Computer-Supported Collaborative Learning
DOI 10.1007/s11412-006-8993-x

Collaborative knowledge building using a design principles database

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Received: 00 Month 0000 / Revised: 00 Month 0000 /
Accepted: 00 Month 0000 / Published online: 00 Month 0000
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Abstract In this study we describe a mechanism for supporting a community of learning scientists who are exploring educational technologies by helping them to share and collaboratively build design knowledge. The Design Principles Database (DPD) is intended to be built and used by this community to provide an infrastructure for participants to publish, connect, discuss and review design ideas, and to use these ideas to create new designs. The potential of the DPD to serve as a collaborative knowledge-building endeavor is illustrated by analysis of a CSCL study focused on peer-evaluation. The analysis demonstrates how the DPD was used by the researchers of the peer-evaluation study in three phases. In the first phase, design principles were articulated based on a literature review and contributed to the DPD. In the second phase, a peer-evaluation activity was designed based on these principles, and was enacted and revised in a three-iteration study. In the third phase, lessons learned through these iterations were fed back to the DPD. The analysis indicates that such processes can contribute to collaborative development of design knowledge in a community of the learning sciences. Readers of ijCSCL are invited to take part in this endeavor and share their design knowledge with the community.

Keywords Design-based research · Design principles · Collaborative knowledge-building · Peer-evaluation

Introduction

In the past decades learning scientists, and especially those conducting design-based research (e.g., Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; Dede, 2005; The Design-Based Research Collective, 2003) have sought to develop their field into a *design-science* of education (Collins, 1992), in which critical elements in learning environments are systematically explored in terms of their effect on learning. Simon

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(1969) identifies various professions, such as architecture, engineering, computer science, medicine, and education with the sciences of the artificial, which Collins et al. (2004) refer to as design-sciences. One of the approaches adopted by these fields is to gather and abstract designers' experiences and research by creating collections of *design principles* or *design patterns* that synthesize design knowledge and can be used to guide new designs. Some examples are from the areas of architecture (Alexander, Ishikawa, & Silverstein, 1977), information science (Tufte, 1983) and computer science (Gamma, Helm, Johnson, & Vlissides, 1995).

The DPD (http://www.design-principles.org) was developed in this spirit, to coalesce and synthesize emerging design knowledge about the use of technologies for education. The current study illustrates how this endeavor can contribute to collaborative knowledge building in the learning sciences community. The article commences with a description of the approach used in the DPD to support collaborative knowledge building. This approach is then demonstrated by analysis of a particular CSCL study, in which researchers used the DPD in three phases. Finally, the potential of the DPD to promote collaborative knowledge building is discussed in terms of knowledge-building communities (Scradamalia & Bereiter, 1994).

The design principles approach

Successful curriculum materials depend on a process of iterative refinement to respond to the complex system that impact classroom learning. Emergent design-based research methods suggest ways to capture this process. These methods describe how research teams gather evidence and make decisions about refinements (e.g., Bell, Hoadley, & Linn, 2004; Linn, Bell, & Davis, 2004). However, the design knowledge residing in traditional forms of publication is difficult to use for creating new designs. In order to make this knowledge more useful, new approaches for its organization and synthesis are needed. Linn et al. (2004) suggested using *design principles* as an organization unit. According to this approach, design principles that cut across a variety of designs are synthesized and abstracted based on various design-based research projects. Bell et al. (2004) refer to such design principles as:

> ...an intermediate step between scientific findings, which must be generalized and replicable, and local experiences or examples that come up in practice. Because of the need to interpret design principles, they are not as readily falsifiable as scientific laws. The principles are generated inductively from prior examples of success and are subject to refinement over time as others try to adapt them to their own experiences. In this sense, they are falsifiable; if they do not yield purchase in the design process, they will be debated, altered, and eventually dropped (p. 83).

Design principles are thus strengthened by the empirical studies that explore their application in new designs, which are based on the cumulative design knowledge of the community.

Following this approach, the DPD was designed to support knowledge building as a community endeavor in which educational technology researchers build on each others' knowledge, articulated as design principles, to create new designs and new

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design knowledge. Contributors to the DPD explore the application of these principles in new contexts, and bring their findings back to the DPD. The design knowledge thus grows in the community and principles are debated, refined, or warranted with additional field-based evidence. The current research illustrates how these activities represent knowledge-building community practices *a la* Scradamalia and Bereiter (1994).

The design principles database

Evolution of the project

The DPD has emerged from meetings, conversations, and collaborative activities that occurred between 2001 and 2004. The design principles project started as a grassroots movement and gradually grew to involve a substantial number of educational software designers who contributed to the development of the current form of the DPD. The project was initiated at a CILT (Center for Innovative Learning Technologies) conference in 2000. Participants in a "Visualization and Modeling" workshop requested a set of guidelines that would synthesize the knowledge in the field and enable designers to create innovative technology-based learning environments that are founded on principled design knowledge (Kali, 2002). This call resulted in a CILT seed-grant project, which subsequently organized a series of invited face-to-face and online workshops that lead to the development of the DPD. The DPD was intended to guide conversations in workshops and interactive poster sessions; to capture the library of features of technology-enhanced learning environments; to link features, empirical evidence, and theoretical underpinnings of this work; and to synthesize design knowledge at multiple levels of analysis. Today, via the NSF-funded Technology Enhanced Learning in Science (TELS) center, we continue to develop the DPD and use it as a core framework to capture, synthesize, discuss and disseminate the research-based design ideas of TELS technology software innovations.

Design vocabulary

The design principles project has stimulated the development of an emergent vocabulary to communicate design ideas. Some of the terms used in this paper include:

Feature is used to refer to any effort to use technology to advance learning. In particular, we use *feature* to describe designed artifacts, or parts of artifacts, such as modeling tools (e.g., Buckley et al., 2004; Wu, Krajcik, & Soloway, 2001), visualizations (e.g., Dori & Belcher, 2005; Kali & Orion, 1997), collaboration tools (e.g., Guzdial, Rick, & Kehoe, 2001; Ronen, Kohen-Vacs, & Raz-Fogel, in press), games (e.g., Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Shaffer, 2005), and assessment tools (e.g., Birenbaum et al., in press). The term is also used for activities designed to support the use of any of these tools. Q2

Learning environment is defined as a system that incorporates a set of *features* along with a navigation system and curriculum materials.

Design principle is used to refer to an abstraction that connects a *feature* to some form of rationale. Design principles are described at several levels of specificity, which are articulated in the following section.

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Structure of the design principles database

The DPD is a set of interconnected features and principles. Each feature is linked with a principle, and principles are linked between themselves in a hierarchical manner. Principles in the DPD are described in three levels of generalization: *Specific Principles* describe the rationale behind the design of a single feature or single research investigation. Due to their direct relation to one feature, specific principles in the DPD are embedded within the features. *Pragmatic Principles* connect several Specific Principles (or several features), and *Meta-Principles* capture abstract ideas represented in a cluster of Pragmatic Principles. Figure 1 illustrates these multiple connections schematically, and provides examples of software features and principles in the three hierarchical levels.

The DPD includes two main modes of interaction: a *Contribute* mode, and a *Search/Browse* mode. The contribute mode enables designers to submit new features and principles to the DPD. To publish features in the DPD, authors are required to provide the following pieces of information: a) a detailed description of the functionality of the feature; b) the rationale behind its design (i.e., the specific principle for the feature); c) the context in which the feature was used; and d) the category, or several categories that describe the feature (e.g., visualization tools, inquiry tools, communication tools, ubiquitous computing, etc.). Finally, it is required that every feature is connected to a pragmatic principle. Once a feature is connected to a pragmatic principle, the author of the feature can edit any part of the pragmatic principle, which is usually authored by another contributor, using Wiki technology (e.g., Nicol, Littlejohn, & Grierson, 2005). The Wiki tools enable multiple authoring, while keeping track of the principle's history to enable retrieval of old documentation if needed. In order to contribute a new pragmatic principle, authors are required to provide: a) a detailed description of the principle; b) its theoretical background; and c) tips for designers including limitations, tradeoffs and pitfalls for designing with the principle. Authors are also required to connect pragmatic principles to meta-principles. There are four meta-principles, which are built into the DPD, and originate from the SKI (Scaffolded Knowledge Integration) framework (Linn et al., 2004). The *Contribute mode* thus enables the DPD to grow

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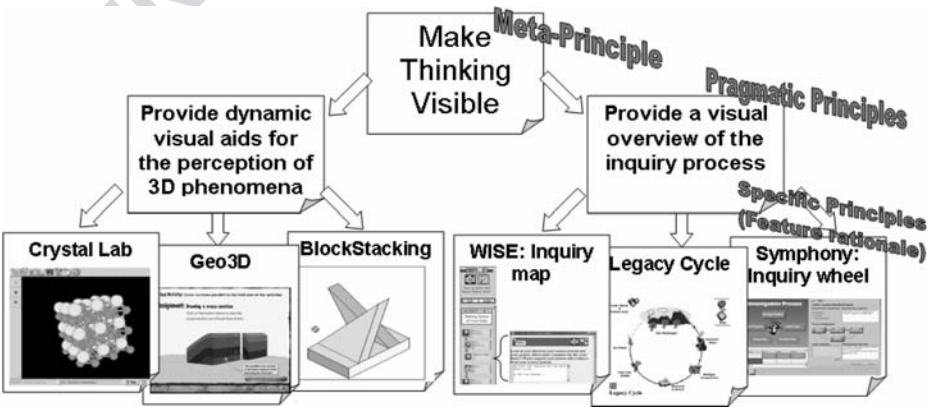

Fig. 1 Schematic representation of structure of the Design Principles Database

while keeping connectedness between features and principles and between principles in the different levels. It also enables the community to continually refine pragmatic principles. About 120 features, with their specific principles have already been contributed to the DPD from a variety of disciplines (mainly from physical, life, and earth sciences, but also from mathematics, humanities and others). About 50 of these features are in the public area, while others are in areas designated for groups, such as workshops and graduate courses or are at draft stages.

The *Search*/*Browse* mode enables users (researchers, teachers, students in the learning sciences) to search for features and principles using filters, which include any of the pieces of information described above. Navigation in the DPD is done via the connections between the features and three levels of principles. For instance, one might start a browsing path by using filters to find all the features in chemistry that are based on inquiry learning for 10th grade. After reviewing the details of one of these features, she might want to link to a pragmatic principle connected to the feature in order to better understand the overarching rationale and to read its theoretical background. Finally, she can review other features connected to this pragmatic principle and see how it is applied in other learning environments in various contexts.

Knowledge building in the design principles database

The potential of the DPD to support community knowledge building is illustrated here by analysis of a particular CSCL design-based research project about a peer-evaluation activity in an undergraduate-level "philosophy of education" course (Kali & Ronen, 2005). The analysis of this particular study demonstrates how the researchers used the DPD in three stages to build on the existing body of knowledge for designing a new peer-evaluation activity, and how this use eventually led to the generation of new design knowledge shared with the community. The following is a description of the study, followed by analysis of the three phases in which the researchers used the DPD in the study.

The peer-evaluation study, which is analyzed here to demonstrate researchers' use of the DPD, took place in a "philosophy of education" course for undergraduates at the Technion, taught by the author of this paper. The main goal of the course was to help students develop their own perceptions about fundamental issues in education and schooling (e.g., what is the goal of schooling? What contents should be taught in school? What should be the role of the teacher?). A main theme in the course was the "ideal school" project, in which groups of 3–4 students constructed a conceptual model of a school that met their evolving educational perceptions. Toward the end of the semester each group gave a short presentation of one day in their ideal school. For these presentations most students used PowerPoint, but other less-conventional means, such as drama performances, were also used. The presentations took place in three class meetings, with three or four presentations in each session. One challenge the instructor faced during these presentations was how to ensure that students get the most out of these meetings. Prior teaching experience in similar contexts revealed that students tend to focus on accomplishing the course's requirements (their own presentations in this case) and are less interested in their peers' projects.

This challenge was addressed by designing a peer-evaluation activity, in which students were involved in the assessment of their peers' "ideal school" presentations.

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The rationale for engaging students in this activity was: a) to ensure their involvement in their peers' projects, b) to create a framework for them to learn from each others' projects, c) to help them develop evaluation skills that they would need as future educators, and d) to reinforce criteria for designing their projects. The analysis of this peer-evaluation activity by the instructor involved the integration of hundreds of assessments (35 students, multiplied by 10 groups, multiplied by about four criteria). To help facilitate the analysis, a computerized system was used, which enabled gathering, presenting and analyzing these assessments in a productive manner. The activity was performed online with the CeLS environment (Collaborative e-Leaning Structures), a novel system that allows instructors to create and conduct a variety of online structured collaborative activities (http://www.mycels.net). The sections below illustrate how this particular study was supported by the DPD, and demonstrate the community knowledge-building processes involved.

Methodological approach

The following section is designed as a meta-study; it analyzes the process in which the particular peer-evaluation study, described above, shaped the design knowledge represented in the DPD. To do this, three main phases of the researchers' use of the DPD in the peer-evaluation study are defined. Phase 1: articulating design principles; Phase 2: design–enactment–refinement iterations; Phase 3: revising pragmatic principles in the DPD. The meta-study uses descriptive analysis to characterize the knowledge-building processes in these three phases. The peer-evaluation study uses design-based research methodologies, described below.

It is important to note that the current analysis was carried out by one of the researchers who conducted the peer-evaluation study analyzed here. In this sense, this analysis is a reflective description of how we used the DPD to support the peer-evaluation study. However, it is assumed that the involvement of the researcher in the study does not constrain the analysis. Rather, it helps in describing the details required to illustrate the potential of the DPD to serve as a collaborative knowledge-building tool for learning scientists.

Phase 1: articulating design principles

Since the DPD was still in its beginning stages, there were no design-principles articulated for peer-evaluation when the study was conducted. Therefore, it was necessary to abstract design principles from existing empirical studies in this field and then design the first version of the peer-evaluation activity based on these principles. The literature review for articulating the pragmatic and specific principles included: Cuddy and Oki (2001); Davies (2000); Dominick, Reilly, and McGourty (1997); Falchikov (2003); Falchikov and Goldfinch (2000); Mann (1999); McConnell (2002); Miller (2003); Ronen and Langley (2004); Suthers, Toth, and Weiner (1997); Topping (1998); and Zariski (1996). At the end of this phase, one pragmatic principle (Fig. 2) linked with three specific principles (embedded within features), were added to the DPD as follows (more details for each principle and feature are available at the DPD via the URLs):

Pragmatic Principle	Enable students to provide feedback to their peers <http://www.design-principles.org/dp/viewPrincipleDetail.php?prKey=343&summary=true>

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Specific Principle 1	Involve students in developing the evaluation criteria for the peer-evaluation <http://www.design-principles.org/dp/viewFeatureDetail.php?feKey=404>
Specific Principle 2	Enable anonymity to avoid bias in peer evaluation <http://www.design-principles.org/dp/viewFeatureDetail.php?feKey=405>
Specific Principle 3	Make the synthesis of the peer-evaluation results visible for learners <http://www.design-principles.org/dp/viewFeatureDetail.php?feKey=406>

It is important to note that the rich body of knowledge concerning peer evaluation can be translated into many more design principles. For the purpose of this study, only ideas that seemed useful for designing the peer-evaluation activity were articulated as design principles and contributed to the DPD.

Phase 2: design–enactment–refinement iterations

Methods in the peer-evaluation study In order to explore the challenges of peer evaluation in our specific context, the study was organized around three design-enactment-refinement iterations. These took place in successive semesters with a total of 144 students (Iteration 1: fall 2003 with 80 students in two groups; Iteration 2: spring 2004 with 29 students; Iteration 3: fall 2004 with 35 students). Each iteration was followed by data analysis and refinements to the design of the online peer-evaluation activity. Data-sources included:

- Peer-evaluation data (numeric grades and textual justifications) gathered in the CeLS environment.
- Artifacts created by each group (PowerPoint slides of the "ideal school" project and online discussions used by each of the groups for developing the conceptions for their project).
- Students' responses to an attitude questionnaire administered at the end of the course.

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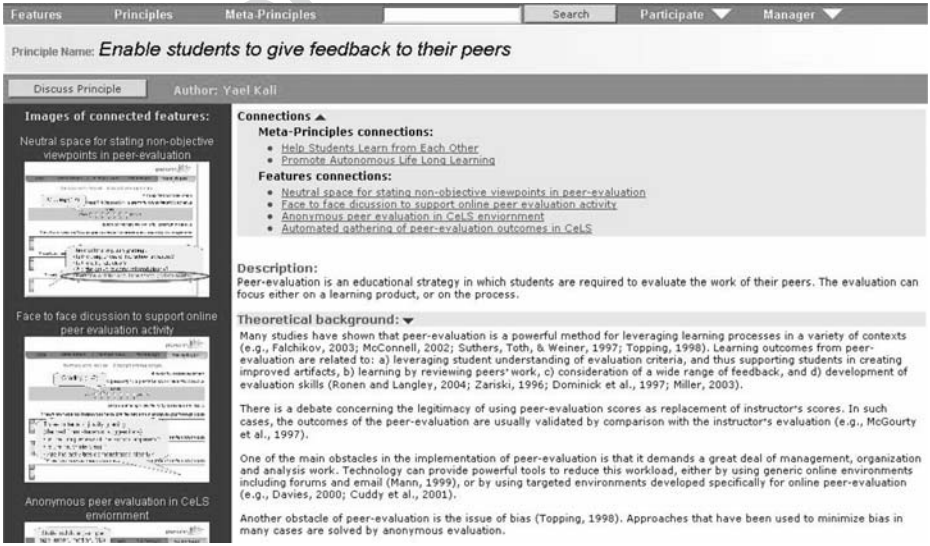

Fig. 2 Pragmatic principle in the Design Principles Database

- Students' spontaneous online discussions in a virtual "coffee corner" at the course's site.
- Instructor's reflective journal including remarks about the events that took place during class.

First iteration: initial design Following specific Principle 1, the initial design of the peer-evaluation activity included criteria that were derived from students' suggestions in a classroom discussion that occurred prior to the presentations and included the following: a) Is the uniqueness of the school apparent? b) Is the rationale clear? c) Are the activities that take place in the school demonstrated clearly? The activity included an online form in which students were required to grade each of the group presentations between 1 (poor) to 7 (excellent). The form also included text fields for students to justify their grading according to the three criteria. Students used prints of these forms to take notes during the presentations, and entered their grades and justifications to the online environment in the next few days. Following specific principles 2 and 3, at the end of the activity all students were able to view: a) a histogram of the scores for each group; b) statistical data (sample size, mean, median, and standard deviation); and c) the individual scores and the justifications for each score (presented anonymously) (Fig. 3). All this information was automatically generated by the CeLS environment without requiring any extra work of the instructor.

In order to assess the validity of student scoring, the set of mean scores that were given by students for each of the ten presentations was compared with the set of scores given by the instructor for these presentations. The analysis indicated that

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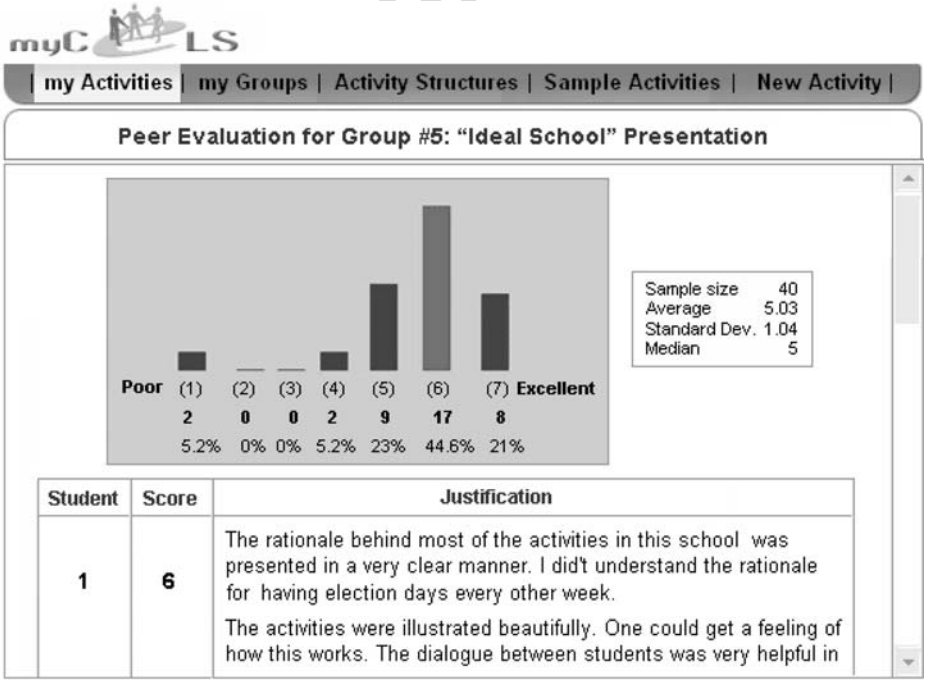

Fig. 3 Interface of the peer-evaluation activity in the CeLS environment

though there was a moderate positive correlation between students' scores and the instructor's scores ($r = 0.43$), it was not significant ($p = 0.1$). A detailed examination of the qualitative data enabled us to identify the cases in which large discrepancies were found between the students' and instructor's scoring. Such discrepancies were especially apparent in presentations that introduced educational perceptions that were relatively "extreme" according to views held by many students. Though students were specifically instructed to try to ignore personal viewpoints in their grading, it seems that they found it difficult to do so. The issue of differentiating between objective criteria and personal stands was taken as a focus for the second iteration. It is important to note that this study assumed that purely objective criteria do not exist, as we are all somewhat subjective in our personal viewpoints. However, an essential aspect of peer-evaluation is to find those criteria that will provide equitable measures that will minimize those biases.

Second iteration: differentiating between objective criteria and personal stands
Based on the outcomes of the first iteration, and in order to foster objectivity, we decided to refine the design of the online peer-evaluation activity so that it would provide students with a way to differentiate between objective aspects of the presentation and their personal, non-objective viewpoints. Our rationale was that if students would be given a chance to express these views in a neutral area, which does not affect the score, they would be more aware of their personal values and emotional stands, and thus, provide a more objective score. Therefore, we defined the following specific principle to explore in this iteration:

Specific Principle 4	Enable students to state their personal, non-objective viewpoints about their peers' work <http://www.design-principles.org/dp/viewFeatureDetail.php?feKey=401>

As in the first iteration, a class discussion about evaluation criteria preceded the activity. To engage students with the issue of personal viewpoints in peer evaluation, we decided to seed the class discussion with ideas for criteria, including a criterion about the degree to which a student is in agreement with views introduced in the presentation. Following the classroom discussion, four text fields for justifying scores were defined. The first three were similar to those defined in the first iteration (referring to uniqueness of the school, rationale, and demonstration of activities), but a forth text-field was added, named "My personal opinion about this school." As suggested by students, this field was not considered a criterion that should effect scoring. Rather, it was intended to provide general feedback for presenters as to the degree of acceptance of their ideas among other students. Another specific principle was defined for further exploration:

Specific Principle 5	Design features to foster discussion about non-objective evaluation criteria <http://www.design-principles.org/dp/viewFeatureDetail.php?feKey=404&summary=true>

Outcomes indicated that the refined design, which enabled students to express their personal viewpoints, assisted students to better differentiate between objective criteria and personal stands. This was evident from a higher correlation, compared to the first iteration, between the set of scores provided by the instructor for each of the groups and those provided by students ($r = 0.62$, $p = 0.03$). Furthermore, the

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learning gains from the peer-evaluation activity, as indicated from the attitude questionnaire, seemed to be higher in the second iteration (Fig. 4). However, it was found that since the contents that were being evaluated involved cultural and political values, tensions arose in class discussion between students and were expressed as biased scoring and inappropriate and even offending justifications in the peer-evaluation activity (Kali & Ronen, 2005). The issue of respecting classroom norms was thus selected as a main focus for design and exploration in the third iteration.

Third iteration: evaluating students as evaluators Based on the findings of the second iteration, and in order to further foster objectivity, classroom norms and tolerance, we designed the third iteration of the activity according to the following design principle:

Specific Principle 6	When the evaluated contents are socially/culturally sensitive, avoid grading students according to peer-evaluation results. Rather, evaluate students as evaluators <http://www.design-principles.org/dp/viewFeatureDetail.php?feKey=403&summary=true>

According to this principle, 15% of students' scores in semester "fall 2004" were derived from the peer-evaluation activity and indicated how well they served as evaluators. The score was comprised of: a) number of evaluations provided; b) respecting classroom pre-defined norms; c) quality of justifications; and d) degree of correlation with instructor's score. Outcomes indicated that implementation of the redesigned activity enabled students to better exploit the vast advantages of peer evaluation, tensions were decreased (Kali & Ronen, 2005), and higher correlations with the instructor's scores ($r = 0.7$, $p = 0.02$) were found. Furthermore, learning gains and student satisfaction, as indicated from the attitude questionnaire, stayed high.

Phase 3: revising pragmatic principles

After the new specific principles were added to the DPD and together with the example features which were explored in Phase 2, it was possible to enrich the original pragmatic principle in the DPD (*Enable students to give feedback to their*

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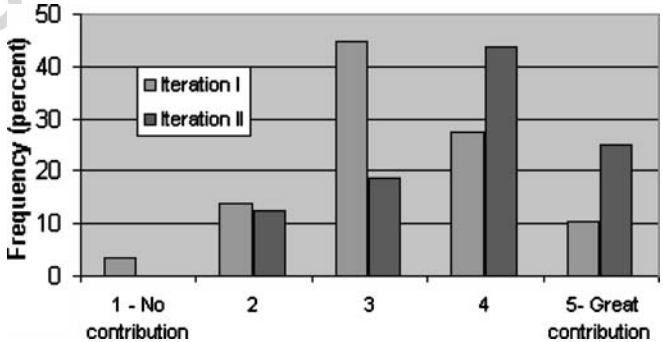

Fig. 4 The degree of contribution of the peer-evaluation activity on student learning in the first two iterations as indicated from the attitude questionnaire

peers), which connects these features, with lessons learned through the cycles of the peer-evaluation study using the Wiki capabilities of the DPD described above. An important way to enrich a pragmatic principle in the DPD is to add emerging design knowledge to the section "Tips (Challenges, Limitations, Tradeoffs, Pitfalls)." As the knowledge gained through this particular DBR had to do with a very specific context, it was decided to articulate this knowledge as limitations of the pragmatic design principle. The limitations were stated in the DPD as follows:

> Note that when the contents being evaluated in a peer-evaluation activity have to do with beliefs and morals, there is higher probability for biased scoring. In such cases it is recommended to enable students to state their personal, non-objective viewpoints about their peers' work in a neutral space, which does not affect scoring. As in other peer-evaluation contexts this feature works best when students are involved in developing the criteria. To do that, it is recommended to seed the discussion (or any other means for criteria building) with ideas for non-objective criteria.
>
> Note also that biased scoring and inappropriate language in peer evaluation can occur when the contents that are being evaluated are socio-culturally sensitive. In such cases it is advised to avoid grading students according to peer-evaluation results. Rather, to reduce tensions it is recommended to evaluate students as evaluators, based on their respecting of classroom norms, and on the quality of their justifications.

Another revision to the original pragmatic principle was done automatically by the system. The new features (and embedded specific principles) that were explored in this study became part of the principle in the form of links that exemplify the use of the principle and provide further evidence.

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Discussion

The analysis described above illustrates a three-phase process, in which design knowledge, abstracted from the existing body of knowledge about peer-evaluation and contributed to the DPD, was explored in a new context. The design knowledge was strengthened by this exploration; the pragmatic principle "*Enable students to give feedback to their peers*" was successfully applied in the "philosophy of education" course, and thus connected with additional empirical outcomes. Furthermore, new theoretical knowledge about issues of bias and objectivity in peer evaluation was created, brought back to the community via the DPD, and synthesized with the existing knowledge. The development of this theoretical knowledge was articulated as practical design knowledge: tips for designing peer-evaluation activities in which the contents being evaluated have to do with morals, values or sensitive issues. The DPD in these processes served as a community database as described by Scradamalia and Bereiter (1994)—an essential tool for collaborative knowledge-building processes:

> The community database serves as an objectification of a group's advancing knowledge, much as do the accumulating issues of a scholarly journal but with additional facilities for reframing ideas and placing them in new contexts (p. 277).

Ideally, researchers who refine pragmatic principles based on their outcomes are not those who are the original contributors of the principles, as in the case of this research. A design study with the DPD could start when a researcher or research group articulate a pragmatic design principle that summarizes outcomes from a design study in a certain area. They provide theoretical background and connect the pragmatic principle with one or more features, which provide field-based evidence and illustrate how the principle was applied in their specific context (this corresponds to Phase 1 in the current study, with the exception that the pragmatic principle was abstracted from the literature). Then, another research group uses the information provided in the pragmatic principle to design new features and explore them in new contexts (this corresponds to Phase 2 in the current research). Up to this stage, this is quite similar to the common process in which researchers build on knowledge presented via traditional means of publication. The added value of the DPD is particularly evident in the next stage (corresponding to Phase 3), in which new contributions to theory are brought back to the DPD and synthesized with the existing knowledge. This can be performed in several ways: a) empirical outcomes from the design iterations are explicitly translated into new features/specific principles and connected to the original pragmatic principle; b) additional practical design knowledge, based on the research, such as limits, tradeoffs and pitfalls, are added to a pragmatic principle; and c) the pragmatic principle is refined, using the Wiki capabilities of the DPD, to capture the new design knowledge gained in the research.

In this way the community produces knowledge that is a collective product and not merely a summary report of individual research projects or a collection of outputs from group work. Scradamalia and Bereiter (1994) make a distinction between first-order and second-order community environments. In first-order environments, participants' learning stems from adaptation to the knowledge in the environment and is limited to that adaptation. They describe this type of learning as being "asymptotic." In second-order environments though,

> ...learning is not asymptotic because what one person does in adapting, changes the environment so that others must readapt. Adaptation itself involves contributions to collective knowledge. Because this very activity increases the collective knowledge, continued adaptation requires contributions beyond what is already known, thus producing nonasymptotic learning. (p. 275)

The capability of the DPD to enable contributors to widen and refine the design knowledge and to make the synthesized knowledge available for use and further development are characteristics of the DPD, which correspond to a second-order collaborative knowledge-building tool.

Conclusions

The analysis above indicates that the DPD can contribute to the collaborative development of design knowledge in the learning sciences community. This knowledge is developed through continuous empirical reexamination, negotiation and refinement of pragmatic design principles by the community. At the same time, these principles become more useful for designers (and thus better deserve their

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name) when they are connected with a variety of features and specific principles that exemplify how they can be applied in different contexts.

The DPD is still in its initial stages, and its framework is open for public negotiation and refinement. There are several research teams that have suggested frameworks for connecting elements of design and generalized design guidelines. One important endeavor in this direction is the Scaffolding Design Framework for designing educational software, suggested by a group from the University of Michigan and Northwestern University (Quintana et al., 2004). Another important venture in this direction is the Design Patterns trajectory (Linn & Eylon, in press), which seeks to identify common factors in promising sequences of activities and define them as patterns that can guide designers of learning environments. Advances to merge efforts between these trajectories are currently taking place.

Additionally, in order to exhaust the full potential of the DPD, there is a need for a critical mass of contents contributed and negotiated by the community. As Collins et al. (2004) state:

> Our approach to design research requires much more effort than any one human can carry out. We put forward these ideas not because we expect each and every design experiment to embody them, but to give an overview of all the things the design-research community is responsible for. In our ideal world, design research will move in the direction of embodying many of the practices we outline here. But it will take teams of researchers and accessible archives documenting design experiments... to make these dreams at all possible (p. 33).

We envision this dream will have come true when the DPD is be populated with hundreds of features and specific principles, connected to pragmatic principles, which continuously evolve through negotiation in a dynamic knowledge-building community. To meet this challenge, the TELS (Technology Enhanced Learning in Science) center continues to organize workshops and graduate courses that support researchers in contributing features and principles to the DPD. Additionally, we encourage the readers of ijCSCL, who explore the design of educational technologies, to take part in this endeavor and share their design knowledge with the community of the DPD.

Acknowledgments The DPD is supported by the US National Science Foundation as part of the TELS center (grant ESI/CLT 0334199). I would like to thank Marcia Linn, TELS Principle Investigator, for her enormous inspiration, support and contribution to the DPD project. I would also like to thank the CILT (Center for Innovative Learning Technologies) postdocs and PIs, who supported and encouraged the design principles project at its early stages. Many thanks to Miky Ronen from the Holon academic institute of technology for providing the CeLS environment and helping with the peer-evaluation analysis; to Orit Parnafes from the University of California, Berkeley, and to the design-group graduate students at the Technion for very thoughtful comments on drafts of this paper. Finally, thanks to all the people who helped shape the framework, and contributed features and principles to the DPD.

References

Alexander, C., Ishikawa, S., & Silverstein, M. (1977). *A pattern language: Towns, buildings, and construction*. New York: Oxford University Press.

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.

UNCORRECTED PROOF

Barab, S. A., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development*, *53*(1), 86–107.

Bell, P., Hoadley, C. M., & Linn, M. C. (2004). Design-based research in education. In M. C. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 73–85). Mahwah, New Jersey: Lawrence Erlbaum.

Birenbaum, M., Breuer, K., Cascallar, E., Dochy F., Dori, Y., Ridgway, J., & Weisemes R. (In press). A learning integrated assessment system. In R. Wiesemes, & G. Nickmans (Eds.), *EARLI Series of Position Papers*. Educational Research Review. Q2

Buckley, B. C., Gobert, J. D., Kindfield, A., Horwitz, P., Tinker, R., Gerlits, B., et al. (2004). Model-based teaching and learning with BioLogica™: What do they learn? How do they learn? How do we know? *Journal of Science Education and Technology*, *13*(1), 23–41.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology* (pp. 15–22). Berlin Heidelberg New York: Springer.

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

Cuddy, P., & Oki, J. (2001). Online peer-evaluation in basic pharmacology. *Academic Medicine*, *76*(5): 532–533.

Davies, P. (2000). Computerized peer assessment. *Innovations in Education and Training International*, *37*(4), 346–355.

Dede, C. (2005). Why design-based research is both important and difficult. *Educational Technology*, *45*(1), 5–8.

Dominick, P. G., Reilly, R. R., & McGourty, J. (1997). The effects of peer feedback on team member behavior. *Group and Organization Management*, *22*, 508–520.

Dori, Y. J., & Belcher, J. W. (2005). How does technology-enabled active learning affect students' understanding of scientific concepts? *The Journal of the Learning Sciences*, *14*(2), 243–279.

Falchikov, N. (2003). Involving student in assessment. *Psychology Learning and Teaching*, *3*(2), 102–108.

Falchikov, N., & Goldfinch, J. (2000). Student peer assessment in higher education: A meta-analysis comparing peer and teacher marks. *Review of Educational Research*, *70*(3), 287–322.

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1995). *Design patterns: Elements of reusable object-oriented software*. Reading, Massachusetts: Addison-Wesley.

Guzdial, M., Rick, J., & Kehoe, C. (2001). Beyond adoption to invention: Teacher-created collaborative activities in higher education. *Journal of the Learning Sciences*, *10*(3), 265–279.

Kali, Y. (2002). CILT2000: Visualization and modeling. *Journal of Science Education and Technology*, *11*(3), 305–310.

Kali, Y., & Orion, N. (1997). Software for assisting high school students in the spatial perception of geological structures. *Journal of Geoscience Education*, *45*, 10–21.

Kali, Y., & Ronen, M. (2005). Design principles for online peer-evaluation: Fostering objectivity. Proceedings of CSCL 2005 (Taipei, Taiwan). In T. Koschmann, D. D. Suthers & T. W. Chan (Eds.), *Proceedings of CSCL 2005. Computer support for collaborative learning: The Next 10 Years!* (pp. 247–251). Mahwah, New Jersey: Lawrence Erlbaum.

Kali, Y., Spitulnik, M., & Linn, M. (2004). Building community using the design principles database. In P. Gerjets, P. A. Kirschner, J. Elen & R. Joiner (Eds.), *Instructional design for effective and enjoyable computer-supported learning: Proceedings of the first joint meeting of the EARLI SIGs instructional design and learning and instruction with computers*. Tuebingen, Germany: Knowledge Media Research Center. Q3

Linn, M. C., Bell, P., & Davis, E. A. (2004). Specific design principles: Elaborating the scaffolded knowledge integration framework. In M. C. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 315–340). Mahwah, New Jersey: Lawrence Erlbaum.

Linn, M. C., & Eylon, B.-S. (In press). Science education: Integrating views of learning and instruction. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology (2nd edition)*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Mann, B. (1999). Web course management "post and vote": Peer assessment using generic Web tools. *Australian Educational Computing*, *14*(1), 15–20.

McConnell, D. (2002). Collaborative assessment as a learning event in E-learning environments. In G. Stahl (Ed.), *Proceedings of CSCL 2002.Computer support for collaborative learning: Foundations for a CSCL community* (pp. 566–567). Mahwah, New Jersey: Lawrence Erlbaum.

Miller, P. J. (2003). The effect of scoring criteria specificity on peer and self-assessment. *Assessment and Evaluation in Higher Education*, *28*(4), 383–394.

UNCORRECTED PROOF

Nicol, D., Littlejohn, A, & Grierson, H. (2005). The importance of structuring information and resources within shared workspaces during collaborative design learning. *Open Learning*, *20*(1), 31–49.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Golan-Duncan, R., et al. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences*, *13*(3), 337–386.

Ronen, M., Kohen-Vacs, D., & Raz-Fogel, N. (In press). Adopt & adapt: Structuring, sharing and reusing asynchronous collaborative pedagogy. *Proceedings of ICLS 2006. Bloomington, IN*. Q2

Ronen, M., & Langley, D. (2004). Scaffolding complex tasks by open online submission: Emerging patterns and profiles. *Journal of Asynchronous Learning Networks*, *8*(4), 39–61.

Scradamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences*, *3*(3), 265–283.

Shaffer, D. W. (2005). Epistemic games. *Innovate*, *1*(6). Reprinted in *Computer Education* (In press). Q2

Simon, H. A. (1969). *The sciences of the artificial*. Cambridge, Massachusetts: MIT.

Suthers, D. D., Toth, E. E., & Weiner, A. (1997). An integrated approach to implementing collaborative inquiry in the Classroom. In R. Hall, N. Miyake & N. Enydey (Eds.), *Proceedings of CSCL 1997: The second international conference on Computer Support for Collaborative learning* (pp. 272–279). Mahwah, New Jersey: Lawrence Erlbaum.

The Design-Based Research Collective (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5–8.

Topping, K. (1998). Peer assessment between students in colleges and universities. *Review of Educational Research*, *68*(3), 249–276.

Tufte, E. R. (1983). *The visual display of quantitative information*. Cheshire, Connecticut: Graphics.

Wu, H. K., Krajcik, J., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching*, *38*, 821–842.

Zariski, A. (1996). Student peer assessment in tertiary education: Promise, perils and practice. In J. Abbott & L. Willcoxson (Eds.), *Proceedings of the 5th annual teaching learning forum: Teaching and learning within and across disciplines* (pp. 189–200). Perth: Murdoch.

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