with educational features can be used for all subject matters and in all grade levels” (Can, 2003). However, as mentioned before many of them resist the adoption of games in their classrooms because as Becker claims “most teachers want evidence of the effectiveness of games as learning objects” (Becker, 2005).

Teachers that are willing to utilise digital games face multiple obstacles and difficulties in their attempt to integrate games into classroom. The following table describes some of their problems (Kirriemuir and McFarlane, 2004; Becker and Jacobsen, 2005; Squire, 2005):

- Not Enough of Limited Access to Computers
- Game use not integrated into curriculum documents
- Lack of adequate technical support
- Lack of support for adequate supervision of students during use
- Games Integration not a School Priority
- Not enough teacher training opportunities
- Difficult to identify the appropriateness of the content within games
- Opposed to Use of Games
- Lack of Time for Projects that Use Games
- Lack of knowledge about ways to integrate games

- Lack of time to ‘ game literate’
- Lack of sources for games and resourc to use them

The educational potential of digital games must be part of media education (Pelletier, 2005) and the obstacles that teachers confront as well as teachers’ perceptions, fears or rejections must be considered in achieving it (Can, 2003). Regarding teachers that are not willing to adopt this new medium in the learning process, Becker (2005) suggests that “one way to help convince more teachers to try games is through pedagogy; by connecting elements of existing games designs with accepted learning and instructional theories... through pedagogy, a convincing case can be made for the applicability of games for learning”.

In their study of the use of computer and video games in the classroom, Kirrimuir and McFarlane (2003) found

> an ambivalence to the use of computer and video games in the classroom. On the positive side, it is encouraging to see that an increasing number of schools are using computer and video games in a variety of situations, many of which are imaginative, or support the learning process within a range of other tools and resources…
>
> However, on the negative side, it is disappointing still to see a general lack of games being used for relevant subject-based learning. It is frustrating when, for example, schools provide games for recreation or as rewards for good behaviour (thus recognising that children like to play them), but fail to use them for learning-oriented purposes even where this potential is recognised…
>
> This is all the more disappointing due to the steadily growing body of schoolbased research indicating the positive use of specific games in certain classbased lessons. Though we have mentioned some of the obstacles that were described to us, there is a need for more research (resulting in practical solutions) into why schools are missing out on opportunities to use such games as learning-supporting tools. Early indications suggest a lack of external recognition of the learning that takes place during game play, with content acquisition still leading the assessment agenda…

We discovered five main scenarios in which games are used in schools outwith of curriculum-lead, lesson-centric activity.

1: Games in schools as research projects

2: Games in school-oriented competitions

3: Games used in computer clubs

4: Games as a vehicle for literacy or critique

5: Games as a reward for good behaviour" (Kirrimuir and McFarlane, 2003)

Thus, even when games are used in the classroom, they can be used in ways that are not directly attempting to communicate elements of the curriculum. For the effective implementation of learning games into classroom, teachers must realise the interconnections between games, learning and the pedagogical value of games (McFarlane et al., 2002; Gros, 2003). From the point of view of school organisations, it is essential to provide teachers with some instructional ideas as well as suggest appropriate games (Can, 2003; Becker and Jacobsen, 2005).

4.2 Examples of the deployment of games in education

Amory et al (1998) assessed student responses to four commercially produced games (Sim Isle, Red Alert, Zork Nemesis and Duke Nukem), to identify which features the students preferred in order to develop their own game for educational purposes. First and second year biology students appear to favour 3D-adventure (Zork Nemesis) and strategy games (Red Alert), were critical of the racism and pornographic elements in the first-person "shoot-em-up" Duke Nuken and found the simulation game Sim Isle unsatisfactory. The development of an adventure game by the research group was used to test the applicability of such technology in education. The pilot project on integrating information into an adventure type game was enjoyed by most students and they also learnt something while playing.

Kirrimuir and McFarlane (2003) conducted a survey into the use of games that were designed for the entertainment industry but had been used in the classroom. They therefore looked only at PC-based games and games produced for video game consoles, i.e. the Xbox, GameCube and Playstation ranges. They found that "Relatively simple simulation games were found to be the most common type of pure game used. More instances of Sim City and RollerCoaster Tycoon were discovered than any other (pure) games." (Kirrimuir and McFarlane, 2003). From the literature reviewed here it would appear that these games (called variously simulation games, real time strategy (RTS) games or God games, are amongst the most popular games to be deployed within the classroom.

Squire (2002a) notes “many edutainment products such as Gettysburg, SimEarth, or Railroad Tycoon have already made their way into K-12 classrooms, as they allow students to explore the complex dynamics of microworlds. The past ten years have seen tremendous advancements in gaming technology that have not been explored within the instructional technology community. However, in their use for educational goals, Squire (2002) argues that 'wrappers' ('instructional resources') are needed in the deployment of these games.

> 'In using a game such as SimCity, minimally, there needs to be a close match among desired learning outcomes, available computer and supporting human resources, learner characteristics (such as familiarity with games conventions), "educational" game play, and potential supplementary learning experiences. Fortunately, one can imagine creating instructional resources around a game like SimCity or Civilization that pushes students to think about their game-playing more deeply. For example, Civilization players might create maps of their worlds and compare them to global maps from the same time period. Why are they the same? Why are they different? Students might be required to critique the game and explicitly address built-in simulation biases. Finally, students might draw timelines, write histories, or create media based on the history of their civilization.'

Dawes and Dumbleton (2002) conducting a study of similar games in the classroom for BECTA ,determined the following:

> “The role of the teacher in structuring and framing the activity of the learner remains crucial if learning outcomes are to be achieved.
>
> “For some games and school contexts, working with elements or sections of the game may be more useful than the game as a whole. Isolating particular elements of games for use in lessons can be difficult. Most games have been designed for use over extended time. Some titles offer shortcuts such as scenario builders, pre-defined scenarios, and the facility to save games.
>
> “Simulation games can offer learners sophisticated scenarios to support meaningful discussion.

> “An imaginative and well-produced game may be flexible and complex enough to offer a range of educational opportunities. This may include modelling and control opportunities through a simulation game (SimCity, for example).
>
> “The teacher wishing to use games must know what kind of content particular titles offer. Many titles have suitable content for teaching and learning, but many others are unsuitable. Teachers should be as aware of the content of games as they are of the content of video, television or film material.
>
> “The teacher requires some understanding of the controls, menus and skill levels of the game in order to use it effectively. These skills are only gained by playing.
>
> “Teachers in the study found that use of the games could provide motivation, develop skills and encourage collaboration. The motivating power of games and their ability to encourage co-operation were felt to support the work of schools in developing independent but social individuals.
>
> “Pupils receive immediate feedback on their decisions in games. In simpler games, the reasons can be obvious (for instance, the character doesn't jump far enough). More complex games require students to evaluate a range of influencing factors and hypothesise new solutions. The effectiveness of solutions is immediately apparent; for example, in The Sims the character becomes happier and goes to work, or stays at home and loses her job.” (p. 8)

Squire’s more recent report of the use of the game Civilization in the classroom (2005) also notes the resistance of some students to the exercise. The reasons for these were threefold. The students who were experienced gamers offered resistance because the game was part of their coursework, and therefore compulsory

> “part of what makes games so appealing and educative is that they give us meaningful choices (Zimmerman and Salen 2003), how will they fare in situations where there are very prescribed learning outcomes? Further, for many, gameplay involves *social transgression*. Games allow us to bend or temporarily dismiss social rules in order to try new ideas and identities.” (Squire, 2005)

Failure at the game was also a bigger problem for this group:

> "failure affronted those students who self-identified as gamers, suggesting that educational games may not be such an easy win for this population of students—who may be inclined to reject educational games out of hand if such games challenge or compromise their identities as gamers." (Squire, 2005)

Some of the more academically-orientated students resisted the inclusion of the game because it detracted from time spent developing their ability to pass exams. Squire notes that:

> "Looking at who wins and loses through a game-based curriculum reminds us that curricular issues are also about power and control. A curriculum based on *Civilization III* overturns traditional hierarchies, supplanting those adept in traditional schooling with those failing school."

Egenfeldt-Nielsen, (2005) describes a case study of teaching Danish history using the game *Europa Universalis II* noting the barriers to using games in the classroom were

- gender differences
- constraints of the allocated periods
- lack of group work spaces
- technical problems
- lack of technical support

These issues seem no more than those typical of any educational development though - the change highlights pre-existing problems that have not been addressed because they are so ingrained. The problems with implementing the game (Egenfeldt-Nielsen, 2005; p. 184) were

- teachers with limited understanding of games
- teachers with limited understanding of how to develop wrappers
- resistance from students regarding whether this was a valid activity for learning history, since it conveyed causal relationships between fictional actions and reactions rather than historical facts
- conservatism about computer games - (op cit; p194)

4.3 Examples of the deployment of games in mathematics education

Unlike the use of games in other areas of education, in which commercially-produced game have been adapted for use within the classroom, the case studies identified in the literature of the use of games for mathematics education are all of smaller games produced specifically for teaching mathematics. Four case studies are referred to here.

4.3.1 Aquamoose 3D

Aquamoose 3D is “a desktop 3D environment designed to help students learn about the behaviour of parametric equations. AquaMOOSE is based on an educational philosophy called constructionism, which advocates learning through design and construction activities. Students use mathematics to design interesting graphical forms and also create mathematical challenges to share with others.” (Elliott, and Bruckman, 2002)

In their study Elliott and Bruckman (2002) found that their
“initial four years of work on the AquaMOOSE project first and foremost serve as a proof of concept: 3D graphical environments have significant potential to support new forms of mathematical learning. They can provide the two hallmarks of good constructionist learning environments: personal connections to things that interest students and epistemological connections to new areas of knowledge. While usability challenges of 3D interface design are substantial, these appear to be surmountable with careful design work.

Second, through this work we have gained deeper insight into the costs and benefits of big-picture design thinking. We chose to focus on matching the affordances of the medium to intellectual ideas, and give lower priority to users’ immediate needs. While this may at one level seem like bad design process, a step back offers a different perspective.” (p. 10)

They concluded that:
“New technology can make different mathematical ideas accessible and salient. However, note that neither the curriculum (designed for old technology) nor innovative designs supported by new technology address the more fundamental question of what students really need to know. Why do we want students to learn math anyway? What intellectual and practical imperatives should be at work?

Fundamental reform of school curricula is needed. We can take better advantage of learning opportunities provided by new technology and also account more carefully for real learning needs of students." (p. 11)

4.3.2 Thinklets

A platform for mathematics games is through dedicated websites, for example, KidsKount in which the authors employed applets (challenging mathematical games or thinklets) developed by the Freudenthal Institute. "These thinklets were developed as mathematical tools and have game-like elements. Some are exploratory, some are more focussed on a single topic." (Jonker and van Galen, 2004). The study examined the use of the thinklets on the web to promote learning in the home and in the classroom and to find ways to bridge these two.

The aims of the deployment of these games were:

"1. to enrich math lessons (game-like)

2. to explore possibilities of Internet use

3. facilitate collaborative learning (mw. looks like a design pattern: how to use the problem of the month)

4. lessen the gap between school-earning and home-learning" (Vincent and van Galen, 2004, p. 1).

It was noted in the study that "Students work with these interactive applets collaboratively at school as well as at home" and a question arising from the study was "How does asynchronous learning ((with) small numbers of students at the computer) fit into the synchronous class activities?" The characteristics of the Thinklets extracted by the authors (as opposed to or related to larger games) were that they should be:

"- available through Internet (extra possibilities: like send in solutions; keep track of students actions; collect and share work/results)

- used at school and at home

- motivating

- some exploratory (open ended-set your own goal), some more focussed (tasks, goals are set)

- small (mini-games); dedicated to one topic" (Jonker and van Galen, 2004)

4.3.3 E-GEMS

Two E-GEMS games, Super Tangrams and Phoenix Quest were used to teach mathematics and their use analysed (Klawe, 1998). Klawe's study is specifically targeted at games and mathematics. In a sense it demands 'wrapping' games in other learning activities in order for them to be effective. The two main questions addressed in this paper are:

A. How should mathematical computer games be designed and used so that students engage in conscious reflective exploration of mathematical concepts?

B. How should mathematical computer games be designed and used so as increase achievement, confidence, and enjoyment in mathematics for girls as well as boys?

Klawe's findings suggest that computer games can be highly effective in increasing children's learning and enjoyment of mathematics. The extent of the effectiveness, however, depends on many things including details of the software design such as interface styles and scaffolding, teacher and student expectations, the level of integration with other learning activities, and the setting and pattern of use. In addition, our studies have frequently revealed gender differences with respect to children's attitudes towards and interactions with computer games.

Inkpen et al (1994) also studied these EGEMS games and concluded:

> "We have found that situating mathematics learning in a computer game environment brings greater relevance to the subject for children. In our interviews with children many of them made comments such as 'if you're doing it [mathematics] out of a book it's really boring, and you don't want to do it,' whereas, 'if you're doing it out of a game or something then you're wanting to do it and you're having fun with it so you can concentrate on what you're doing instead of just getting it over with and then forgetting about it 5 minutes later.' We found that CBMGs provide environments in which children find learning mathematics to be meaningful and useful." (Inkpen et al, 1994)

6.1. 4.3.4 VETA Learning Games

VETA Learning Games were used in 150 schools by 3,500 students and teachers in Sweden (Varcoe, and Rydberg 2004). This study concluded:

> 'Game play, interaction and story must support and subordinate to learning processes and knowledge objectives. The overall purpose is not to play a game but to learn in an engaging and effective way! Characters, story, interaction etc., must be relevant to the learning context of the specific subject or it will cause frustration.
>
> “example from mathematics: In mathematics, the learner gets to know a number of characters who need the learner's help where mathematical understanding and skill development are necessary - from building up a taxi business with the help of functions, to coaching the career of a young journalist by using statistics.
>
> “Finding of teachers: 'games are useful tools for collaborative learning; students solve assignments together.” (Varcoe and Rydberg 2004, p. 4)

4.3.5 Zoombinis

Zoombinis is a game designed specifically for math by researchers from TERC (Hancock and Osterweil, 1996). They formulate four design principles:

- “putting the learner in charge (e.g. offering choices, define success on their own terms)
- integrating math, stories and rewards ('the set game problems are inherently rewarding to solve')
- depth ('developing underlying concepts and ideas, rather than superficial procedures')
- coherence ('clusters of puzzles which develop a common main idea, these clusters are in turn interconnected by a web of common themes and ideas' in contrast to a 'grab-bag of activities') (Hancock and Osterweil, 1996).

The essential notion of the design of the Zoombinis was that they:

“found the 'game in the math; rather them putting math in a game' and almost by necessity, the math looks different from how it does in a classroom” (Hancock and Osterweil, 1996)

6.2. 4.3.6 Mathematical Equitable Game Software

Rubin (1999) reviewed mathematical games according to the following criteria:

- What does it mean to be a good piece of mathematics education software?
- What does it mean to be an equitable piece of game software?
- What does it mean to be a good computer game?

and identifies the following : "Questions to ask as you evaluate the mathematical content of a computer game"

"1. What mathematics is included in the game?
Is it primarily drill and practice or is there authentic mathematical problem-solving involved?
2. Is it possible to do much of the mathematics by trial and error only?
Does the game provide incentives to develop more sophisticated strategies?
3. How is the mathematics integrated with the rest of the game?
Is it possible to avoid the mathematics? Is the math merely an obstacle to be overcome or does it play a more central role?
4. Do players have time to have discussions about the mathematics in the game (e.g., little or no time pressure)?
5. Is the feedback helpful and informative?
6. Is there a way for a range of players (from beginning to more experienced) to engage with the mathematics? Are there multiple levels of difficulty? Do the players have control over the current level or does the game choose?
7. Would children view the game as mathematical? Would parents?" (Rubin, 1999)

Conclusions

The literature indicates strongly the educational value of using games within education, and even some suggestions that education in general could be improved by adopting some of the principles of gaming. Not only are changes in technology driving this change, but also the increasing likelihood of teachers being gamers themselves. The experience of teachers affects strongly the manner in which games are used, teachers that are not gamers are wary of using games or use them as rewards for learning, not as learning technologies themselves, teachers that have experience of games use them mainly as a motivational tool, but few teachers have experience of multiplayer online gaming, which may be a constraint to using games as tools for collaborative learning. In a study of the deployment of games, therefore, part of the study would need to be the attitudes and experience of the teachers with respect to games, and to mathematics games, since the literature indicates that this is a central factor in the games' successful deployment.

The types of students is also an important factor, perhaps more than gender or ethnicity is the self-definition of gamer or non-gamer, since this positioning of the student appears to influence their interaction with the games, for example, gamers being more dissuaded by failure at an educational game than a non-gamer.

The notion of "a game being used in education" is itself ambiguous, since games are used far more widely in education than to teach. In the study, the parameters of what is meant by "use" need to be defined. If use includes using the games simply as a reward, or as a way to get students to bond, is this within the remit of the study?

The literature reveals a wide divergence between the way in which games are used in mathematics education and how games are used in education in general, in that games for mathematics education are small, bespoke games, other examples take large commercially-produced games and reapply them to learning and teaching. Should the study make attempts to bridge this gap, attempting the deployment models identified in section 4.2?

Gamer clans as learning sets is another interesting possibility for incorporating some of the attributes of games into the study. Is it within the remit of the study to import some of the more generic models of gaming – for instance the online communities of gamers – to educational activity rather than use a specific game?

Another question for the study, raised by the report is whether it is learning within the classroom or learning as a whole that would be investigated, for example the use of Thinklets to bridge home-learning and classroom learning.

Finally, the literature seems to indicate that there is a great deal that learning design in general can be informed by games design. The study could also look for which of the elements of what gamers do as a matter of course that could be incorporated into teaching; i.e. we would not only be learning how to teach maths through games, but also, through games, learning how to teach maths.

Part 3:

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