

## PUTTING THE *LEARNING* BACK INTO E-LEARNING

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*The design of web-based learning environments is primarily focused on the production and delivery of content to a learner. The principles of constructionism are intended to guide the development of learning environments where the learner has more control. In this paper, we describe characteristics of constructionist and learning environments that can foster the learning of mathematics. Our experiences are drawn from the development of microworlds for an e-museum. Reflecting on this process turns out to provide some fresh insights into how e-learning environments might be re-conceptualised in the future.*

### 1. INTRODUCTION

In this paper, we reflect on our experiences of developing microworlds as part of an e-museum to draw inferences about issues related to using web-based environments for the teaching and learning of mathematics. The broad aim of the e-Muse project<sup>1</sup> was to investigate the concept of developing an Internet museum. A museum consists primarily of exhibits, supplementary explanatory material related to the exhibits together with hands-on activities to engage visitors. The e-Muse website is in essence a large collection of assets related to the ancient Olympic Games that comprises text, images, videos, interactive areas for participating in discussions and facilities for uploading work and downloading other children's work.

When we began this project, we were interested in two tensions. In order to develop a virtual museum that bridged museum and school environments, it was apparent that there was likely to be a cultural conflict. Perhaps museologists would be concerned primarily with accuracy and appropriate presentation, whereas classroom practitioners' foremost concern was likely to be about interaction and engagement. Of course this is a characterisation in so far as both cultures would have concerns about accuracy and engagement but we felt that the priorities might be distinctive.

The second tension is an extension of the first. In a sense, museologists might be characterised as most interested in the efficient *delivery* of accurate materials, and we perceive this to be an aspiration shared by designers of so-called e-learning environments. In contrast, our own approach is heavily influenced by the constructionist literature (Harel & Papert, 1991), which places emphasis on ownership of ideas by the learner. In that respect we would tend to align

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<sup>1</sup> E-Muse: e-learning for museum and schools environments, <http://emuse.cti.gr>  
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ourselves more closely with classroom practitioners who place the accent on learning rather than delivery.

To provide an interactive experience for e-museum visitors, we have developed two microworlds that are intended to engage and stimulate exploration of the e-museum. These microworlds, based on the throwing events of the Olympics, are targeted at children of 10 years old and upwards. Our aim in this paper is to describe our experiences of developing these microworlds in order to explore the larger question: How do we invest constructionist principles into web-based situations? In section 2, we will describe related literature before describing the development of the two microworlds in section 3. In section 4, we discuss the characteristics of these microworlds, and then return in section 5 to consider the above question in light of our research.

## **2. THE PEDAGOGIC CONTRIBUTION OF MICROWORLDS**

Examples of the careful design of microworlds began to emerge in the 1960's when a team, headed by Papert and Feurzeig, was developing the computer language, Logo, at MIT. This early work was primarily concerned with programming and problem-solving (see Papert, Watt, diSessa, & Weir, 1979; Watt, 1979). In particular, they advanced the radical notion that children need to play with and use mathematical concepts within a supportive computer-based environment before being introduced to formal work with those concepts (Papert, 1972).

When mathematizing familiar processes is a fluent, natural and enjoyable activity, then is the time to talk about mathematizing mathematical structures, as in a good pure course on modern algebra. (p.18)

These initial ideas reached a climax (Papert, 1980) in which a radical vision of education was proposed. Since then, the work has been elaborated to the point where a new paradigm for the teaching and learning of mathematics, the *constructionist* approach, was put forward (Harel & Papert, 1991). We believe that this paradigm has much to teach developers of e-learning platforms and that reflection on the design of our microworlds can help to crystallize what those lessons are. First, let us distil six constructionist criteria from the literature.

### **i) Quasi-Concrete Objects**

Turkle and Papert (1991) have referred to the way that the computer offers access to formal ideas in a concrete way, since abstract mathematical ideas, represented in iconic form on the screen, can be manipulated directly by the user.

### **ii) Using Before Knowing**

In our everyday lives, we typically use artefacts for particular purposes. Through that use, we learn about the effectiveness of the tool, its limitations, how well it serves that purpose and sometimes we may gain some understanding of how it works. In schools,

mathematics is a subject where you learn how to generate the object before you use it. In practice, more often than not, the former task proves too difficult, especially when disconnected from purpose. The computer offers the possibility of turning the learning of mathematics round so that use precedes generation (see the *Power Principle* Papert, 1996).

### iii) Integrating the Informal and the Formal

diSessa has suggested that we incorporate versions of the formal representations of the mathematical objects in such a way that the child may be able to make connections between the various formalisations and their informal use (diSessa, 1988).

### iv) Dynamic Expression

When Papert proposed the turtle as a tool for constructing a dynamic notion of angle (and of course much else), he acknowledged that the computer offers a medium which unlike paper and pencil can incorporate dynamic representations of the world. He suggests that the use of systems which are expressive of dynamic and interactive aspects of the world are more engaging to learn than static and abstract formalisms.

### v) Building

Constructionists base their approach on a tenet that encouraging the building of artefacts is a particularly felicitous way of teaching mathematics. Pratt (2000) has demonstrated how this approach can be modified into related approaches such as mending.

### vi) Purpose and Utility

The microworld approach can encourage purposeful activity through the building and modification of artefacts. In so doing, emergent knowledge is imbued with *utility* (Ainley, Pratt & Hansen, in press), in which the abstractions are seen as useful and the limitations of those abstractions are gradually discriminated.

In the next section, we move on to describe the microworlds themselves.

## 3. THE MICROWORLDS

As described above, the primary motivation for the development of the two throwing microworlds was to provide context and motivation for engaging with the museum content. We adopted the methodology of design experiments (Cobb etc, 2003). Using this approach, we cycled between design and testing phases. As the design stabilised, we used increasing numbers of children, allowing us to be more systematic in our study of their activity. Each design in effect encapsulated emergent conjectures about the relationship between the tools and

the children's learning. We describe below the objectives of the microworlds and discuss their final designs.

### 3.1 Shotput

The shotput microworld was intended as a multidisciplinary environment, bringing together physics, maths and physical education. Its primary objective was to explore factors involved in projectile motion, situated in the challenge of maximising how far a child might throw a shotput. Children were given the opportunity to throw the shotput, after which the distance thrown, the time of flight and their release height were measured. These values were entered into the computer microworld, which could replay the actual throw. In Figure 1, the flight path of an example throw can be seen.

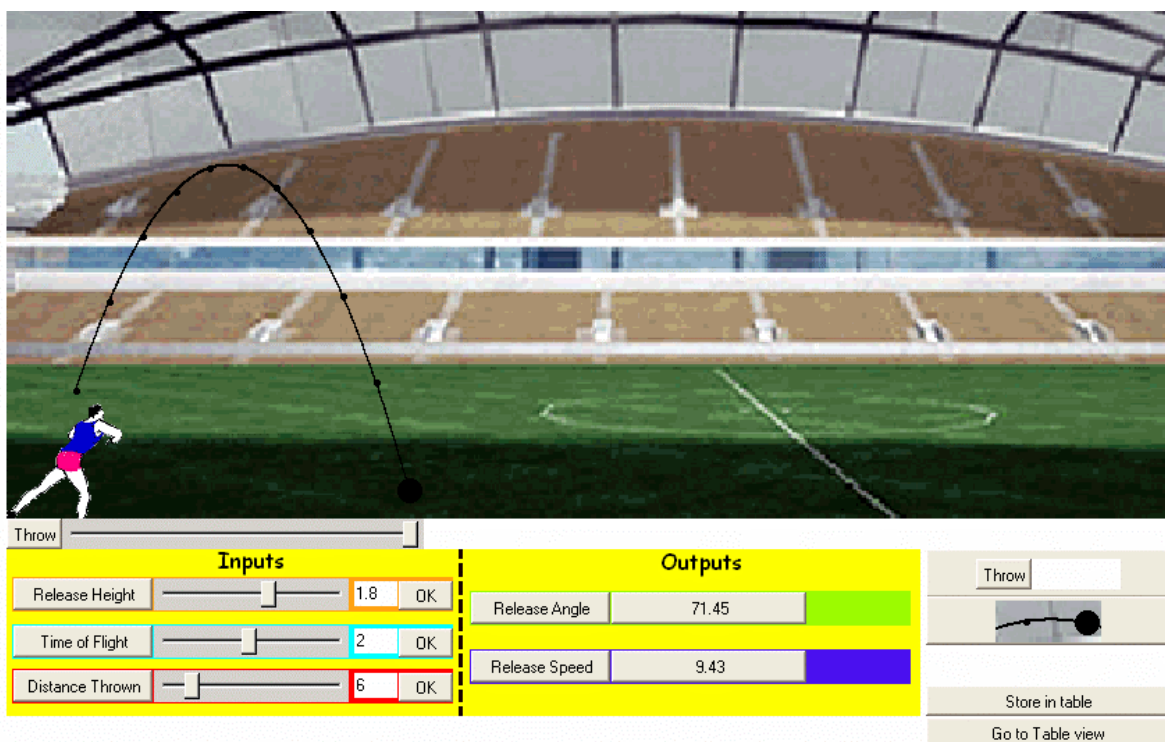


Figure 1: The shotput microworld

Children were then able to experiment with the different parameters in the model to try and improve their throw, aiming to establish the optimal release angle for a given release height and release speed. The main challenge was to understand the distinction between inputs and outputs, knowing which variables were sensible to change and how they might be changed. The microworld also contained facilities for children to tabulate interesting results, compare multiple flight paths in parallel, and produce graphs of the table of results.

### 3.2 Discus

The discus microworld shared common interface structures with the shotput microworld, enabling prior experience to be leveraged. Children threw a discus, made relevant measurements and then entered that data into the microworld to

produce a simulation of their throw<sup>2</sup>. Children could then explore how to improve their throw and how to design a good discus. Experimentation with the input variables (the release height, release angle, release speed, discus tilt and the wind speed) could establish the optimal flight path for each individual. As with the shotput microworld, there were facilities for storing interesting throws, comparing multiple flight paths in parallel and producing graphs of the tabulated results. The discus microworld also contained a design view where children could experiment with discus design to explore how diameter, weight and colour affect the distance thrown (see Figure 2).

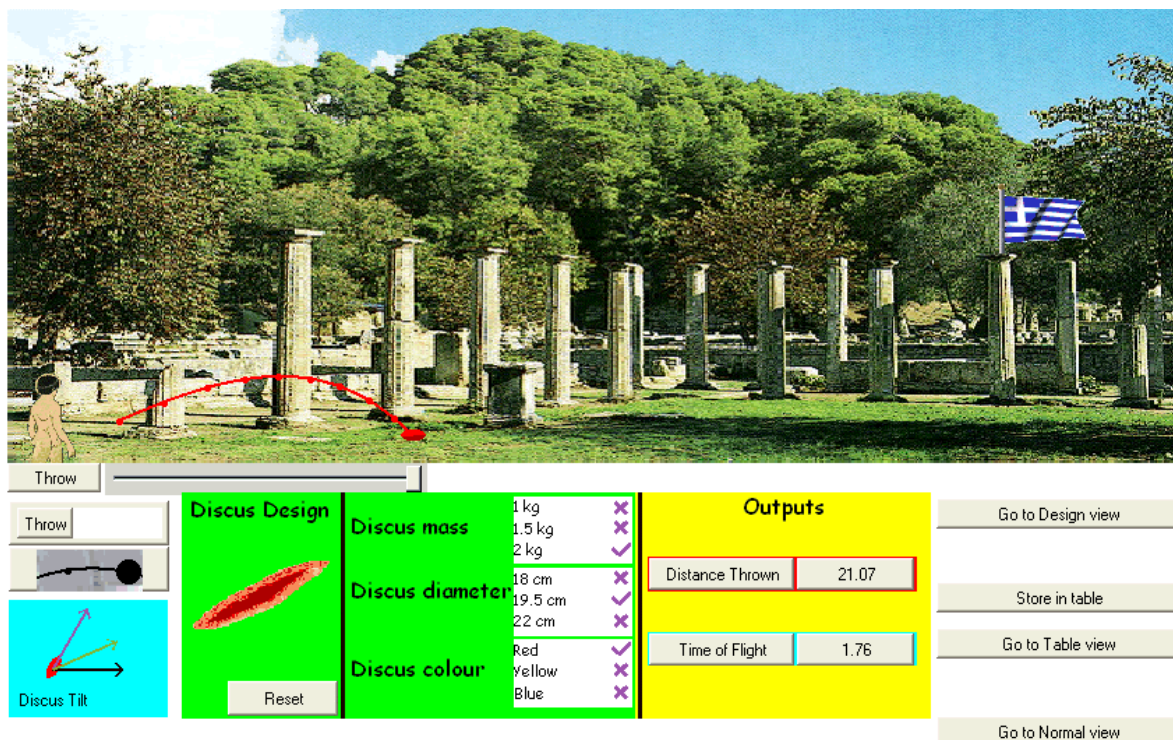


Figure 2: The discus microworld in design view

## 4. TOOL CHARACTERISTICS

Having described the microworlds, we now wish to reflect on some of the tensions that we faced during the design process, expecting that such deliberation should yield useful insights into the process of designing web-based resources. In particular, we wish to articulate how our struggle with those tensions distributed across the six constructionist principles outlined above.

### 4.1 Plug-and-play versus programming

Since the earliest days of Logo, programming has been an integral part of the constructionist paradigm. Yet modern languages have become increasingly high-level, and direct manipulation tools have become so available, that it is increasingly difficult to distinguish programming from related activities. Our

<sup>2</sup> Completely accurate determination of a discus flight path is exceedingly complex. Our model is based on the work of Frohlich, 1981, and Hubbard & Hummel, 2000.



microworlds were written in Imagine<sup>3</sup>, an extraordinarily powerful version of Logo. The designer (or indeed user) has available a vast array of direct manipulation devices such as buttons, switches, text boxes, sliders and so on. These features afford the quasi-concrete representation of mathematical or physics concepts. The sliders for release angle and speed, for example, gave the children direct control over complex ideas and, through exerting this control, they began to appreciate projectile motion, a demonstration, we would say, of Papert's Power Principle.

However, the same features that allow direct manipulation also make it relatively easy for a designer to design conventional programming *out of* the microworld. In our context of integrating the two microworlds into an e-museum, we exploited a facet of Imagine to create web-based projects, in which the user can run the project from a web browser without requiring Imagine itself. However this facility does not permit programming by the child. Compared to the creativity afforded by more conventional microworlds, we felt this was a loss. The plug-and-play nature of web-based resources seems to constrain the integration of the formal and the informal.

## 4.2 Open/Closed microworlds

Designers of educational software have to consider just how open or closed they should make their software. The constructionist principles of Papert assert that children will learn best if they are left to their own devices to explore and construct in line with their own interests (Papert, 1980). As such, the design of educational software would be as open as possible – children would be free to follow their own interests within an environment where a particular theme could be investigated. For instance, in Logo, children free to explore projectile motion in idiosyncratic ways might develop a mediaeval project involving catapults or they may instead find the optimum way of throwing a cricket ball. In an educational system where accountability is important, the constructionist approach is hazardous since the teacher has relatively little control over the material, making assessment more difficult.

An alternative approach is closed software where a program is designed to support restricted interaction related to solving a particular task. Within such software, a child is shielded from making mistakes and exploring their own hypotheses, both of which are important elements of the learning process (Lewis, Brand, Cherry & Rader, 1998, include these ideas in a set of design principles emerging from work using *Agentsheets*, a graphical grid-based programming environment). For instance, a program for learning about projectile motion could simply allow the input of parameters for a throw (release angle, speed and height) to generate display of the flight path. In this type of

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<sup>3</sup> Imagine is an object-oriented parallel-processing version of Logo that allows the programmer considerable interface design options. It is published by Logotron: <http://ns.logotron.co.uk/imagine/>

environment, a child has little scope for either exploring a range of questions related to projectile motion or the ability to make and test personal hypotheses.

The perspectives of openness and closedness have impacts on the way that educational software can engage learners. In between the two extremes described above educational software can be partially open within a closed area.

For instance, the shotput microworld is closed within the domain of exploring projectile motion – yet it remains open to the possibility of exploring hypotheses, making mistakes or generating irrelevant results. In the shotput microworld, inputs are distinguished from outputs but in a way that may be unfamiliar to children. The children were comfortable with the notion that the inputs were those factors that they influenced during a physical throw (release angle, speed and height):

1. Researcher: As the person throwing the shot, what are the things that you can input?
2. L: What at the moment?
3. Researcher: If you were actually throwing it. What would you have control over?
4. J: The angle that you throw it.
5. L: Your release height... oh no you can't.
6. Researcher: I guess you could stand on a box, or something.
7. J: you can change your release speed.
8. Researcher: How?
9. J: You could throw it with more power.

Yet mathematically, any variable might be an input (as to a formula). Rather than protect them from this possible conflict, we felt this was an issue to be grappled with and hopefully understood:

10. Researcher: Are you happy with your inputs and outputs?
11. L: You can't really control the distance.
12. Researcher: What do you mean by that?
13. L: Well once you throw it you can't choose where it ends.

Without a programming language available to the children, there was an inevitable constraint on the creativity. We can repackage this issue as a lack of opportunity to build, one of the fundamental aspirations of constructionism. The children using the microworlds played with models but they did not construct their own versions.

### **4.3 Real-world familiarity / Design for purpose**

Emergent understanding of projectile motion was of course contingent on feedback. Our microworlds exploited extensively the principle of dynamic expression. For example, the simultaneous throwing of several projectiles was designed to promote a 'feel' for the relative motion of one object against another.

Both of the throwing microworlds were designed to look and feel similar to their real-world counterparts. The microworlds exhibit both *surface familiarity* (objects look and behave like their real-world counterparts) and *cultural familiarity* (objects behave like their real-world counterparts) (Pratt, 1998). For instance, in the microworlds the animations of the throwers and the behaviour of the throwing implements exhibit the familiarity required to enable children to leverage prior experience of the activities into their understanding of the microworld. Indeed, by encouraging children to physically throw the shotput and discuss, we reinforced that familiarity. This is not just of pedagogic advantage but also aids research into children's thinking since it provides a *window* on their thinking (Noss & Hoyles, 1996).

Familiarity supports the construction of purpose when sufficiently interesting tasks are created. Nevertheless, purpose does not guarantee the construction of utility by the child. According to constructionist principles, the child needs to be able to play with the pertinent concepts in order to take ownership of them. The more constrained the environment, the less likely it is that children will take this critical step.

## 5. CONCLUSIONS

The process of attempting to embed microworlds into an e-learning environment has illuminated what we see as particular problems with e-learning environments as they are currently designed. The development of e-learning environments has been driven by university needs where the lecture is the dominant teaching method. Lectures are essentially delivery and the Internet is an efficient mode of operationalising such delivery. In some situations, the delivery of factual information is entirely appropriate. On the other hand, educationalists recognise the importance of interaction and constructionists go further to propose a range of principles that facilitate learning.

We have shown that those principles are not easily embedded into a web-based resource. On the credit side, we have demonstrated that the range of direct-manipulation tools available in modern programming environments afford the forging of connections with complex scientific ideas through the use of quasi-concrete objects in dynamic settings. On the debit side, we would argue that integration of formal and informal representations was limited by the lack of facility to program, which would have allowed the children to build their own models. Similarly, the children were not able to test out idiosyncratic conjectures about behaviour since they had limited facility to express their own ideas. The facility to recognise cognitive conflict and construct new meanings to resolve such tensions is an essential foundation of constructivist learning.

The predominant delivery model for e-learning exhibits this same failure, though perhaps to an even more marked extent. As Bannan-Ritland et al (2002)



have indicated, designers of these environments structure content in a particular sequence for delivery to the learner. We agree that:

...there are alternative theoretical foundations other than a traditional instructional system design perspective that can be applied to learning object systems based on constructivist philosophy of learning. To the best of our knowledge, a learning object system based in theoretical approaches steeped in constructivism has not yet been developed. (p.12)

It is not of course self-evident that the level of interaction implied by constructivist philosophy is achievable. Indeed, Ehrmann (2000) has argued that the attainment of interactive courseware is a mirage. He claims that this mirage is due to the high human costs needed to achieve appropriate levels of interactivity. We maintain that the use of Constructionist principles offers the potential for achievement of far greater levels of such interactivity in e-learning environments.

We therefore exhort developers to re-consider design principles for such environments, in effect to put the learning back into e-learning. We are impressed by the approach of the WebLab project<sup>4</sup> where children are being encouraged by the design of the WebLab portal to share their projects, written in ToonTalk (Kahn 1996), with other, usually remote, children. Such sharing involves posting a project onto the website, commenting directly on other people's projects, running projects directly on the web, and downloading them to allow re-programming in ToonTalk. The Weblab project seems an important step forward in thinking about e-learning platform design, even if the download before programming style involves a certain degree of discontinuity in the constructionist process.

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<sup>4</sup> WebLabs is creating new ways of representing mathematical and scientific knowledge of young learners through collaboration, construction and interpretation of how things work. For more information, see the WebLabs project website: <http://www.weblabs.eu.com/>

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