The Role of Concretization in Acquiring Design Knowledge

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Abstract: This research explored the nature of design knowledge by examining the processes in which graduate students in education learned to design educational technologies. We developed two rubrics to assess: (a) the degree to which students were able to translate their design ideas into concrete design artifacts (concretization rubric), and (b) the degree to which they designed artifacts that followed a socio-constructivist pedagogical approach versus a teacher-centered transmissionst model (epistemology rubric). Outcomes indicated that as students developed their concretization skills, they were able to become aware to and reduce gaps between their "theoretical" and "applied" epistemologies. By making their design ideas more concrete, students were able to carry out productive negotiations about these ideas with instructors and peers, and to explore them in relation to theory and to expert design knowledge.

Rationale

Research in the learning sciences has shown that many opportunities to learn arise in the course of designing an artifact in general, and in designing an artifact 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. Researchers in various disciplines, such as the sciences of *learning, instruction* and *design* have recently begun to synthesize practical and theoretical knowledge regarding how to guide and inspire creators of innovative educational tools (DiGiano, Goldman, & Chorost, 2009). However, more research is required to better understand the ways in which graduate students in education—who are potential educators, curriculum-designers, learning-scientists, or policy makers—develop skills in designing technology-based curriculum modules, and how they can be supported in this process.

In an earlier study, Ronen-Fuhrmann, Kali, and Hoadley (2008), showed that there is an important added value in engaging graduate students in designing their own technology-based curriculum modules; while working on their design projects, students became more aware of gaps between what was defined as their "theoretical epistemologies about learning" (ideas expressed during general discussions about design, usually representing a socio-constructivist approach) and their "applied epistemologies about learning" (ideas reflected in artifacts they created, which tended to apply more transmissionist approaches), and were able to reduce these gaps. In this manner, students' epistemologies about learning became more coherent – an important outcome for students in education, whether or not they intend to design curriculum materials. In the current study we focus on the nature of knowledge and skills that students gain in educational technology design courses – a type of knowledge which the literature generally refers to as design knowledge. We focus on a specific aspect of design knowledge found in this research – the ability to concretize abstract design ideas, and explore the relationship between students' development of concretization skills and their ability to reduce their epistemological gaps.

Research Settings

This research investigated the learning that took place in a semester-long course named "*Designing Educational Technologies*" designated for graduate students in science education, which was designed, developed and instructed by the authors of this paper. Students in the course were introduced with theoretical and practical aspects of educational technology design; they worked in groups of two or three to design a mockup of an educational technology module, but were not required to develop or implement these modules. The rationale was to focus on exploring students' learning while designing, without the constraints caused by any development tool, and without requiring a time-consuming development process.

The course was based on an instructional model, which evolved in an iterative design process in a previous study (Ronen-Fuhrmann et al., 2008). The final version of the model includes three main elements, which reflect a unique application and integration of three frameworks: (a) the ADDIE structure (Analyze, Design Develop, Implement, Evaluate) (Dick, Carey, & Carey, 2001). (b) the studio approach to instruction (Hoadley & Kim, 2003; Schon, 1983), and (c) the use of the Design Principles Database (DPD) (http://edu-design-principles.org), a web-based resource of socio-constructivist pedagogical design-principles, which were written by design experts (Kali, 2006; Kali & Linn, 2007; Kali, Linn, & Roseman, 2008).

Methodology

We used a case-study methodology to examine students' learning processes and their development of design knowledge throughout the course. A collective case-study approach–often referred to as "multiple case study" (Stake, 1994)—was implemented. This approach is aimed at providing insights into an issue or problem or to refine a theory by exploring similarities and patterns between several case-studies. In this research, each group of 2-3 students, who worked on one design project during the course, was defined as a case-study.

The study was conducted with 14 groups (33 graduate students) who participated in three enactments of the *Designing Educational Technologies* course between the years 2005-2007. Most students had some experience in teaching or were active science teachers. They had some experience in designing curricula but most of them had no experience in designing technology-based learning modules. In order to characterize student learning in each of the iterations the following data sources were used (Table 1).

Table 1: 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.
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 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 artifacts	During the semester we collected documents produced at various stages of the course. These documents included formal design artifacts 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 analyzing each group's learning processes.

These data were analyzed using two rubrics; the first, entitled "concretization rubric" was used to evaluate the degree to which students were able to translate their design ideas into design artifacts; the second, entitled "epistemology rubric" was used to examine the epistemological changes that students went through during the course. We explain our rationale for developing these rubrics, and the way we used them in the sections below.

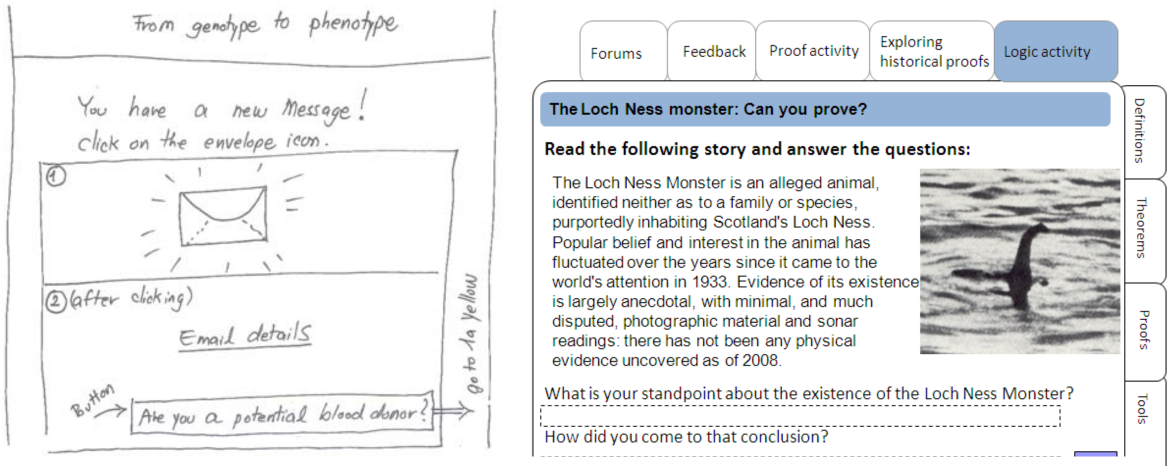
Concretization Rubric

From early stages of the research we noticed that some students were able to easily translate their design ideas into concrete artifacts, while other students found this process very difficult. Following our preliminary observations, we decided to focus our assessment of design artifacts created by students using this lens. We developed a rubric (Table 2) which describes six levels of concretization of design ideas. Each level is associated with a stage in the design process in which a higher level of concretization is required. Thus, level 0 represents a stage in which students are required to discuss their module only in a theoretical manner. Level 5 represents the highest level of concretization; an artifact at this level should depict a full learning environment with a clear navigation system illustrating sequences of activities with clear instructions for learners.

It is important to note that although each stage in the instructional model was designed to provide students with the design skills required at that stage, including guidelines for concretization, we did not anticipate a one-to-one relationship between the knowledge taught and the knowledge gained by students at each stage. We also want to stress that we do not view concretization as a goal of the design process. Rather, we refer to concretization as important means to reach pedagogically sound artifacts.

Table 2: Rubric for assessing concretization of design ideas.

Level of concretization	***Design Artifact Characteristics***	***Example Student Expressions and Artifacts***	***Required in Stage***
0 – Theoretical knowledge	No design artifact. Only theoretical sayings regarding a planned module.	"It's very important to build activities that would be relevant and interesting to the learner"	Analysis
1 – Collection of design ideas	A collection of design ideas for the module. The ideas only generally refer to the way a learner might act in the module.	"Learning throughout the whole module should follow a specific inquiry question". (Excerpt from a discussion of one of the groups regarding their design of a biology module. They planned to design the activities around an inquiry question but were not concerned at this stage about the nature of this question).	Brainstorm Activities
2 – Initial activity sequence	Graphical or verbal description of a set of activities, with an indication of which activity should take place before or after another.	"First we should show them [the learners] the story about the family tree, then have them review the algorithm for scanning the tree, and then use the simulation" (Excerpt from a discussion regarding the design of a technology for high-school computer-science learners)	Build Flow
3 – Initial translation into features	Ideas are translated to actual features and presented in a way that shows how a learner might act in the module.	Figure 1a shows a sketch of the way students envisioned an activity they planned for a module in genetics. Learners in this activity were required to decide whether they can donate blood to a kid with cystic fibrosis. At this stage this was the only activity they developed in their module.	Design Features
4 – Initial learning environment	Mockup of the module showing some of the activities, with instructions for learners. An initial navigation system is present.	(See Figure 1b showing design knowledge level 5 – full learning environment as reference).	Mockup: Iteration 1
5 – Full learning environment	Mockup of the module showing most of the activities with clear instructions for learners. A clear navigating system is represented.	Figure 1b shows one screen from a mockup of a module designed for teaching logical thinking for middle school math students. The buttons at the top and side of the screen indicate that this screen is part of the whole learning environment. Each of these buttons was linked to a screen in the mockup, which was developed in a similar level of detail.	Mockup: Iteration 2



(a) Design artifact showing level 3 of concretization (b) Design artifact showing level 5 of concretization

Figure 1. Examples of artifacts showing levels 3 and 5 of concretization.

Epistemology Rubric

The term "epistemology" in the learning sciences has traditionally referred to several entities in the nature of knowing, such as beliefs, conceptual understanding, perceptions, feelings and emotions. Since our analysis did not enable us to fully distinguish between these entities, we decided to use the general term "epistemology" in order to refer to any idea regarding how people learn expressed by the students, in their sayings and doings.

As mentioned above, a gap between students' "theoretical" and "applied" epistemologies was revealed in an earlier stage of this study (Ronen-Fuhrmann et al., 2008); at the beginning of the semester, when engaged in theoretical discourse, students tended to advocate socio-constructivists paradigms, whereas when engaged in designing their technology-based modules, more than half of the students tended to neglect these ideas and apply more traditional approaches.

In order to quantitatively assess "low" and "high" levels of epistemology, we relied on studies that describe an instructionist view of learning as equivalent to naïve epistemology, and a socio-constructivist view, as analogous to sophisticated epistemology (Maor & Taylor, 1995; Schommer, 1990). Inductive analysis of our data indicated that there are three main dimensions in students' sayings and artifacts in the design process, which express their epistemologies: (a) learner activity, (b) collaboration, and (c) content accessibility. We used these dimensions to develop the epistemology rubric (Table 3)

Table 3: Epistemology rubric.

Dimension	Low	Medium	High
Learner activity The degree to which students expressed ideas that support active engagement of learners within a technology-based learning environment.	Passive: e.g. learner reads or views information.	E.g. learner clicks on links.	Active: e.g. learner manipulates variables
Collaboration The degree to which the students supported using technology in ways that enable learners to learn from each other	Individual learning	Group work is not supported by technology	Collaboration is intrinsic to the activity
Content accessibility The degree to which students expressed views that support making the contents of a learning environment accessible to learners.	No effort to connect contents to student world	Motivational aspects are extrinsic to activities	Motivational aspects are intrinsic to activities

We would like to note that we used the epistemology rubric to assess the level of epistemology expressed in the artifacts created by *groups* of students rather than by individuals. Although in many studies epistemology is attributed to the individual, our rationale for studying group epistemology is based on the work of researchers such as Fuller (1987) and Goldman (2008), who claimed that there is a strong social aspect to epistemology, which cannot be overlooked; the individual's way of thinking is considerably influenced by the ideas expressed by the group of people he or she is interacting with.

Data Analysis Procedure

To assess the design artifacts of the 14 case-study groups using the two rubrics, we first created digital portfolios for each group, which included all in-progress and final documents created by the group, all of the individual students' posts in the course's discussion forums, transcriptions of interviews (if there were any for students in the group), and their reflective essays. Each portfolio was organized by the stage of the design process (Analysis, Brainstorm, Build flow etc.). To refine initial versions of both rubrics, we took one example case-study, and had four researchers—two external researchers and the two authors of this paper—assess the degree of concretization and epistemology of the group at each stage of the design process. Initially, about 60% agreement was reached. Following several cycles of refinement of the rubric, in which more case studies were assesses, we reached a degree of about 90% agreement between researchers using the current version of the rubrics. In this manner seven of the portfolios (50% of the cases) were assessed. The rest of the case-studies were then assessed by the authors of this paper together (without comparison of individual assessments).

Combining the Two Rubrics to Map Findings

Initial analysis of the findings showed that using each of the rubrics described above, we can distinguish between two patterns of learning. Using the concretization rubric, we found that one pattern was represented by groups who had difficulties in concretizing their design ideas. The concretization level of their artifacts at various stages of the design process was lower than the level required at that stage (see Table 2). On the other hand there were groups whose pattern did not show any difficulty with the concretization and were sometimes even ahead of the required level in the design process. This enabled us to refer to the dichotomy: *Low versus High* pace of concretization skills acquisition. Using the epistemology rubric, we were able to clearly distinguish between one pattern, in which groups of students showed a gap at beginning stages of the semester, as described above, versus another pattern of those who showed a coherent epistemology throughout the semester. This enabled us to refer to the dichotomy: *Coherent versus Non-coherent* pattern of group epistemology. Using these two dichotomies, we developed a four-quadrant matrix (Figure 2) to map our findings regarding the relations between concretization and epistemology.

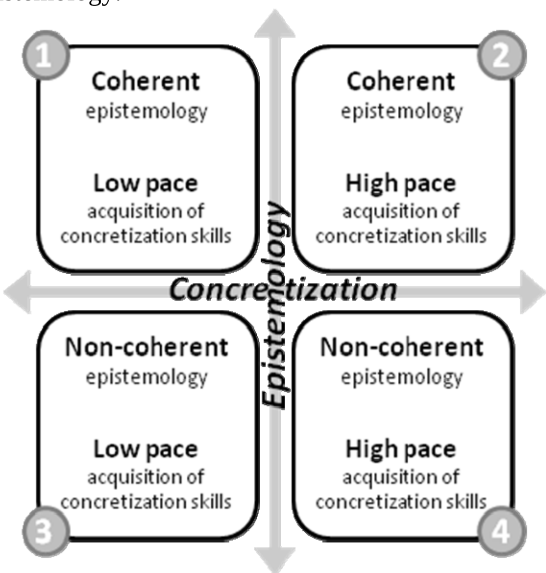


Figure 2. The four-quadrant concretization/epistemology matrix.

Outcomes

Following an in-depth analysis of each of the 14 case-studies, in which we used both the concretization and the epistemology rubrics using all the data sources, we were able to map the cases into the four-quadrant matrix. The results of this mappying are represented in table 4. As can be seen from the the table, two of the cases were mapped in quadrant 1, another two in quadrant 2, three more in quadrant 3, and 7 cases—more than half of the students—were mapped in quadrant 4. Additionally, the anaysis of each of the cases' patterns of learning revealled that groups that were classified as belonging to quadrant 4 significantly reduced their episteomogical gaps throughout the semester, whereas groups that belonged to quadrant 3 only did so to a small extent. We argue that the high pace of their acquisition of concretization skills was an important factor in enabling groups in quadrant 4 to reduce their epistemological gaps. To support this claim, which we further discuss in the final section of this paper, we first describe in detail one case-study representing and illustrating the learning processes of groups that were classified as belonging to quadrant 4.

Table 4: Mapping of the 14 case-studies using the concretization/epistemology matrix.

Quadrant	***# of Groups***	***# of Students***	***Pattern***
1	2	5	Coherent epistemology throughout the semester Low pace of acquiring concretization skills
2	2	4	Coherent epistemology throughout the semester and High pace of acquiring concretization skills
3	3	6	Non-coherent epistemology at beginning of semester ***Minor reducing of epistemological gap*** Low pace of acquiring concretization skills
4	7	18	Non-coherent epistemology throughout the semester and ***Major reducing of epistemological gap*** High pace of acquiring concretization skills
Total	14	33	

Illustrating Learning Processes in Quadrant 4: The case of I,S&E

I,S&E designed a technology-based module designated for high-school computer-science learners. Their module focused on recursive algorithms for scanning data-structure trees. One of the features they designed, from very early stages of the design process was an animation that demonstrates a certain algorithm for scanning a tree. Their (potential) learners were required to solve problems that utilize the demonstrated algorithm.

Analysis of the design artifacts they produced at various stages of the design process using the concretization rubric (left graph in Figure 3) indicates that this group's acquisition of concretization skills was of a high pace (high pace was defined as a slope that is higher or equals to 0.75, where each stage of the design course was numbered consecutively starting with "*Analysis=1*"). I,S&E had come up with the idea of the animation as early as the *Analysis* stage (in which they were still not required to suggest ideas for activities). They continued at a "normal", or "required" pace (see dotted line in Figure 3 - left graph) in the *Brainstorm Activities* and *Build Flow* stages. When required to design features, they were still struggling with their flow of activities, but they gradually progressed until they reached level four of concretization in their final mockup.

The analysis of IS&Es' learning process using the epistemology rubric (Figure 3, right side) revealed that at the beginning of the semester, in general discussions about educational technologies, each of these students expressed ideas that we classified as high level of sophistication with regards to epistemology (level 3 in each of the dimensions of the epistemology rubric). However, as can be seen in figure 3, there was a large drop at the *Analysis* stage, with respect to the *Learning Activity* and *Content Accessibly* dimensions, which continued with a drop of the *Collaboration* dimension at the *Build Flow* stage. These drops represent the gap described earlier, between "theoretical" and "applied" epistemologies. Specifically, when IS&E began to design their animation, it required learners only to passively watch the animation, and there was no attempt to make the contents more accessible. Collaborative aspects were minimal (a forum was designed for Q&A). Gradually, as this feature was revised following discussions with peers and instructors, and following the use of the Design Principles Database, this feature became a manipulable tool, which enabled learners to solve problems by exploring various ways to scan given trees, as well as their own trees. Our analysis of their final mockup, using the epistemology rubric was as follows: Learning Activity = 3 (learner manipulates variables); Content Accessibility = 2 (motivational aspects were eventually at an intermediate level); Collaboration = 3 (activities that required learners to solve problems in tasks created by their peers were designed). Thus - we interpreted their learning process as representing a major reduction of their groups' epistemological gap. The dotted line in left graph of Figure 3, which represents the average between the three dimensions, illustrates this reduction of the epistemological gap.

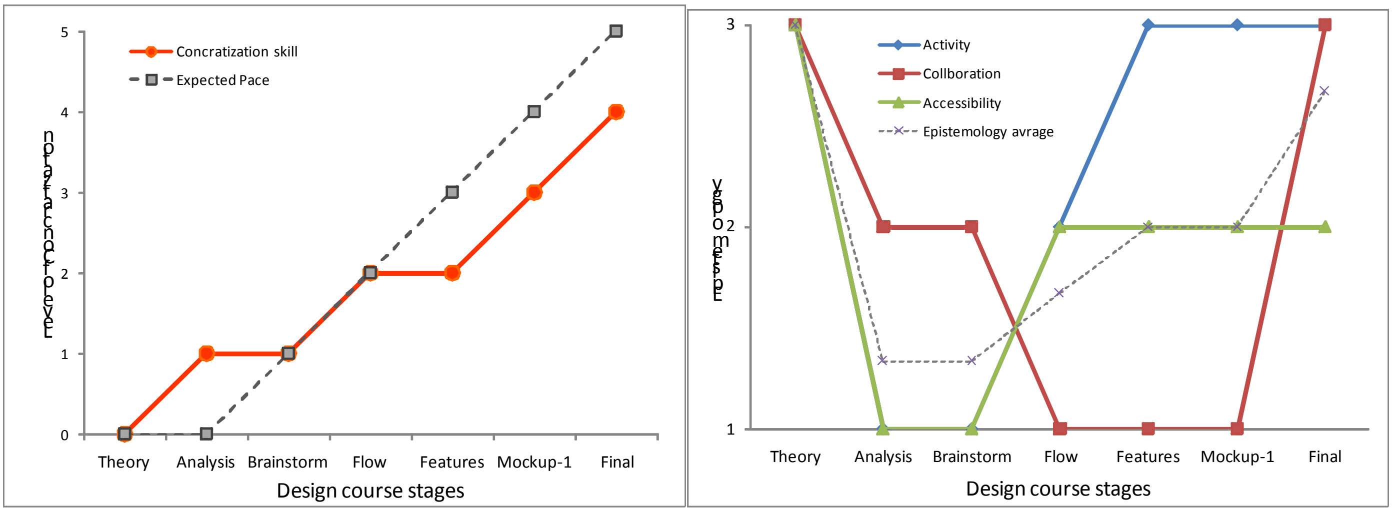


Figure 3: Analysis of the learning processes of I,S&E: Acquisition of concretization skills (left), and changes in group epistemology (right)

Discussion

The mapping of the 14 case-studies using the four-quadrant concretization/epistemology matrix, revealed the important role of concretization in helping students to reduce epistemological gaps. The cases mapped in quadrants 1 and 3 illustrate that moving from general design ideas to actual activities was a difficult task for many of the students. Concretization of a high level, in the context of educational technology design, requires not only to design the details of certain features, but also to be able to describe how these features fit together in a coherent learning environment, and design different paths learners will be able to use in the environment. This requires a designer to deal with very high level of detail of the activities, and at the same time envision a flow of activities or scenarios that would enable a potential learner to acquire knowledge using the designed module.

Our findings illustrate that as students concretized their design ideas and represented them in sequences of activities, they exposed their pedagogical way of thinking to others. This enabled them to negotiate and reexamine their thinking with peers and instructors and to compare the design solutions they came up with, with those of experts. The exposure of ideas, induced by the concretization, brought to identification of gaps between students' views about how people learn, and pedagogical notions expressed in artifacts they designed at initial stages of the course (Ronen-Fuhrmann et al., 2007). Their views of learning, as stated in discussions, usually represented socio-constructivist approaches, while many of their initial design artifacts represented more naïve, transmissionist views of learning. As students' artifacts became more concrete, they also represented more advanced pedagogical views of learning. The gaps were reduced as a result of refinements students made throughout the design process. Following Wilensky's (1991) notion of concretization as representing the richness and connectedness of abstract concepts, we argue that a person who can verbally explain abstract pedagogical ideas, but has a difficulty to concretize them as features in a learning environment, lacks a deep and connected understanding of these ideas, and of the theoretical underpinnings behind them. To design concrete features that convey their ideas about learning, students in the current research were engaged in a process of connecting their ideas with design knowledge of peers, instructors, and experts. This process enabled them to develop a richer set of connections in their knowledge about learning theory, and thus develop a deeper understanding about learning.

Thus, in the context of educational technology design, we view concretization as: (a) an essential skill in the process of gaining design knowledge, and (b) a way to assist students to reflect and reduce gaps in their understanding about learning theory. This twofold notion of concretization is in agreement with the Learning By Design literature (e.g., Harel, 1991; Kafai, 2006; Kolodner et al., 2003; Papert, 1991), which shows that when learners design an artifact that explains a certain topic in a certain subject matter, they learn many things about design, but they also learn a whole lot about the topic they are designing for. In this study, the topic was not only the science or math embedded in the students' modules, but also the learning theory behind the instruction that they designed.

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