How to design educational technologies?
The development of an instructional-model

Abstract: The potential of design to support learning has been documented for a wide range of ages. In this research we explore the added value of engaging learners in a design process, with a target audience that received little attention in the learning-by-design literature, namely, graduate students in education. Our exploration of student learning is conducted as a design-based research study, with students who participated in national and international, multi-institutional design-courses. Findings indicate that by integrating approaches from the Learning Sciences and the Instructional Systems Design worlds, the instructional model developed in this study supported students to design pedagogically sound educational technologies. An “anchoring stage”, in which students shift from philosophical to practical design was found as a crucial stage in student learning. Interpreting the findings in terms of the novice-expert literature, we found that as we refined our instructional model, students were better supported in making expert-like design decisions.

Introduction

Research in the Learning Sciences and in the CSCL field has shown that many opportunities to learn arise in the course of designing an artifact, in general, and a computer-based artifact, in particular. Papert (1991), in his description of Constructionism claimed that a productive way to support learning is to engage learners in constructing a public artifact "whether a sand castle on the beach or a theory of the universe." The potential of design to support 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 designed 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 interfaces, as well as representational, pedagogical, and communicational issues. 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. After all, the game player is not partial to the discussions involved in developing valid instructional game ideas, designs and strategies. What finds its way into the final designs is only a substrate of those discussions." (p. 39). The impact of design on learning was also found with middle school students; for instance, Kolodner et al. (Kolodner et al., 2003) indicated that their Learning By Design approach significantly enhanced middle-school students’ motivation, their collaboration and metacognitive skills, and their scientific understanding in topics included in their designs (earth and life sciences).

Recently, the notion that those who design gain important insights about their own learning processes has been recognized and developed not only as an instructional strategy, but also as an approach for conducting research in education. Design-based research methodology (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004) has become a well accepted manner of conducting research, and a powerful methodology to investigate how learning takes place when supported by curricular innovations. In this research we explore the added value of engaging learners in a design process, with a target audience that received very little attention in the learning-by-design literature, namely, graduate students in education. Studying the way these students develop their skills in designing educational technologies, and how they can be supported in developing these skills, should be of specific interest to our community, in order to better understand how to promote these potential educators, curriculum-designers, learning-scientists, or policy makers.

The few studies that have begun examining how graduate students learn the art of designing educational technologies, usually follow one of two main approaches for supporting students’ learning processes. The first approach, usually 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 & Kim, 2003), class-meetings are devoted to students’ working on their design projects, providing feedback to their peers, and refining their design artifact based on peers’ and instructor’s input. In this manner, they play a role of a reflective practitioner (Schon, 1983). The second approach, usually taken by researchers from the Instructional Systems Design world, support the design process in a much more structured manner, namely the ADDIE (Analyze, Design Develop, Implement, Evaluate) model (Dick, Carey, & Carey, 2001). Recently, researchers have begun advocating for synthesizing between these approaches (Barab, 2004; Hoadley, 2004; Smith, 2004). This study follows this call, and provides students with both the structure of the ADDIE model, and the openness of the reflective practitioner studio approach.

Our exploration of student learning is conducted as a design-based research study, with students who participated in national (Israel) and international, multi-institutional design courses. By documenting the iterative process in which we designed an instructional-model for supporting graduate students’ learning to design educational technologies, we were able to achieve two research goals: a) to get an insight into the students' learning processes, and b) as find ways in which these processes can be supported. We interpret our findings in terms of the novice-expert literature (e.g., Clement, 1998).

Context

This research focuses on three design courses, in which graduate students in education learn how to design educational technologies (Table-1). The three courses are based on an instructional-model developed in this study, which advocates a socio-constructivist pedagogical approach, and uses a web-based resource - the Design Principles Database. The Design Principles Database (Kali, 2006; Kali & Linn, in press) was developed to capture, coalesce and synthesize design knowledge. The database (http://design-principles.org) is a mechanism to support researchers and curriculum designers to share their design knowledge in the form of design-principles, exemplified by descriptions of features from various learning environments.

At initial stages of this study, we taught the "Curriculum Development" course, which was the first iteration of the instructional-model (Tables-1 and 3). Students were required to individually develop their educational technologies in an open-ended reflective approach, mentored by us, the instructors. Emerging challenges students were faced with in this process were the impetus for developing the instructional-model, which continued to develop in an iterative process. This model serves as the core of the three design courses, and is integrated in different manners according to each of the courses' goals and constraints. In this section we present the final version of the model, and further on in this paper we describe how it evolved throughout the study.

As described in detail below, pretty early in this research it was clear that students need structuring to support them in designing their educational technologies. As described above, we decided to integrate instructional approaches from both the Learning Sciences and the Instructional Systems Design research communities. From the ISD world, we borrowed the ADDIE model. The learning sciences in general and particularly the Scaffolded Knowledge Integration framework (Linn, Davis, & Bell, 2004) served as the main resource for the contents in the Design Principles Database, which is used throughout the model. Our model for the design process includes the five ADDIE stages, in which we expand the Design stage, to include three other non-linear iterative stages: Brainstorm, Build-flow and Design-features. The Design Principles Database is used in four stages in this model. The three courses focused on the Analysis and Design stages of the model. The three other ADDIE stages, i.e., Development, Implementation and Evaluation were only partially enacted: rather than developing their designed technologies students developed a mockup; rather than implementation in the field students presented their mockups in class; and rather than field-based evaluation students conducted peer evaluation.

Table 1: The three courses involved in the study

Course Name	Description
Curriculum Development of Computer-based Learning Environments (Technion)	• Graduate students in a non-thesis master's degree • A requirement in program: to individually develop a curriculum unit. • Focus on design and development (no literature reading). • About 4-5 students a semester • Course format: about 7 group meetings.
Designing Educational Technologies (Technion)	• Graduate students (with thesis) at Technion. • Focus mainly on design (no development and implementation). • Students design a mockup as final artifact. The course includes three main themes: 1. *Technology analysis*: students interact with a technology and analyze it, and discuss relevant research papers. 2. *Design studio*-students design their own learning environment. 3. *Theory*- students review and discuss educational technology design literature.
Designing Educational Technologies (Mulit-institution International)	Similar to Technion course with the following exceptions: • Multi-institution international course (UCB, PSU, ASU, Technion) taught by 4 instructors. • Students developed projects in the Web-based Inquiry Science Environment (WISE). • Theory theme included more literature.

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 (Barab & Squire, 2004; Collins et al., 2004).

We developed the instructional-model through three iterations (Figure-1, Table-3). An iteration was defined as a major change in the instructional-model. We analyze the conclusions from this study through two types of lenses: the *Learning lens* where we looked at learning processes of students as they gain design knowledge, and the *Design lens* in which we looked at: i) outcomes confirming design decisions from previous iterations, and ii) challenging outcomes that led to refining the design of the instructional-model for next iteration (Figure-1).

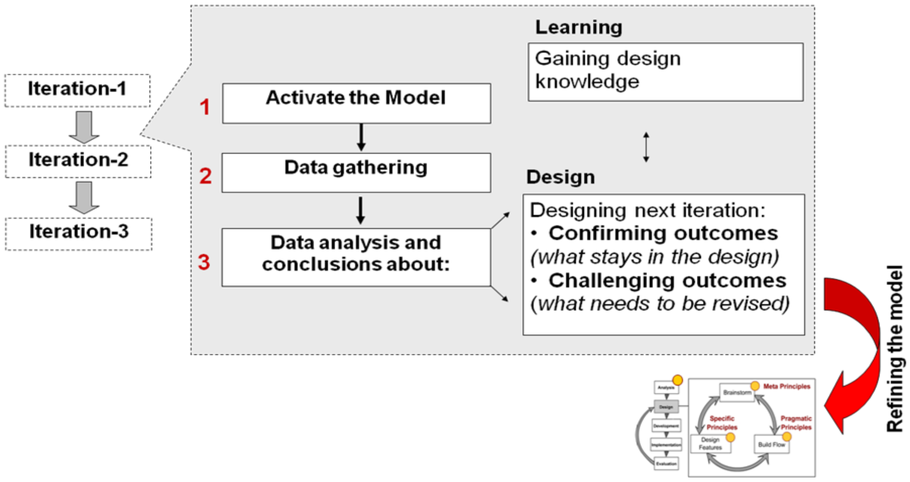

Figure 1. Refining the instructional-model in a design-based-research approach

Data sources and analysis

In order to characterize student learning, rich qualitative data was gathered throughout the semester in each of the course enactments (Table-2).

Table 2: Data source

Data source	Description
Lykert type surveys	Students were asked to evaluate various elements of the course (such as analyzing technologies, design studio, working with peers etc.).
Reflective assay	Administered at the end of each course. Students were required to write a reflective assay about their design process with specific reference to: design decisions; design stages and the use of the database.
Semi-structured interviews	Conducted with six students who were asked to reflect about their design process.
Records of online discussions	Whole class online discussions about the literature, Group online discussions about the design studio and analyzing technologies projects.
Student artifacts	Documents produced at various stages of the design studio in which students designed their own educational technologies. These artifacts were analyzed using a rubric for characterizing the degree to which educational technologies are based on a socio-constructivst approach (Ronen-Fuhrmann, Kali, & Hoadley, in press) The rubric includes four dimensions: *Learner activity*, *Collaboration*, *Autonomy*, and *Content accessibility*.
Reflective journal	Documentation of important events in each of the class meetings.

Sample

The sample included a total of 48 students who participated in the three courses and in the three iterations (Table-3). About half of the students (20) participated in the multi-institution, international course. Although there was a large heterogeneity between the students, they were all students who were accepted to graduate schools of prestigious universities.

Outcomes

In this part we describe the main outcomes that were drawn from the three iteration described above. We specified two types of outcomes: (a) challenging outcomes which led to design decisions for refining the instructional model, and (b) confirming outcomes which reinforced design decision from previous iterations. A summary of all challenges and design decisions is provided in Table 4.

Table 3: Iterations and sample

Iteration	Description	Sample	Date
1	This iteration was enacted in the course "Curriculum development of computer based learning environments". It was taught to 4 graduate students at the Technion. The course was originally supposed to take place as an individually guided project, but due to requests from the students was changed during the semester to include meetings every other week. The meetings did not have any pre-defined structure.	*4*	Fall 2005
2	The second iteration used a preliminary version of the instructional model developed based on iteration 1 (see outcomes). Two courses were enacted using this version of the model: "Curriculum development of computer based learning environments" (taught for the second time) with 5 students, and "Designing educational technologies", which was taught for the first time to 14 graduated students at the Technion.	*19 (14+5)*	Spring 2005
3	The revised instructional model was used in the third iteration as the core of two courses: 1. the multi-institutional course "Designing educational technologies". And, 2. : "Curriculum development of computer based learning environments" (taught the third time) with 5 students.	*25 (20+5)*	Fall 2006
Total		*48*	

Iteration-1

Challenging outcomes

Following are outcomes about challenges that came up in iteration 1, which led to design decisions that eventually brought us to develop the preliminary version of the instructional-model.

1. *Difficulties due to the open-ended nature of task* – The four students who participated in the first iteration, which was supposed to take place as an individually guided project, expressed much frustration from the open-ended nature of the task; they felt that they did not know where to start and asked to have meetings to think together about how to approach the task. To respond to their needs, 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". Therefore, the design decision that was made for the next iteration was to build a structured design process, which would guide the whole design process, inspired from two fields, the Instructional Systems Design and the Learning Sciences, as mentioned above.
2. *Unawareness to rational*e – Documentation in our reflective journal about students while working on their projects showed that their design decisions relied, to a large extent, on their intuition. Students hardly mentioned the rationale behind these decisions. This was when we made the design decision to use the Design Principles Database as part of the design process, in order to increase students' awareness to the rationale behind their design.
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. For example, one student said in an interview: "In the past, when I designed learning materials I learned while doing… I'll be happy to get skills and tools that'll help me learn from research". Our design decision was to enrich students' intuition by integrating the instructional-model in a design course that would include, in addition to the "design studio" theme, two more themes; one that would focus on educational technologies literature, and another that would engage students in analyzing state-of-the-art technologies.
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 of the students says: "I had a collection of unorganized ideas … discussions with the instructors during the meetings helped me connect these ideas to some pedagogical principles". To enable students to take advantage of our guidance, but also enable them become independent, we made a design decision to employ a cognitive apprenticeship model, which includes modeling, coaching, and fading away phases (Collins et al.,1989) for the instruction of the whole course.
5. *Peer learning needed strengthening* - the reflective questionnaire outcomes indicated that students greatly valued, and took advantage of peer feedback and dialog, but thought there was not enough of that. We therefore made a design decision strengthen peer learning by including peer feedback in several stages of the instructional-model. We also decided to define the main project of the course, i.e. designing the educational technology, as a collaborative project.

Iteration-2

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). 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. It also enabled us to go back and forth between looking at the big picture – things we want our learners to eventually learn, and the little details – how a specific feature can be designed to support local goals".

The decision to use the Design Principles Database to emphasize awareness to rationale (design decision #2), was confirmed by analyzing students' artifacts and reflections. The results show that students made more rationale-based decisions. For instance, one group developed a learning environment intended to assist middle school students understand how to solve motion problems. One of the features they designed at the beginning of the semester was a feature in which learners view an animation of a motion problem to assist them in solving the problem. When the students who designed this feature were required to search for design principles in the Design Principles Database which can support this decision, they found the design principle "Enable manipulation of factors in models and simulation". They read the rationale of this feature, reviewed some examples that employ this principle, and decided to change their animation to a simulation, to make their learners more active and to better support their learning processes. In the reflective assay, one of the students says: "The Design Principles Database helped us see the pedagogical reasoning behind some of the decisions we had intuitively made. It also made us think again about what we are really looking for in the features we design and to refine them accordingly".

The decision to enrich students' intuition by integrating the instructional-model in a design course (design decision #3) was verified by survey results. Outcomes indicated that students viewed the following aspects as an important contribution to their learning: Analyzing state-of-the-art technologies (4.4 of 5); and Reading and discussion educational technology literature (4.3 of 5). 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". We also found evidence that the cognitive apprenticeship approach (design decision #4) was productive in supporting student learning, as indicated in many open-ended comments that students wrote in the survey, in which they stress the importance of our guidance. 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 helpful to work in teams on the design project (4.7 of 5), and also appreciated the peer-feedback added to the model (4.2 of 5).

Challenging outcomes

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

6. *Tendency to build flow according to content hierarchy-* 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 objectivist: "If the designers and users of CBE [Computer Based Education] 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 moon-phases. They designed a computerized 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 (e.g., information about the moon being a reflector and not a source of light). The interaction with the model included mainly problem solving (e.g. questions such as "what would the moon look like at a certain configuration of the system?"). Following feedback from peers and instructors, who claimed that the initial stages and the problem solving might weary the users, they decided to completely reorganize the flow of activities in order to make it more appealing to users (Ronen-Fuhrmann et al., in press). In order to free 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 on a needs analysis. We assumed that if students would figure out the structure of the contents early in the project, they would be able to focus on building engaging flows of activities at the "Build flow" stage.
7. *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, students did not have a chance to employ this feedback. In interviews, students expressed their frustration about this. Thus, we made a design decision to include, in addition to the peer-review stages within the instructional-model, a second cycle in the design process.

8. *Gap between theoretical and applied epistemologies* – At the beginning of the semester, when engaged in theoretical discourse, students tended to advocate socio-constructivists paradigms, whereas when engaged in designing technologies they tended to neglect these ideas and apply more traditional approaches. This gap, which was found in four dimensions: Learner activity, Collaboration, Autonomy, and Content accessibility significantly reduced during the course (Ronen-Fuhrmann et al., in press). Preliminary outcomes from the current research indicate that the earlier in the semester students were forced to "get their hands dirty", and create screen-sketches of their technology, rather than discuss it in a philosophic manner, the earlier they realized this gap, and were able to reduce it by designing features that better suit a socio-constructivist approach. We postulated that the addition of a second iteration (the design decision described above), would require earlier submission of the first design stages and encourage students to anchor their ideas in real design-making earlier in the course. We assumed that this would support students in achieving artifacts that are more pedagogically sound toward the end of the course.

Iteration-3

This iteration too, indicated improved learning outcomes, which confirmed some of our design decisions, and yet again illuminated new challenges.

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-institution international "Designing educational technology" course, and the "Development course" at the Technion. When students were required to develop their flow of activities, it was already after mapping the contents they planned to cover in their educational technology. As a result, they were focused much more than students in iteration 2 on building engaging activities. For example, one group developed a technology named "How micro-organisms can 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 students are provided with an article about a scientist who is developing a new genetically-based vaccine. The learners are supposed to play the role of another scientist who critiques her colleague. To base their critique on the science, and learn the contents, students were provided with guiding questions and "just in time" content knowledge. The design of this activity is an example of students' focusing on student engagement rather than constrained by the hierarchy of contents.

Design decision #7, i.e., to add a second design cycle, also proved to support the design process; the quality of the projects at the second design cycle, as assessed by the rubric for evaluating the degree to which educational technologies employ socio-constructivist approaches, significantly improved. However, with regards to "anchoring" students' design ideas in practical design work, as early as possible (Design decision #8) our data was somewhat ambiguous. We still found that the earlier this "anchoring" happens, the earlier students decrease the gap between their theoretical and applied epistemologies. Many students also indicated in their reflective assays that having to design the details of their activities helped them better articulate their design solutions, as illustrated in the following except: "To me the most crucial part of the work happened during the 'build flow' stage. That was when we began thinking of how our technology would actually work. We had to imagine scenarios, and try to feel what a user of our environment would go through. This was really a milestone in the design, where we had to neglect some ideas that were just too vague, and design realistic solutions". However, we did not find evidence that by having to submit practical design documents earlier in the process "anchoring" occurred earlier. It seems that other factors, related to students' personal traits, self confidence and the interactions within the group were also involved in this "anchoring" process. Some groups did not "anchor" at all, and continued to talk about their designs in a theoretical manner until the end of the course.

Challenging outcomes

9. *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 from the documentation of each of the design stages. This outcome was also supported by the survey; relatively low attitudes (3. 9 of 5) were attributed to "Online peer-review". We thus made a design decision to combine between online-peer-assessment and face-to-face dialog between groups, and to support the online peer-review with better tools, integrated into the work environment.
10. *Confusion due to dual infrastructures*- Students in iterations 2 and 3 were required to use two different infrastructures: a) a course website (Moodle), which included the course plan, assignments, and all the online communication, b) the Design Principles Database. 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 Design Principles Database was limited due to these

confusions. Although we found the use of the Design Principles Database was productive, as described above in the confirming outcomes following the second iteration, some of the students devoted only little time to search for design principles that could better support their design decisions. To make this knowledge accessible, and increase its usability, we made a design decision to embed the entire instructional-model into the Design Principles Database.

Table 4: Summary of challenges and design decisions

#	Challenging outcomes	Design decisions
1	Difficulties due to the open-ended nature of task	Structuring the design process
2	Unawareness to rationale	Use the Design Principles Database to emphasize awareness to rationale
3	Limited intuition	Enrich students' intuition by integrating the instructional-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
6	Tendency to build flow according to content hierarchy	Adding the content analysis stage
7	Frustration from inability to implement feedback	add a second design cycle
8	Gap between theoretical and applied epistemologies	Make concrete design artifacts earlier in the design process (supported by design decision #7)
9	Limited online-peer-assessment	Add Face-to-face dialogs between groups
10	Confusion due to dual infrastructures	Embed the entire instructional-model into the Database

Discussion and Conclusions

The challenges that came up in each of the iterations provide an interesting perspective for characterizing the process in which graduate students acquire skills in designing pedagogically sound educational technologies, and how these students can be supported in this process. Our initial attempt to support student learning in the first iteration was to provide them with an open-ended reflective setting. Acting according to Schon's (1983) reflective practitioner approach, and employing a learning sciences tradition, we felt that with such a creative task in hand students would benefit mostly if we will serve as guides in this process, and adjust our guidance to their emerging needs. The importance of the guidance and peer learning came up in the findings as aspects that need more emphasis (challenging outcomes #4 and #5), backing our decision to employ a design studio approach. However, from the first iteration, it was evident that students' most pressing need, in spite of their rich background regarding educational theory, stemmed from this open-ended approach (challenging outcome #1); they felt that the they needed more structure. As reflected from students' remarks, the instructional model developed following these findings, which integrates the openness and reflective nature of the studio approach with the structure of the ADDIE model, indeed relieved students from having to deal with all aspects of the design at the same time. Students in the second and third iterations felt that this was crucial to their ability to design artifacts of high quality.

This finding can be interpreted in terms of cognitive load, and novice-expert literature (e.g., Clement, 1998). Learning scientists who are expert curriculum designers do not necessarily follow a structured design process (Barab, 2004; Hoadley, 2004; Smith, 2004). Their immense theoretical knowledge about the challenge they are designing a solution for, and their acquaintance with a large number of solutions that have been developed for dealing with similar problems provide them with a good intuition, which guides their design. While designing, they simultaneously reflect upon various aspects of the design, including the needs and requirements of their audience, the hierarchical structure of content, creating a clear and engaging flow of activities, and designing features that have the potential to promote learning in each of these activities. However, as indicated from our findings, for novice designers, for whom these knowledge and practices are new, the cognitive load is just too large. Dividing the task into a series of finer grain tasks (design decision #1), such as those found in the ADDIE model, and to even smaller tasks such as those we defined in the Design stage, (Brainstorm, Build flow, and Design features), reduced the cognitive load and enabled students to focus each time on a different aspect of the design. The cognitive apprenticeship model (Collins, 1990) for supporting novices, advocates for exactly this type of scaffolding. According to this model, when experts reflect on the cognitive processes they go through in solving a problem (in this case, the problem can be defined as designing an educational technology), they can best break the problem into bits that are manageable for novices.

Other challenges that emerged in this study can also be explained in terms of cognitive load and a novice-expert continuum. For instance, students' tendency to develop features based on their search for "cool" solutions, without being aware of the pedagogical rationale behind these features (challenging outcome #2), their limited intuitions (challenging outcomes #3), and their tendency to develop activity flows that depend on hierarchy of contents (challenging outcomes #6), can also be compared with the expert practices. As described above, experts too, tend to rely on their intuitions. They also seek to design innovative solutions, and are concerned with the hierarchy of contents they are designing their solutions for. However, in contrast to novice designers, at the same time they take into account pedagogical concerns, and are more reflective about their thinking processes. Using the Design Principles Database as part of the instructional model (design decision #2), and integrating it into a design course (design decision #3), which included literature reading and analysis of state of the art educational technologies, enabled students to rely on expert knowledge, found in these resources. In this manner they were able to move toward the expert side of the novice-expert continuum.

The gap between students' theoretical and applied epistemologies (challenge 8), which was identified in an earlier research (Ronen-Fuhrmann et al., in press), was found in this research as an important stage in student learning. By "getting their hands dirty" with practical design of their technology, rather than discussing it in a philosophic manner, students realized this gap and were able to reduce it. This anchoring stage, as indicated from students' doing and saying, served as a crucial stage in students' learning. Although we did not find a way to make this stage occur early enough in all groups, we view this finding as an important contribution for understanding the learning process of novice designers.

Finally, other outcomes, such as students' frustration from their inability to implement their feedback, the limitation of the online peer assessment, and students' confusion from the dual infrastructure (challenging outcomes # 7, #9 and #10), enabled us to refine our instructional model. The latest version of the instructional model is currently embedded as the "Design Mode" of the public Design Principles Database. We encourage the learning sciences community to take advantage of the resource and continue this fascinating line of research.

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