Teaching to design educational technologies

Yael Kali*

Technologies in Education Graduate Department,
Faculty of Education, University of Haifa,
Mount Carmel, Haifa, 31905, Israel
E-mail: yael.kali@edtech.haifa.ac.il
*Corresponding author

Tamar Ronen-Fuhrmann

Department of Education in Technology and Science,
Technion – Israeli Institute of Technology,
Technion City, 32000, Israel
E-mail: tamarrf@gmail.com

Abstract: Finding ways to support novice educational technology designers is of high importance in many design fields. In this research we examined three courses in which graduate students learned to design technology-based curriculum modules. The courses were based on a teaching model developed in a design-based research methodology with four iterations. The model integrates the openness of a studio approach, with the structure of a well-known instructional systems-design process. It also takes advantage of experts' design knowledge embedded in a database of design principles. Qualitative data was used to evaluate the affordances and challenges of progressive versions of the teaching model. A generalised model for teaching educational technology design was derived, in which the following constructs are intertwined:

a structuring the design process
b building on accessible repositories of expert design knowledge
c enabling dialogic learning.

Keywords: design-based research; DBR; educational technology design.

Reference to this paper should be made as follows: Kali, Y. and Ronen-Fuhrmann, T. (2011) 'Teaching to design educational technologies', *Int. J. Learning Technology*, Vol. 6, No. 1, pp.4–23.

Biographical notes: Yael Kali is an Associate Professor of Educational Technology. Her research interests include technology enhanced learning in science, design principles for technology-based learning environments and web-based learning in higher education. She has lead the development and research around the design principles database. Her book, *Designing Coherent Science Education: Implications for Curriculum, Instruction, and Policy* (with Marcia Linn and Jo-Ellen Roseman, 2008) has gained excellent reviews. Before recently joining to the Haifa University, she has served for seven years as a faculty member at the Department of Education in Technology and Science at the Technion – Israel institute of Technology.

Tamar Ronen-Fuhrmann received her PhD in Technology and Science Education from the Technion – Israel Institute of Technology. Her prior background is BA in Biology and MSc in Biochemistry from the Hebrew University in Jerusalem. Previous to her PhD studies, she worked as a Game Designer, Interactive Designer and Instructional Designer, designing educational technologies and managing projects in the industry (IBM, EduSoft, and Tower Semiconductors). Her research interests include investigating how people learn to design educational technology, and how learning can be affected by educational technology tools designed to make the learning process more meaningful for students.

1 Introduction

Research from the past decades has shown that many opportunities to learn arise in the course of designing an artefact in general, and in designing an artefact intended for others to learn with, in particular (Papert, 1991). The potential of designing as a process that supports learning has been documented for a wide range of ages and levels of expertise. For instance, Harel (1991) explored the learning that takes place when fourth grade children develop mathematical software products for other students in their school. She showed that the young designers learned not only about mathematics (fractions) and programming (logo), but also about design and user interface. Kafai (2006) showed similar outcomes with fifth grade children who designed and developed computer games for their peers. She argues that: "The greatest learning benefit remains reserved for those engaged in the design process, the game designers, and not those at the receiving end, the game players" (p.39). The impact of engaging students in design processes on their learning was also found with middle school students; for instance, Kolodner et al. (2003) indicated that the learning by design approach significantly enhanced middle school students' motivation, their collaboration and metacognitive skills, and their scientific understanding in topics included in the products they developed (earth and life sciences).

In this research we explore the learning that occurs in a design process with a target audience that received only little attention in the learning by design literature, namely, graduate students in education. Studying the ways these students develop their skills in designing technology-based curriculum modules, and how they can be supported in developing these skills, should be of specific interest, in order to better understand how to promote these potential educators, curriculum-designers, learning-scientists, or policy makers.

1.1 Teaching educational technology design

The education design literature includes two main approaches for teaching design of educational technologies. The first approach, often taken by researchers from the learning sciences, is an open-ended reflective approach. In this approach, which some researchers compare to the architects' design studio (Hoadley and Kim, 2003), class-meetings are devoted to students' working on their design projects, providing feedback to their peers, and refining their design artefact based on peers' and instructor's input. The second approach, usually taken by researchers from the instructional systems design arena

(Willis and Wright, 2000), support the design process in a much more structured manner, such as the analyse, design develop, implement, evaluate (ADDIE) model (Dick et al., 2001). Recently, researchers have begun advocating for synthesising between these approaches (Barab, 2004; Hoadley and Cox, 2009; Smith, 2004). The current study follows this call, and provides students with both the structure of the ADDIE model, and the openness of the reflective practitioner studio approach. In addition, the teaching model developed in this research takes advantage of a web-based resource – the design principles database (DPD). The DPD is a mechanism to support researchers and technology-based curriculum designers share and connect their design knowledge in the form of design-principles (Kali, 2006). The structure of the DPD consists of design principles in three hierarchical levels:

a ‘meta principles’, which describe general ideas of socio-constructivist pedagogy

b ‘pragmatic principles’, which provide recommendations for design solutions for a set of similar problems

c ‘specific design principles’, which convey designers’ rationales for developing particular technology-based features, and serve as examples for the employment of pragmatic principles.

1.2 Research goal

The goal of this research was to explore ways to support graduate students in education (whom we often refer to as novice designers) to design educational technologies. By examining the learning processes of these students in courses that were based on the teaching model developed in this study, and by documenting the challenges that they encountered, and achievements they reached in successive versions of these courses, we were able to build a generalised pedagogical model for teaching educational technology design.

2 The teaching model and the design courses

Our study focuses on three semester long courses, designed and taught by the authors of this paper, in which graduate students in education learned to design educational technology modules. The three courses are all based on one teaching model, which evolved in an iterative process in this study, and was integrated in different manners in each of the courses according to specific goals and constraints of the course. We commence this section by presenting the final version of the teaching model. Then we describe the three courses and explain the rationale for developing each one.

2.1 The teaching model

The final version of the instruction model (Figure 1) includes three main elements, which emerged from the current research, and reflect a unique application and integration of the three frameworks reviewed in the introduction:

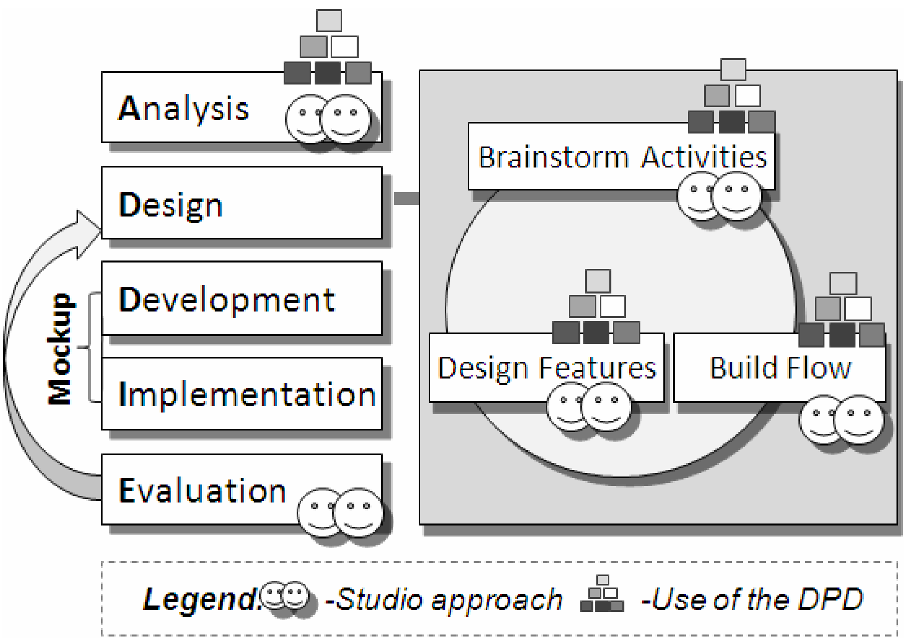
a the ADDIE structure

b the studio approach to instruction

c the use of the DPD.

As we further explain below, the three elements are integrated in an inseparable manner, so that all activities in the model apply to all three. We would also like to note that although the combination of these elements is unique to this study, we view this integration as one possible application of a more generalised model.

Figure 1 The teaching model: application and integration of the ADDIE structure, the studio approach and the use of the DPD



2.1.1 How we used the ADDIE structure

We embraced the five ADDIE stages and expanded the design stage, to include three other non-linear iterative stages: *brainstorm activities*, *build flow*, and *design features* (Figure 1).

- *Analysis stage:* Students select a topic for their module. They first bring up topics which according to their experience and knowledge involve instructional challenges. Then they conduct a needs-analysis; they analyse the instructional challenge using relevant literature, and search for curricular solutions that might have already been developed to cope with similar challenges. Finally, they conduct a content-analysis of the topic; they map the contents and the relations between them, and decide which to focus on in their module.
- *Design stage:* Students start by brainstorming ideas for activities that can help learners[1] gain the skills and knowledge required for understanding the topic of the module they are designing. Then they build a flow of activities, or several possible scenarios for learners to follow in their module. Finally, they design features for each

activity, showing in detail how each activity would be viewed by a learner, including a screen layout, interactive elements, and instructions.

- *Development and implementation stages (mockup):* Depending on the course's goals, this stage is either implemented as an actual development and implementation process, or as a mockup of the module. In the first case, students use authoring environments such as the web-based science inquiry environment (WISE) (Slotta and Linn, 2009), or a learning content management system, such as Moodle, to develop a portion of the module they designed in the *design* stage. In the second case, students design a detailed mockup of their module using tools such as PowerPoint.
- *Evaluation stage and second design cycle:* Students present their modules in class and provide extensive feedback to each other. Based on this feedback they conduct a second design cycle (represented by the arrow pointing at *design* in Figure 1), which culminates in a final presentation and evaluation in class. Students who enact their technologies with learners also conduct observations and interviews of the ways learners interact with the module, and use this data to evaluate their design.

2.1.2 How we used the DPD

To enable students to benefit from the expert design knowledge embedded in the DPD, we decided to integrate the use of the DPD as part of the teaching model. As can be seen in Figure 1, students use the DPD in four stages of the design process. In the *analysis* stage, when they are required to search for solutions that have already been developed for an instructional challenge similar to the one they have chosen, they start with reviewing features of technologies documented in the DPD.

In the *brainstorm activities* stage, students use the four meta-principles to elicit ideas for activities that employ a socio-constructivist view of learning. For example, the contents of the meta-principle *make contents accessible* might assist students to design activities that build on learners' previous knowledge, connect to their experiences, and actively engage them in complex and interesting activities related to their everyday lives.

In the *build flow* stage, students use the *design patterns* section of the DPD to put their activities together in a sequence that would be beneficial for learners. Finally, in the *design features* stage, students use the pragmatic design principles section of the DPD to decide how to design features for the activities in their module. They search for a design principle in the DPD that reflects a rationale similar to their own for designing the activity, they read the contents of the design principle, review other features in the DPD that are connected to this design principle, and use this information to enrich their ideas for designing their own features.

2.1.3 How we applied the studio approach

An emerging need that came up since the first enactment of the course was to provide students with many opportunities to present and discuss their design artefacts with us, as mentors, and with their peers, at all stages of the design process. To respond to this need we decided to conduct the course using a studio approach (Schon, 1983; Hoadley and Cox, 2009), and to integrate the dialogic nature of this approach into the teaching model. Figure 1 shows that the studio approach was implemented in all stages in the model.

Figure 2 Example of the design principle 'enable manipulation of factors in models in simulation' in the DPD (see online version for colours)

2.1.4 Application of the three course elements as one integrated model

The three elements of the model: the ADDIE structure, the usage of the DPD and the application of the Studio Approach were implemented as one integrated model. For instance, in the *build-flow* stage (Figure 1), all students worked in groups on a particular (extended) ADDIE stage. To receive guidance for this stage they used design patterns in the DPD, and were mentored in a studio approach, as described above.

2.2 The three design courses

As mentioned above, the teaching model was the core element in three design courses. The courses were:

a *curriculum development of computer-based modules* course (which we refer to as the *curriculum development* course)

b *designing educational technologies* course

c *multi-institutional designing educational technologies* course.

For each of the courses we developed interactive websites, which enabled students to share their in-progress design artefacts, interact with each other and view instructions for tasks and activities.

2.2.1 The 'curriculum development' course

This course was the first one we developed. Its first enactment was the impetus for developing the teaching model described above and the additional design courses. The course is intended for graduate students in a non-thesis master's degree programme in science education in a science and technology oriented university. A requirement in the non-thesis programme is that students individually develop a curriculum unit, guided by an instructor.

Students in the *curriculum development* course develop a computer-based module, enact some of the activities (about four hours) with a few school students, and report on their observations in a written assay. The meetings in the first enactment of this course did not have a pre-defined structure; students presented their progress and their emerging challenges, while the other students and mentors provided feedback. To better support students in the process of designing and developing their modules, we refined this course, and additional enactments were already based on the teaching model.

2.2.2 The 'designing educational technologies' course

Based on findings from the first iteration of the *curriculum development* course, we decided to construct a new course, focusing on design. The *designing educational technologies* course is intended for graduate students in science education at the same institution mentioned above. In this course, instead of *developing* their web-based modules, students work in groups of two to three students to *design a mockup* of their final artefact.

The course includes three main themes: one theme is the *design studio* in which students design their own module using the teaching model described above. The other two themes are:

a *technology analysis*, in which students interact with a technology, analyse it, discuss relevant research papers, and have phone interview with the designer

b *theory*, in which students review and discuss educational technology design literature.

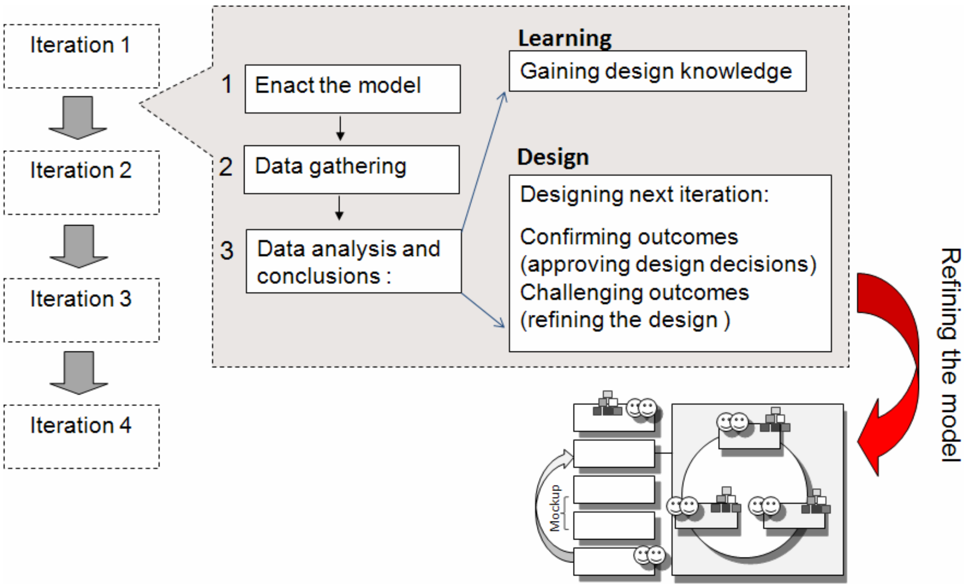
2.2.3 The multi-institutional 'designing educational technologies' course

Following the success of the *designing educational technologies* course, we were invited to implement it as one of the courses provided to students from four universities in a centre for learning and teaching with a technology-enhanced learning orientation. Each university held face-to-face meetings with local instructors. The student teams in the *design studio* theme were uni-institutional. All other activities, such as analysing technologies, discussing the literature in online forums, or providing written feedback on students' artefacts, were multi-institutional.

3 Methodology

This study was conducted in a design-based research methodology, in which learning is explored through lenses of design. Design-based research is iterative; each iteration involves enactment, data gathering, analysis and refinements aimed at improving the learning materials. The analysis of the ways learners interact with a designed artefact enables the researcher to draw hypotheses about learning in a specific context, and to refine the artefact in a way that would enable examination of these hypotheses in a set of successive iterations (Barab and Squire, 2004; Collins et al., 2004; diSessa and Cobb, 2004).

Figure 3 Refining the teaching model in a design-based research approach (see online version for colours)



The teaching model in the current study was developed in four iterations. An iteration was defined as an enactment of one or more of the courses, in which a major change was made in the teaching model. For each iteration we characterised student learning processes. We focused our analysis on challenges students were faced with while designing their computer-based modules. For each 'challenging outcome', we made a design decision for refining the teaching model, which was enacted in the next iteration. Then, in the following iteration, we examined the effect of the refinements on students' learning, and sought for 'confirming outcomes' and for additional challenges. In this manner we were able to carefully examine students' learning processes as they gained design knowledge on one hand, and to improve our teaching model on the other (Figure 3).

3.1 Research participants

A total of 67 students studied in the three courses in all the iterations between the years 2004 to 2007 (Table 1). Forty-nine of the students worked in groups of two to three students (a total of 21 groups), and the rest (18) worked as individuals. Altogether 39 modules were designed. The participants had a good background in theory regarding learning and instruction. Most students also had some practical experience in teaching or were active science teachers. For all students, this course was the first educational technology design course. The modules they chose to design were typically in science, math and computer science topics (21% life sciences, 18% earth and astronomical sciences, 16% computer science, 13% math, 12% physics, 10% teacher professional development modules, and 10% others).

Table 1 Iterations and sample

Iteration	*Courses*	*# of students and groups*
I (spring 2004)	Curriculum development	4 (*individual work*)
II (spring 2005)	Curriculum development	5 (*individual work*)
	Designing educational technologies	11 (4 *groups*)
III (spring 2006)	Curriculum development	5 (1 *group* and 3 *individuals*)
	Designing educational technologies	15 (5 *groups* and 4 *individuals*)
	Designing educational technologies (multi-institutional)	8 (3 *groups* and 1 *individuals*)
IV (spring 2007)	Curriculum development	5 (2 *groups* and 1 *individual*)
	Designing educational technologies	14 (6 *groups*)
Total		67 students (39 projects)

3.2 Data sources

In order to characterise student learning in each of the iterations the following data sources were used to collect data (Table 2):

Table 2 Data sources

Data source	*Description*
Likert type surveys	At the end of each enactment students were asked to evaluate various elements of the course (such as the structuring of the design process, working with peers, using the DPD etc.) on a 1 to 5 scale. The survey included 20 questions and required about ten minutes for completion.
Reflective essay	At the end of each enactment students were required to write a reflective assay about their design process.
Semi-structured interviews	At the end of each enactment we conducted interviews with two students (total of 16 students) who were asked to reflect about their design process.
Records of online discussions	Whole class online discussions about the literature and group online discussions regarding the design of the group's module were automatically recorded at the courses' website.
Student artefacts	During the semester we collected documents produced at various stages of the *design studio*. These documents included formal design artefacts students were required to write, as well as informal notes and sketches students created to discuss their ideas with peers and with us.
Reflective journal	Following each class meeting we documented events related to each of the groups' progress, the discussions we had with students, or other events that seemed relevant for analysing each group's learning processes. To increase the reliability, for about 25% of the class meetings both authors documented the events individually. About 80% of the sum of events recorded by both authors referred to similar events. Our interpretations were usually pretty similar, with some different nuances, which helped to enrich the understanding of things that occurred in class. In cases where we had different interpretations we looked for additional evidences, and finally reached agreement. The remaining 20% of the sum of events were documentations of occurrences that only one of us was aware of, due to the fact that as mentors, each of us had different discussions with the students. These were combined into a merged record in the reflective journal.

3.3 Data analysis

3.3.1 Making design decisions

In order to make design decisions regarding which features of the teaching model (Figure 1) require refinements that would better support student learning, for each iteration, all data sources (Table 1) were reviewed and analysed in the following stages:

a identification of outstanding events and interesting behaviours – we began by reviewing the reflective journal, in which we documented events in the learning process

b triangulation of events – at this stage we sought additional evidence from all the other data sources to corroborate our interpretations from stage a

c recognition of phenomena – we sought commonalities in events between students, and if found, we defined them as phenomena.

d taking a stance – for each of the phenomena recognised in stage c, we decided whether it was a favourable phenomena, which we wanted to continue supporting, or whether it was unfavourable, and required refinement to the teaching model

e making design decisions – following the previous stages, we made design decisions, which included refinements to the teaching model (when change was necessary) for each of the phenomena

f evaluating the refinements – to evaluate the refinements, stages a, b, c, d and e were conducted for the next iteration.

4 Outcomes

In this section we describe challenging and confirming outcomes that were drawn from each of the four iterations. A summary of these challenges and the design decisions we made to respond to them is provided in Table 3.

Table 3 Summary of challenges and design decisions

	#	*Challenging outcomes*	*Design decisions*	*General description*
Iteration I	1	Difficulties due to the open-ended nature of task	Structure the design process	This iteration occurred only in the curriculum development course. To fulfil institutional requirements, the course was initially conducted as a one-on-one project, in which individual students were guided by us, the instructors, through occasional non-structured meetings. Due to requests from the students (N = 4) in the first enactment of the course, this was changed during the enactment, to include class meetings every other week. The meetings at this stage did not have a pre-defined structure; students presented their progress and their emerging challenges, while the other students and mentors (us) provided feedback.
	2	Unawareness to rationale	Use the DPD to emphasise awareness to rationale	
	3	Limited intuition	Enrich students' intuition by integrating the teaching model in a design course	
	4	Dependency on guidance	Employ a cognitive apprenticeship model	
	5	Peer learning needed strengthening	Add collaborative aspects to the model	
Iteration II	6	Tendency to build flow according to content hierarchy	Add a content analysis stage early in the design process	This iteration occurred in the curriculum development course and the designing educational technologies course. The teaching model included the ADDIE structure and the use of the DPD. It was embedded in a design course, a cognitive apprenticeship model was employed, and collaborative aspects were added. In this iteration we still did not employ a content analysis at an early stage of the design process. There was only one design cycle.
	7	Frustration from inability to implement feedback	Add a second design cycle	

Table 3 Summary of challenges and design decisions (continued)

	#	*Challenging outcomes*	*Design decisions*	*General description*
Iteration III	8	Limited online peer assessment	Add face-to-face dialogic critique between groups	This iteration occurred in all three courses. The teaching model was implemented as in Iteration II except that now a content analysis stage was employed early in the design process, and a second design cycle was added. Students still worked with two online learning environments: the Moodle (in which all instructions and online interaction took place) and the DPD (in which students searched the repository of expert design knowledge)
	9	Confusion due to dual infrastructures	Embed the entire teaching model into the DPD	
Iteration IV		None	None	This iteration occurred in the curriculum development course and the designing educational technologies course. The final version of the model was enacted, in which all design decisions from former iterations were implemented.

4.1 Iteration I

The first iteration of the teaching model took place in the *curriculum development* course, with four students, who were originally required to work individually on their projects, with occasional non-structured meetings. This was changed during the course to respond to students' requests.

4.1.1 Challenging outcomes

Following are outcomes regarding challenges that came up in Iteration I, which led to design decisions that eventually brought us to develop the preliminary version of the teaching model.

1 *Difficulties due to the open-ended nature of task:* At the beginning of the semester, the four students who participated in the first iteration, expressed much frustration from the open-ended nature of the task; they felt that they did not know where to start such a big task of designing their own educational technology. To respond to their needs, we decided to change the way the course was conducted. Instead of having students cope with the task individually, and in their own pace, we decided to set bi-weekly meetings. We defined tasks for each meeting and provided guidelines for the whole design process. As these scaffolds were provided, tensions dramatically decreased. For example one student said in an interview: "Initially, I really didn't know how to begin thinking about the project… but after each stage, things became clearer. It was like another piece of the puzzle was exposed at each stage…" Based on such evidences, we made a design decision to build a structured design process for the next iteration, which would guide the whole design process. This was the reason we decided to adopt the ADDIE framework stages as a structure for the teaching model (Figure 1).

2 *Unawareness to rationale:* Documentation in our reflective journal about the way students worked while designing their modules showed that their design decisions relied, to a large extent, on their intuition. Students hardly mentioned the rationale behind these decisions. They tended to design features that they thought were 'cool' to have, but when asked, they were often unsure about the pedagogical reasoning for designing them. This was the reason we made the design decision to use the DPD as part of the design process. Our intention was to increase students' awareness to the rationale behind features they develop in their educational technologies.

3 *Limited intuition:* As described above, students relied mainly on their intuition for designing their educational technologies. We also found that this intuition was based on limited experience and knowledge. Similar to other educational technology design courses (e.g., Hoadley and Cox, 2009), our design decision was to enrich students' intuition by integrating the teaching model in a design course that would include, in addition to the *design studio* theme, two more themes; one that would focus on the educational technology literature, and another that would engage students in analysing state-of-the-art technologies. This was the reason for the decision to develop the *designing educational technologies* course with the three themes described above.

4 *Dependency on guidance*. The interviews with the four students in this iteration showed that they depended heavily on the guidance and coaching of the instructors. For example, one student says: "I had a collection of unorganized ideas … discussions with the instructors during the meetings helped me connect these ideas to some pedagogical principles". This finding echoes other studies in design education, which show the critical role of the instructor in design courses in various design topics such as in architecture (Goldschmidt, 2002; Schon, 1983). To enable students to take advantage of our guidance, but also enable them become independent, we made a design decision to adopt the three phases of a cognitive apprenticeship model: modelling, coaching, and fading away (Collins et al., 1989).

5 *Peer learning needed strengthening:* The reflective essays indicated that students greatly valued, and took advantage of peer feedback and dialogue, but many students felt that they could benefit from more opportunities to present and discuss their work-in-progress with peers. To respond to this need, and the need for guidance described above we decided to embrace Schon's (1983) reflective practitioner approach, and to conduct the main part of the course as a design studio, with a special emphasis on peer feedback. This was the reason for the decision to embed the studio's dialogic approach as an integral part of the teaching model (Figure 1).

4.2 Iteration II

4.2.1 Confirming outcomes

Outcomes from this iteration, indicated that structuring the design process (design decision #1), assisted students to cope with the complexity of this task both in the *curriculum development* and in the *designing educational technologies* courses; no significant differences were found between the two courses with regards to survey results, which showed that students highly evaluated the structured design process (mean score of 4.4 of 5.0). This was also evident from interviews and the reflective essays. For instance, one student wrote: "No doubt that without the structuring we wouldn't have been able to reach the product that we've designed. Working in stages enabled us to refine our design all the time, each time looking at it with a different focus".

The decision to use the DPD to emphasise students' awareness to their rationales in designing features (design decision #2), was confirmed by analysing their artefacts and their reflective assays. The analysis showed that students made more rationale-based decisions in the second iteration. One example is a group of students who designed a module to assist elementary school learners in gaining intuitive understanding of motion problems. Their use of the DPD encouraged them to reflect on their rationale for designing their time-speed-distance animation, and decide to change it to a simulation.

The decision to enrich students' intuition by integrating the teaching model in a design course (design decision #3) was verified by the survey results. These results indicated that students viewed the following aspects as important contributions to their learning: *analysing state-of-the-art technologies* (4.4 of 5.0); and *reading and discussion educational technology literature* (4.3 of 5.0). This was also supported by students' remarks in the final class meeting, as documented in our reflective journal. For instance, a student says "my intuition for designing educational technologies was raised in an order of magnitude".

There were many evidences from the reflective essays indicating that the cognitive apprenticeship approach (design decision #4) was productive in supporting students to become more independent as designers. For instance, a student says "At the beginning of the course it was really helpful to have someone point at things in my project that could be improved. Towards the end of the course I didn't need that anymore". The decision to add collaborative aspects to the model (design decision #5), contributed to student learning as well; survey results show that students found it very helpful to work in teams on the design project (4.7 of 5.0), and also appreciated the peer-feedback (4.2 of 5.0).

4.2.2 Challenging outcomes

In spite of the confirming outcomes in this iteration, some new challenging outcomes emerged:

1 *Tendency to build flow according to content hierarchy:* At the *build flow* stage, students were mainly concerned with what learners should know at each stage of the flow, and less concerned with how to make this flow engaging for the learners. Reeves (1994) describes such an approach as leaning on an objectivist epistemology: "If the designers and users of CBE (computer-based education)[2] lean toward an objectivist epistemology, they will be primarily concerned with assuring that the content of the CBE they create and implement is comprehensive and accurate with respect to ultimate 'truth' as they know it. They will seek to establish the definitive structure of knowledge for a given domain based upon the advice of the most widely accepted experts in a field" (p.223). For instance, one of the groups designed a technology about the phases of the moon. They designed a computerised three-dimensional model showing the moon orbiting around the earth to assist learners develop the spatial perception required for understanding the phenomenon. At the beginning of the semester they designed numerous stages which included prerequisite information that users had to go through before they interact with the model. The interaction with their module included mainly abstract tasks. Following

feedback from peers, who claimed that the initial stages and the abstract tasks might weary the users, they decided to completely reorganise the flow of activities in order to make it more appealing to users (Ronen-Fuhrmann et al., 2008). This finding strengthens the notion made by DiGiano et al. (2009) claiming that getting student designers to give balanced consideration to providing both educational value and user engagement is a common challenge faced in educational technology design courses. In order to free our students from being constrained by the structure of contents, we made a design decision to include a content analysis task in the *analysis* stage, which previously focused only on a needs analysis. We assumed that if students would figure out the structure of the contents early in the design process as an important part of the design process, they would be able to focus on building engaging flows of activities at the *build flow* stage.

2 *Frustration from inability to implement feedback:* The last two meetings of the courses in this iteration were devoted to presentations of students' projects, with extensive discussions and feedback after each presentation. However, due to a preliminary design decision we made, to enable students enough time to work on one design cycle on the expense of a second design cycle, students did not have a chance to employ this feedback. In interviews, students expressed their frustration about this. This was the reason we decided to include, in spite of the one-semester limit of this course, a second cycle in the design process.

4.3 Iteration III

In this iteration too, we found evidences that confirmed our design decisions, and yet again illuminated new challenges.

4.3.1 Confirming outcomes

Adding the content analysis stage (design decision #6) indeed assisted students to focus on building engaging flows of activities. This was evident from both the multi-institutional course, and the *development course*. When students were required to develop their flow of activities, it was already after mapping the contents they planned to cover. As a result, they were focused much more than students in Iteration II on building engaging activities. For example, one group developed a module named *How can micro-organisms help us?* Earlier, the students created a very detailed mapping of the contents. When they came later on to develop the flow of activities, they designed an activity in which learners are provided with an article about a scientist who is developing a new genetically-based vaccine. The learners were supposed to play the role of another scientist who critiques her colleague. To base their critique on the science, learners were provided with guiding questions and with 'just in time' content knowledge.

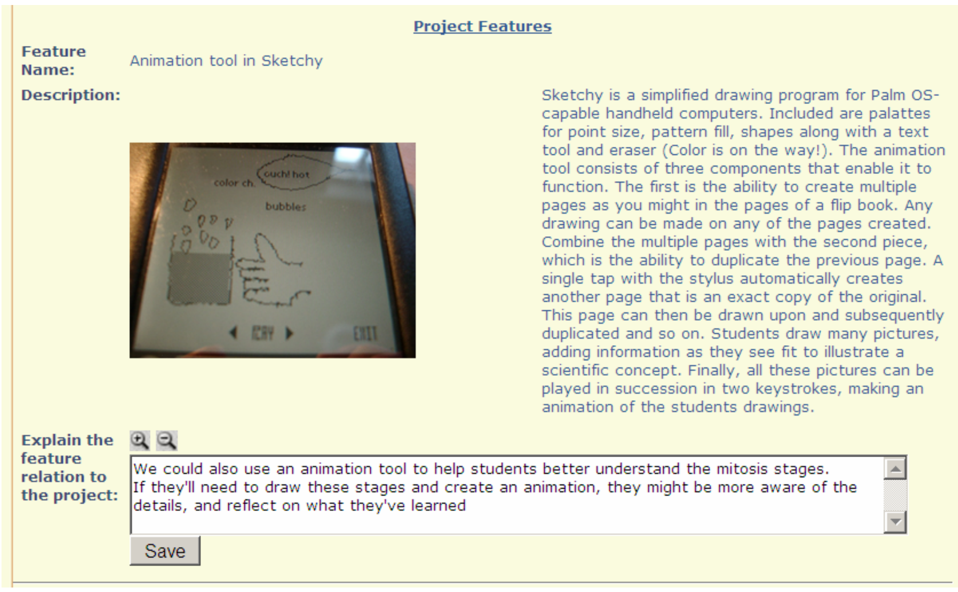
Design decision #7, i.e., to add a second design cycle, also proved to support the design process; the quality of the projects in the second design cycle notably improved (Ronen-Fuhrmann and Kali, 2010).

4.3.2 Challenging outcomes

1 *Limited online-peer-assessment:* The analysis of the assessments that students provided to each other showed that students found it difficult to understand their

peers' design ideas by reviewing written and visually represented documentation. This outcome was also supported by the survey; relatively low attitudes (3.9 of 5.0) were attributed to *online peer review*. This was the reason we decided to devote the first thirty minutes of each class meeting for each group to present their work to another group they were coupled with, and provide feedback to each other. We also decided to support the online peer review with better tools, integrated into the work environment. For instance, we developed a feature that enabled students to add 'notes' to textual and visual online descriptions of their peers' projects, as part of the review process.

Figure 4 The design mode of the DPD: example showing how students adopt design ideas from the DPD (the animation tool) to their projects (text at bottom explaining how such an animation tool would assist in a genetics module) (see online version for colours)



2 *Confusion due to dual infrastructures:* Students in Iterations II and III were required to use two different infrastructures:

a the course website (Moodle), which included the course plan, assignments, and all the online communication

b the DPD.

Documentation in our reflective journal showed many instances in which students were confused about where to find information and post assignments. Their use of the information in the DPD was limited due to these confusions. Although we found that the use of the DPD was productive, some of the students devoted only little time to search for design principles that might have supported their design decisions. To make this knowledge more accessible, and increase its usability, we made a design decision to embed the entire teaching model into the DPD. A new section was added to the DPD, entitled *design mode*, which includes all the instructions that were refined through the former iterations, with links to appropriate sections of the DPD. In essence, what this meant was that students used only the DPD website (and not the Moodle). At the end of the semester they had a complete online design document in the DPD website, which was shared with the whole class. Figure 4 illustrates how the *design mode* prompts students to relate features (and associated design principles) from the DPD to their project, and to explain what design ideas they can use from these features in their projects. The features that students imported to their projects became part of their online design documents.

4.4 Iteration IV

4.4.1 Confirming outcomes

The decision to devote significant time for peer feedback at class meetings (design decision #8) proved as a most productive way for students to 'make their thinking visible'. Students noted that these feedback sessions were crucial for developing their design artefacts. Having to explain their ideas to others brought students to better articulate their design ideas and represent them in more detail. We also noted in our reflective journal many instances in which the feedback from peers enabled students to identify gaps between the ideas they wanted to convey, and the artefacts they developed, and seek to bridge these gaps.

The decision to embed the entire teaching model into the DPD (design decision #9) was also confirmed in this iteration. Although there were still some bugs in the system, students used the contents of the DPD much more than in earlier iterations to guide their design process. This was evident in students' design artefacts, which included more references to design principles and features from the DPD in Iteration IV (an average of about eight or nine references to different features and principles) than in Iterations III (about five references).

5 Discussion and conclusions

We view the capacity of the teaching model, developed in this study, to help students concretise their design ideas and gain design knowledge as resulting from a combination of its three main elements (the ADDIE process, the use of the DPD, and the design studio approach). It is important to note that we view these elements as specific implementations of three more generic ideas, which we believe are an essential set of constructs for guiding educational technology design:

a structuring the design process (as we implemented via the ADDIE structure)

b building on accessible repositories of expert design knowledge (implemented in the current study by the use of the DPD)

c enabling dialogic learning (implemented via the studio approach).

Structuring the design process, a common recommendation for teaching design courses (e.g., Dick et al., 2001), was vital in getting students to concretise their ideas (Ronen-Fuhrmann and Kali, 2010). The ADDIE stages of the design process required students to follow a step-by-step procedure in which each time, more concrete artefacts were required. However, concretisation of design ideas is not enough for designing sound learning environments in general, and technology-based modules in particular. Without leaning on expert design knowledge that has accumulated in the past decades of research, novice designers can easily fall into designing what Brown (1992) entitled as 'lethal mutations' – curriculum materials that are lacking sound pedagogical rationales.

The connection to experts' design knowledge was accomplished in this research via the DPD. This repository of design knowledge enabled students to get acquainted with design ideas and the rationales behind them, as well as with experts' clustering of these ideas into design principles at different hierarchical levels. Thus, we see the main role of the *structuring the design process* (the first construct of the generalised model) in assisting students to concretise their design ideas, and the main role of *building on accessible repositories of expert design knowledge* (second construct), in enriching, and relating these ideas to experts' design knowledge. It is important to note that we view these two processes as inseparable; concretisation of design ideas was crucial in students' ability to relate their ideas to experts' design knowledge. Only when students translated their design ideas into concrete design artefacts they were able to become aware to these relations, and to identify, and reconcile gaps between their ideas and the experts' knowledge.

The process of concretisation of design ideas, and identification and reconciliation of gaps with experts' design knowledge were greatly supported by the studio approach. *Enabling dialogic learning* (third construct) requires students to constantly expose their ideas to critique by peers and instructors, as well as to their own reflection.

The strength of combining the three elements in the model can be exemplified by an excerpt from the reflective assay of a student who studied the course in the fourth iteration:

> "The four meta principles were one of the strongest tools in the course. They created a common language and helped focus the design on socio-constructivist pedagogies (*building on accessible repositories of expert design knowledge*). The course's website served as a great model for what we tried to build. We experienced a learning process in an environment that had a framework and structure, and at the same time great openness for every student to develop in her own knowledge domain, and implement her ideas (*structuring the design process*). But no doubt that the peer-feedback sessions and the ongoing discussions between the two of us during the course meetings were critical in leveraging our final project (*enabling dialogic learning*)."

Finally, we would like to stress that each of the elements of the model presented in this article has been shown in the literature to promote design processes in general, and designing educational technologies in particular. For instance: Willis and Wright (2000) indicate the importance of structuring the design process; Goodyear and Retalis (2010), note the added value of building on accessible repositories of expert design knowledge in the form of design patterns; and Mor and Winters (2008), describe how dialog between teachers can support their design of educational technologies. However, we believe that the combination of the three elements in the model described in the current study can provide a generic framework that builds on such evidences, and brings our knowledge about how to guide educational technology design one step further.

Acknowledgements

This article is based on work supported by the National Science Foundation under grant number ESI-0334199. Any opinions, findings, and conclusions or recommendations expressed are ours and do not necessarily reflect the views of the National Science Foundation.

References

Barab, S.A. (2004) 'Using design to advance learning theory, or using learning theory to advance design', *Educational Technology*, Vol. 44, No. 3, pp.16–19.

Barab, S.A. and Squire, K.D. (2004) 'Design-based research: putting our stake in the ground', *Journal of the Learning Sciences*, Vol. 13, No. 1, pp.1–14.

Brown, A. (1992) 'Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings', *The Journal of Learning Sciences*, Vol. 2, No. 2, pp.141–178.

Collins, A., Brown, J.S. and Newman, S.E. (1989) 'Cognitive apprenticeship: teaching the craft of reading, writing, and mathematics', in L.B. Resnick (Ed.): *Cognition and Instruction: Issues and Agendas*, pp.453–494, Lawrence Erlbaum Associates, Hillsdale, NJ.

Collins, A., Joseph, D. and Bielaczyc, K. (2004) 'Design research: theoretical and methodological issues', *Journal of the Learning Sciences*, Vol. 13, No. 1, pp.15–42.

Dick, W., Carey, L. and Carey, J.O. (2001) *The Systematic Design of Instruction*, 5th ed., Addison-Wesley Educational Publishers, New York.

DiGiano, C., Goldman, S. and Chorost, M. (2009) *Educating Learning Technology Designers: Guiding and Inspiring Creators of Innovative Educational Tools*, Routledge, N.Y.

diSessa, A.A. and Cobb, P. (2004) 'Ontological innovation and the role of theory in design experiments', *Journal of the Learning Sciences*, Vol. 13, No. 1, pp.77–103.

Goldschmidt, G. (2002) ''One-on-one': a pedagogic base for design instruction in the studio', in D. Durling and J. Shackleton (Eds.): *Proceedings of the Design Research Society International Conference*, pp.430–437, Brunel University, Stoke-on-Trent, Staffordshire University.

Goodyear, P. and Retalis, S. (2010) 'Learning, technology and design', in Goodyear, P. and Retalis, S. (Eds.): *Technology-enhanced Learning: Design Patterns and Pattern Languages*, Rotterdam, Sense Publishers.

Harel, I. (1991) *Children Designers: Interdisciplinary Constructions for Learning and Knowing Mathematics in a Computer-Rich School*, Ablex Publishing, Norwood, NJ.

Hoadley, C. and Cox, C. (2009) 'What is design knowledge and how do we teach it?', in C. DiGiano, S. Goldman and M. Chorost (Eds.): *Educating Learning Technology Designers: Guiding and Inspiring Creators of Innovative Educational Tools*, pp.19–35, Routledge, N.Y.

Hoadley, C. and Kim, D. (2003) 'Learning, design and technology: the creation of a design studio for educational innovation', in A.P.d. Reis and P. Isaías (Eds.): *Proceedings of the IADIS International Conference e-Society 2003*, pp.510–519, IADIS Press, Lisbon, Portugal.

Kafai, Y. (2006) 'Playing and making games for learning', *Games and Culture*, Vol. 1, No. 1, pp.36–40.

Kali, Y. (2006) 'Collaborative knowledge building using the design principles database', *International Journal of Computer Support for Collaborative Learning*, Vol. 1, No. 2, pp.187–201.

Kolodner, J.L., Crismond, D., Fasse, B., Gray, J., Holbrook, J. and Puntembakar, S. (2003) 'Putting a student-centred learning by design™ curriculum into practice: lessons learned', *Journal of the Learning Sciences*, Vol. 12, pp.495–548.

Mor, Y. and Winters, N. (2008) 'Participatory design in open education: a workshop model for developing a pattern language', *Journal of Interactive Media*, p.13.

Papert, S. (1991) 'Situating constructionism', in I. Harel and S. Papert (Eds.): *Constructionism*, pp.1–11, Ablex, Norwood, NJ.

Reeves, T.C. (1994) 'Evaluating what really matters in computer-based education', in D.K.M. Wild (Ed.): *Computer education: New Perspectives*, pp.219–246, MASTEC, Perth, Australia.

Ronen-Fuhrmann, T. and Kali, Y. (2010) 'The role of concretization in acquiring design knowledge', in K. Gomez., L. Lyons and J. Radinsky (Eds.): *Learning in the Disciplines: Proceedings of the 9th International Conference of the Learning Sciences* (ICLS 2010) – Vol. 1, pp.468–475, Full papers, International Society of the Learning Sciences, Chicago IL.

Ronen-Fuhrmann, T., Kali, Y. and Hoadley, C.M. (2008) 'Helping education students understand learning through designing', *Educational Technology*, Vol. 48, No. 2, pp.26–33.

Schon, D. (1983) *The Reflective Practitioner: How Professionals Think in Action*, Basic Books, New York.

Slotta, J. and Linn, M.C. (2009) *WISE Science: Web-based Inquiry in the Classroom*, Teachers College Press, N.Y.

Smith, B.K. (2004) 'Instructional systems and learning sciences: when universes collide', *Educational Technology*, Vol. 44, No. 3, pp.20–25.

Willis, J. and Wright, K.E. (2000) 'A general set of procedures for constructivist instructional design: the new R2D2 model', *Educational Technology*, Vol. 40, No. 2, pp.5–20.

Notes

1 In this article we use the term *students* to refer to the graduate students who designed the modules, and *learners* to refer to potential users of those modules.

2 Text within square brackets in this article indicates words added by authors to explain citations.