Helping Education Students Understand Learning Through Designing

Tamar Ronen Fuhrmann (Technion), Yael Kali (Technion),
and Christopher Hoadley (Penn State University)

Abstract: This paper describes a course in which graduate students in education learn practical and theoretical aspects of educational design by creating technologies for learning. The course was built around three themes: *Analyzing technologies* in which students study state-of-the-art technologies and interview their designers, *Design studio* in which students design their own technologies using an instructional model that was developed in this study and *theory* in which literature is reviewed. Outcomes illustrate tensions between students' professed beliefs about learning and their actual design practices in four dimensions that characterize the technologies they designed: *Learner activity*, *Collaboration*, *Autonomy*, and *Content accessibility*. By peer-negotiating of these tensions in each of the course themes, students developed their skills to design educational-technologies and increased the coherence of their epistemological understanding of how people learn.

The Learning by Design Trajectory

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. (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; Dede, 2005; Edelson, 2002; The Design-Based Research Collective, 2003) 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; these students were taking a course on educational technology, but this was not their major field. We describe an instructional model that we developed and implemented in a graduate course named *Designing Educational Technologies* (we refer to this course as "the design course" or simply "the course"), and show how this course affected students' epistemologies about learning.

Developing the Design Course: Challenges and Solutions

Initially, the Technion had an educational technology design and development course for education students, which was based on individual projects and one-on-one consultation. Students in this course used a database of design principles (Kali, 2006; Kali, in press; Kali & Linn, in press) to guide their design process. However, through pilot research (Ronen-Fuhrmann and Kali, 2005) and feedback from students, it became clear that a more structured, group-oriented course was necessary. The pilot study, conducted with four master's students, concluded that students:

- had difficulties in approaching the task of designing their own curriculum, due to its open-ended nature.
- relied mainly on their intuition in their design process, and hardly referred to theories of learning.
- tended to design traditional instructionist type of activities with hardly any constructivist and socio-cultural applications.
- depended heavily on the individual guidance and coaching of the instructors.
- greatly valued, and took advantage of the group-meetings and the feedback from their peers.
- took advantage of the Design Principles Database mainly as a metacognitive tool, which helped them become more aware of the rationale behind features they designed

These outcomes served as a basis for developing the design course. To address the difficulties students had with the openness of the assignment, as indicated in the pilot study, we decided to provide a more structured framework for the design process in the design course using the studio approach. The studio approach is common in traditional design fields such as architecture or graphic arts, in which learners examine examples, conduct lengthy design projects in the company of others doing similar projects, and proffer and receive frequent peer and expert feedback. Schon (1983; 1985), and Glaser (1996) have described this as an important way to teach design and professionalism in other disciplines. Hoadley & Kim (2003) describe how such methods can be used in teaching educational design.

In order to enrich students' intuition for designing educational technologies, we decided to widen the resources compared to those we provided students with in the pilot study. We decided that the design studio would constitute only one of three components in the course (Fig. 1). The other two were technology analysis and theories of learning with technology. The *technology analysis* component was structured to include student interaction with a technology, discussion of research papers about the technology, and online discussions with its designer. The *theory* component included students' review and online discussions of relevant literature, particularly studies that explore the impact of technology-enhanced curriculum on learning. The course started with the technology analysis component, which served as background for the subsequent main component, the design studio. The theory component took place throughout the semester and was aligned with activities of the two other themes.
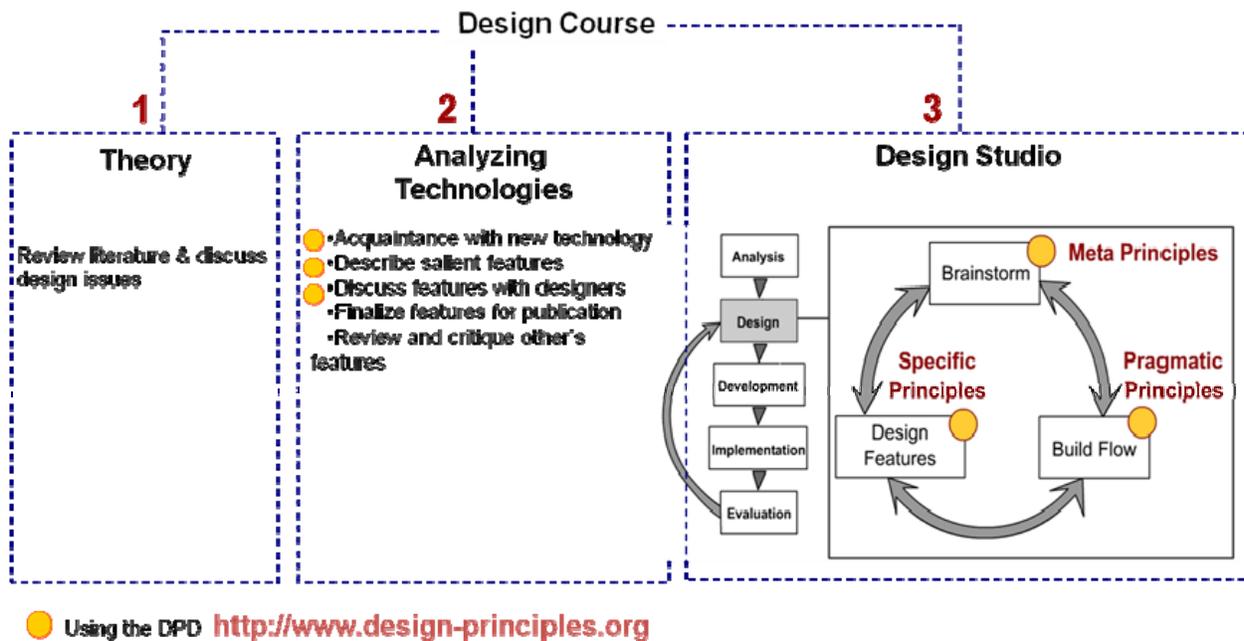

Figure 1: Three components in the revised design course – the dots indicate stages in which the Design Principles Database is used

Since the outcomes from the pilot study indicated a need for close guidance in the design process, we decided that the main type of instruction in the design course would follow the modeling-coaching-fading-away cognitive apprenticeship model (Collins et al., 1989). *Modeling* is accomplished via the design of the course, which itself follows a constructivist and sociocultural approach for teaching and learning, and via the examples used in the technology analysis. *Coaching* is achieved via the format of the course in which meetings are dedicated mostly to students' working in groups on their projects and mentored by the instructors. *Fading away* is built into the structure of the course; engaging students initially with analyzing technologies and only afterwards in designing their own technologies in the design studio is meant to start the process with much guidance in the first theme and fade it in the second. To enable students benefit from peer learning, in addition to having students work together on their projects, we incorporated several stages in the instructional model in which students review each other's projects and provide constructive feedback.

The design studio model (Figure 1) developed in this study employs approaches from two fields that study the design of educational technologies, namely the ISD (Instructional Systems Design) and the Learning Sciences. Hoadley (2004) claims that both fields could greatly benefit from synergy between them. From the ISD world, we borrowed the ADDIE (i.e., analyzes, design, develop, implement, evaluate) approach (Dick, Carrey, & Carrey, 2001). The learning sciences in general and particularly the Scaffolded Knowledge Integrations (SKI) framework (Linn et al. 2004) served as the main resource for the contents in the Design Principles Database, which is used throughout the course. Incorporating these resources into the course was also expected to foster a more socio-constructivist instructional approach which was missing in the pilot study. Our instructional design model 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* (Figure 1).

Evaluating the effect of the design course on learning

The design course described above was enacted in spring semester 2005 with fourteen graduate students at the Technion. In order to characterize what the students in the design course learned, rich qualitative data was gathered throughout the semester. Data sources included whole class online discussions about the literature, group online discussions (for 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), entries in the Design Principles Database, and a reflective journal in which we documented important events in each of the class meetings.

To analyze the data and characterize student epistemologies at various stages of the design process we developed a rubric based on two existing frameworks. The first is Reeves' framework, which includes 14 pedagogical dimensions for assessing computer-based education (Reeves, 1994). The second is the SKI framework, mentioned above, for designing web-based inquiry curricula (Linn et al. 2004). Since these frameworks do not include a rubric for quantitatively assessing the design of educational technologies, we combined and modified these frameworks to develop the following rubric which could help characterize the students' designs (Table 1).

Table 1: Rubric for assessing the design of educational technologies

Dimension	Description	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
Autonomy	The degree to which students expressed ideas that support learners to control their learning paths within a technology-based environment.	Progress is determined according to performance	Semi-open environment	Open activities, which enable diverse learning paths

*The term "learner/s" refers to potential users of the educational technologies designed by the graduate students in the design course

The Effect of the Design Course on Students' Epistemologies

In this section, we describe the effect of the design course, and the instructional model embedded in it, on the graduate students' learning, using the four-dimension framework described above. For each dimension we illustrate ideas expressed by students during discussions (online and face to face), and those expressed by the artifacts they created at various stages of the design process. We refer to ideas expressed during discussions as "theoretical epistemologies", and those expressed in their artifacts as "applied epistemologies". The outcomes are also summarized schematically in Figure 2.
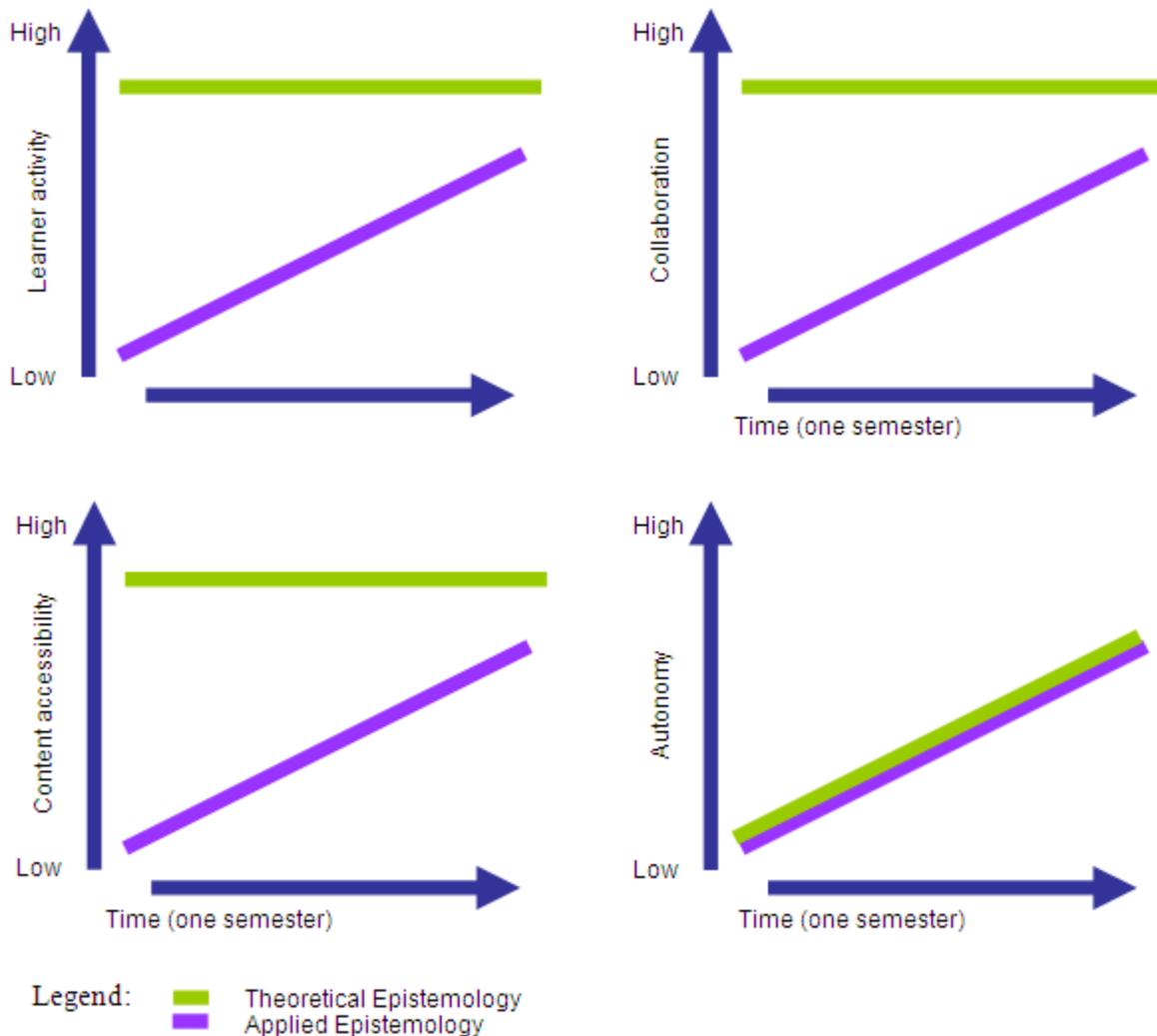
Figure 2: Schematic representation of changes in students' theoretical and applied epistemologies throughout the course

Learner activity. The analysis of the data indicates that when engaged in online or face-to-face discussions, most of the students, as expected from graduate students in education, were strongly in favor of active learning. However, when they began designing their technologies, many of them designed modules in which learners have a passive role as consumers of information, whose interaction with the technology is restricted to reading or watching things on the computer screen. As the semester proceeded, their designs incorporated more and more components in which learners have an active role, and are engaged in constructing knowledge in interactive environments, using tools that allow them to express their ideas, manipulate elements, or build artifacts. One example is from a group of three graduate students who designed a technology for high-school computer-science learners. The technology focused on recursive algorithms for scanning data-structure trees. One of the features the grad students designed was an animation that demonstrates a certain algorithm for scanning a tree. Users were required to solve problems that utilize the demonstrated algorithm. This feature, which initially required users to passively watch the animation, went through several revisions in this group's design

process. By the end of the course it became a manipulable tool, which enabled users to solve problems by exploring various ways to scan given trees, as well as their own trees.

Collaboration. The analysis of the online discussions in the course indicated that most of the students greatly advocated socio-cultural instructional strategies. For example, expressions such as "…learning from each other is an essential skill - It is important for kids' to develop the ability to listen to others and also explain their ideas to their peers and not only to their teacher" were common. Nonetheless, when it came to designing their own technologies, students tended, at initial stages of their design studio project, to design environments in which users work with the technology individually, at their own pace. As they went through the stages of the design studio, students tended to embed more and more social supports in their designs, and enabled their potential users to negotiate their understanding with their peers. For example, at the beginning of the course the same group of students, who designed the computer-science technology described above, designed it as an environment for personal use only. As the course continued, they decided to add peer learning elements to their environment, such as a forum for students "to ask each other questions, and talk about things they found interesting or challenging."

Content accessibility. Our data indicates that many students expressed their concerns about how to motivate students to learn, how to relate school topics to real world topics and to students' interests. For instance, in one of the first online discussions a student said: "as a school teacher, I see that learning is meaningful when the context is tangible and relates to the learners' world; when I teach about the concept of pendulum in physics, I connect it to the swing at the schoolyard". However, when they began designing their technologies, students tended to build the flow of activities in their technologies based solely on the structure of knowledge in the domain they intended to teach. They 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 this as an objectivist approach for design:

"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."

Throughout the course, students became more concerned that the domain content within the technology environments builds on learners' prior knowledge, connects with their everyday lives, and engages the learners. An example is a group who designed a technology about the moon-phases. The main feature in their technology was a dynamic model showing the moon orbiting around the earth while both bodies are half illuminated by the sun (Figure 3). 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, and following careful review of principles and features in the Design Principles Database, they decided to completely reorganize the flow of activities in order to make it more appealing to users.

Eventually, their design included a set of more authentic problems (e.g., "your friends would like to organize a party when the moon is full… help them find the configuration of the Sun-Earth-Moon system to find when this happens"), in which the model served as the main tool, and additional information, initially designed as prerequisite stages, was transformed to just-in-time retrievable information via "hint" buttons.

Figure 3: A screen mockup of a student design in which a dynamic model would show the moon orbiting around the earth while both bodies are half illuminated by the sun

Autonomy. As apposed to the other dimensions, the autonomy dimension did not reveal a clear gap between students' epistemologies as expressed in their sayings and their doings (Figure 2). However, we did observe a change in students' epistemologies in this aspect throughout the course. From the beginning of the semester, many concerns were expressed by our students about the lack of control that teachers have in open-ended environments. The notion that technology (or the teacher) should monitor and control student learning was most prominent. This notion was consistent with their designs at initial stages of the design process. Many of the projects were tutorial-type environments that funnel learners in different learning paths according to their performances and provide teachers with precise information of learners' progress. As the design process proceeded, students' designs increasingly included open-ended activities and tools in which learners have more flexibility in directing their own learning paths. For example, one of the groups designed an online environment for teachers to share and construct lesson plans using modular units contributed by the community of teachers. One of the features was a search engine for finding relevant materials. At initial stages of the design process, the students wanted to make sure that the teachers will use the search button only after they read the instructions and fully understand how to use the environment. To do so they decided to hide the button until all instructions pages were browsed. Eventually, they decided that this was not a useful strategy, and decided to locate the button at the main toolbar, and thus provide the users with more autonomy as to how they want to use the environment.

The previous sections demonstrate changes in students' epistemological beliefs, as reflected in the gradual development of the technologies they designed. The analysis of each of the groups' design process, indicates that different elements in the design of the course act together to support this change. These elements include the various activities students were engaged with in the three themes of the course: a) interacting and critiquing state-of-the-art technologies and interviewing their designers in the *technology analysis* theme, b) designing technologies using our design studio model and the design principles database in the *design studio* theme, and c) discussing the literature in the *theory* theme. Additional analysis also

indicated that the embedded supports for peer learning and the cognitive apprenticeship model of instruction in the course had a crucial role in supporting these changes. A general summary of the findings shows that engaging students in the practical doing of design, served as a productive way to bring up epistemological issues such as those reflected in the four-dimension framework. Discussion of these issues between students made their thinking visible to others and thus negotiable within and between groups. They also enabled students and instructors to make connections of these ideas to theory and to examples of applications in other technologies.

Designing helps students understand learning

This study revealed a gap in students' "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. The analysis also indicated that in three of the four dimensions (learner activity, collaboration, and content accessibility) this gap was reduced during the course. Thus, as students developed their skills to design educational technologies, they also increased the coherence of their epistemological understanding.

We believe that the three-theme structure of the course, including the, *Technology Analysis, Design Studio* and the *Theory* themes, and the instructional design model used in this case provided a rich variety of resources that made it possible for students to learn important aspects of not only design but also learning theory. The cognitive apprenticeship model of instruction, and the supports for peer learning in the course, enabled students to take advantage of these resources, and eventually brought to widening their intuition for designing educational technologies, and to development of their epistemological understanding.

While certainly it is desirable for the preparation of technologists to help teach design skills, we believe that in this case design provided an important opportunity for students who might not ever design educational technologies again to apply and solidify their own understanding of how learning takes place. Technology provided a concrete way for these students to express, reflect on, and refine their own assumptions about teaching and its relationship to learning.

We view the incoherency that characterized students' epistemologies at the beginning of the course as an important stage in their learning process. As in diSessa's "knowledge in pieces" perspective (diSessa, 1988; Smith et al., 1993), we consider learning as a process of building more complex systems of knowledge in which:

"…Some conceptions can fail in some contexts and still play productive roles overall. Some conceptions may come to play small but necessary roles in expert reasoning; others will become irrelevant without being replaced. Contexts of application may shift rather than the conceptions themselves, and even the descriptive vocabulary that defines contexts may change substantially." (p. 148).

Here, diSessa is discussing how students refine their conceptions in physics, but it applies equally well to how our students refined their conceptions of learning (and teaching).
In agreement with this perspective, we realize that novice and experts alike will use a variety of instructional strategies and epistemologies in their design decisions. However, we

would expect experts to be more knowledgeable in the process that Collins (1996) described as weighing tradeoffs and affordances in the design process.

This study reveals that epistemologies that are based on theoretical understanding about various approaches in the field of education may lack coherency if they are not applied to real situations. Engaging students in design during this course proved to be a productive way for students to examine their own epistemological beliefs, negotiate them with peers and experts, and explore them in relation to theory. Such engagement can support expanding students' design intuition as well as meaningfully enhance their epistemological understanding. We therefore suggest that learning to design educational technologies in a design studio fashion should become an integral part of the academic professional development program for graduate students in education in general, and for those studying instructional design in particular. An online step by step version of the instructional model developed in this study is currently available for public use in the Design Principles Database (http://design-principles.org). We invite instructors, students in educational technology and instructional designers to take advantage of this resource.

References

Barab, S. A., & Squire, K. D. (2004). Design-based research: Putting our stake in the ground. The Journal of the Learning Sciences, 13(1), 1-14.

Collins, A. (1996). Design issues for learning environments. In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.), International perspectives on the design of technology-supported learning environments (pp. 347-361). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics (Technical Report No. 403). Cambridge, MA: Bolt, Beranck, and Newman. (ERIC Document Reproduction Service No. ED 284 181)

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences, 13*(1), 15-42.

Dede, C. (2005). Why design-based research is both important and difficult. Educational Technology, 45 (1), 5-8. Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-8.

diSessa, A. A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), Constructivism in the computer age (pp. 49-70). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Dick, W., Carey, L., & Carey, J. O. (2001). The systematic design of instruction (5th ed.). New York: Longman, p. 1-34.

Edelson, D. C. (2002). Design Research: What we learn when we engage in design. *Journal of the Learning Sciences*, 11(1), 105-121.

Glaser, R. (1996). Changing the agency for learning: Acquiring expert performance, in Ericsson, K.A. (ed.), The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games, Mahweh, NJ, Erlabaum, pp 303-311.

Harel, I. (1991). Children designers: Interdisciplinary constructions for learning and knowing mathematics in a computer-rich school. Norwood, NJ: Ablex Publishing.

Hoadley, C., & Kim, D. E. (2003). Learning, Design, and Technology: Creation of a design studio for educational innovation. In A. Palma dos Reis & P. Isaís (Eds.), Proceedings of

the IADIS International Conference e-Society 2003 (pp. 510-519). Lisbon, Portugal: International Association for the Development of the Information Society (IADIS).

Hoadley, C. (2004). Learning and design: Why the learning sciences and instructional systems need each other. Educational Technology, 44(3), 6-12.Kafai, Y. (2006). Playing and Making Games for Learning. Games and Culture Volume 1 Number 1 January 2006 36-40

Kali, Y., (2006). Collaborative knowledge-building using the Design Principles Database. International Journal of Computer Support for Collaborative Learning, 1(2), 187-201.

Kali, Y., (in press). The Design Principles Database as means for promoting design-based research, in Kelly, A. E., & Lesh, R. (Eds.) (in progress). Handbook of design research methods in education. Mahwah, NJ: Lawrence Erlbaum Associates.

Kolodner, Janet, L. Paul J. Camp, David Crismond, Barbara Fasse, Jackie Gray, Jennifer Holbrook, Sadhana Puntambekar, Mike Ryan (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design(tm) Into Practice Journal of the Learning Sciences, Vol. 12, No. 4: pages 495-547

Linn, M.C., Davis, E.A., & Bell, P. (2004). Internet Environments for Science Education. Mahwah, NJ: Lawrence Erlbaum Associates.

Papert, S. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), Constructionism (pp. 1–11). Norwood, NJ: Ablex.

Reeves, T. C. (1994). Evaluating what really matters in computer-based education. In M. Wild, & D. Kirkpatrick, (Eds.), Computer education: New Perspectives (pp. 219-246). Perth, Australia: MASTEC.

Ronen-Fuhrmann, T., & Kali, Y. (2005). Designing technology-based curricula using the design principles database. Paper presented at AERA 2005, Montréal.

Schön, D.A. (1983). The Reflective Practitioner, NY, Basic Books.

Schön, D.A. (1985). The Design Studio, London, RIBA Publications.

Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions Reconceived: A Constructivist Analysis of Knowledge in Transition. Journal of the Learning Sciences, 3(2), 115-163.

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