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BUILDING COMMUNITY USING THE DESIGN PRINCIPLES DATABASE

In this study, we describe a mechanism to support designers in sharing and building design knowledge. The *Design Principles Database* was developed as an infrastructure for designers to publish, connect, discuss and review design ideas. The database is intended to be built by and serve the community of educational software designers. In this study we examine how the activities of a two-week workshop with educational software designers helped participants synthesize their knowledge. Our outcomes are based on qualitative analysis of online asynchronous discussions, teleconference transcriptions, participants' artifacts and interviews. The findings are grouped in three areas: a) the ways participants communicated their features, b) the ways participants synthesized design knowledge, and c) strategies for leveraging contributions to the database. The findings indicate that using appropriate activities, the database has the potential to serve crucial functions in enabling the field to synthesize the creative contributions of its members.

INTRODUCTION

Successful curriculum materials depend on a process of iterative refinement to respond to the complex system that impacts classroom learning. Emergent design-based research methods suggest ways to capture this process (Barab & Squire, in press; Brown, 1992, Collins, 1992; Edelson at al., 1999; Linn & Hsi 2000; The Design-Based Research Collective, 2003). These methods describe how research teams gather evidence and make decisions about refinements (Bell, Hoadley, & Linn, in press; Linn, Davis, & Bell, in press).

This paper introduces a mechanism for extending these methods to the community of designers in a field—in this case, designers of innovative approaches to science learning. The *Design Principles Database* supports the evolutionary process of building on the successful ideas from multiple research groups to create innovative features.

Many researchers share the lessons learned from their studies, and make their innovations available on the Web, yet other designers rarely make use of these artifacts to enhance their own innovations. Learning by simply interacting with the available software is difficult because the rationale behind the design of the features is not always clear. Also, the iterative process of the design is invisible for the software users. Publications usually report success stories in technology-enhanced learning and instruction, rather than the lessons learned from the design process.

We describe a mechanism we developed as part of an NSF funded project, to support designers in sharing and building design knowledge. The *Design Principles Database* was developed as an infrastructure for designers to publish, connect, discuss and review design ideas. The database is designed to bridge research and design in a communicable and systematic manner. It also has the potential of enabling designers to build on the successes and failures of others rather than reinventing solutions that others have struggled to develop. The database is intended to be built by and serve the community of educational software designers. Although we expect our main audience to be educational researchers who are involved in software design, we believe other audiences could also benefit. Ultimately, we envision the database informing and guiding communities harvesting their design knowledge, designers creating new applications, teachers and curriculum developers customizing and tailoring existing instructional materials, as well as graduate students in the learning sciences learning about, and contributing to the design field. The database synthesizes findings from multiple research groups and also validates these findings by supporting the process of community-wide peer review of innovations.

We report here about the first phase of a larger research project that will explore the impact of the database on the educational software design field. In this first phase we explore the potential of the database to serve as a tool for designers to synthesize their knowledge while they contribute their research-based design experience to the database, and connect them with other designers' ideas. In the second phase will also investigate the utility of the *Design Principles Database* to support educational technology designers, curriculum designers and others in using the contents of the database to inform new designs and technologies.

Our poster describes one approach to using the Database to *build* and *synthesize* community-wide knowledge. At February 2003, The Center for Innovative Learning Technology (CILT) carried out an online workshop in which leading researchers in the educational design field, from various institutions, negotiated their ideas using the *Design Principles Database*. We examine how the activities of the workshop and the framework embedded in the database helped participants synthesize their knowledge. This study centers around the following research questions: How did the *Design Principles Database* and the activities of the workshop support designers in 1) contributing new features to the database and 2) synthesizing new design principles between several features.

DESIGN VOCABULARY

The design principles project (described below) has stimulated the development of an emergent vocabulary to communicate design ideas. Terms used in this paper follow:

We use *feature* 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, simulations, micro-worlds, visualizations, collaboration tools, games, and assessment tools. We define a *learning environment* as a system that incorporates a set of these along with a navigation system and curriculum materials. We use *design principle* to refer to an abstraction that connects a feature to some form of rationale. Design principles can be at several levels of specificity—articulated below. Principles can link to one feature, to several features, and can link several principles together. Design principles emanate from and connect to theories of learning and instruction.

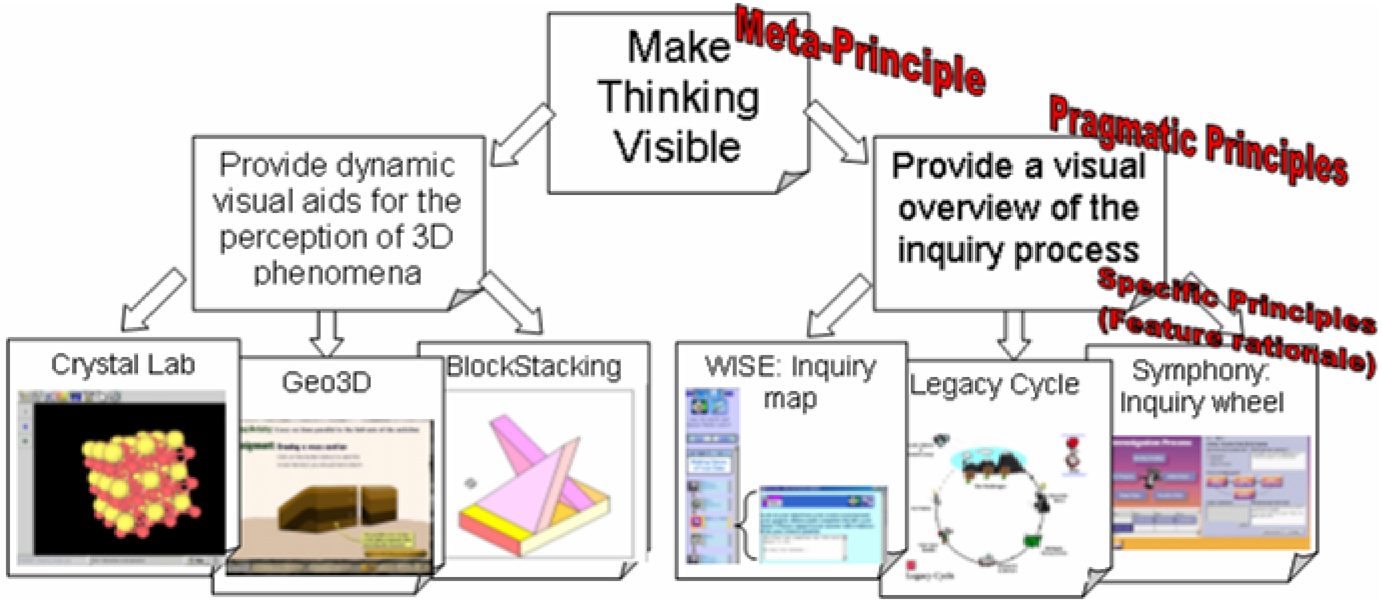
THE DESIGN PRINCIPLES DATABASE

The *Design Principles Database* (http://wise.berkeley.edu/design) 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 database are described in three levels of generalization: *Specific Principles* are those that connect directly to a single feature or single research investigation and provide the specific rationale behind the design of that feature. *Pragmatic Principles* connect several *Specific Principles*, and *Meta-Principles* capture abstract ideas represented in a cluster of *Pragmatic Principles*. Figure 1 illustrates these multiple connections, and provides examples of software features and principles in the three hierarchical levels.

The database includes two main modes of interaction: a *Contribute* mode, and a *Search/Browse* mode. The *Contribute* mode enables designers to describe features of their software with the theoretical framework and evidence of their success. In order to contribute a *feature* to the database a designer is required to provide several pieces of information including: a detailed description of the feature, a rationale (i.e., the specific design principle that led to the design of the feature), the context in which the feature is used, evidence of success or lack of success, reference, and an image illustrating the feature.

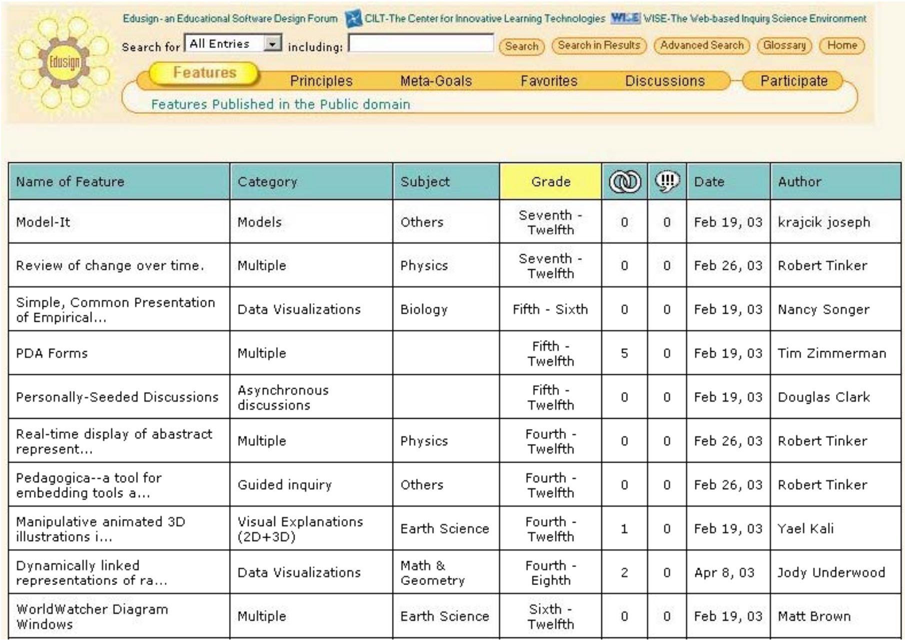
Features have already been entered into the *Design Principles Database* from several different disciplines (Figure 2). As a feature is entered into the database, the designer is also required to choose a category, or several categories to describe the feature (e.g., visualization tools, inquiry tools, communication tools, ubiquitous computing, etc.), and provide URLs for downloads. Finally, it is required that every feature is connected to a *pragmatic* design principle. In order to contribute a *pragmatic* design principle, designers are required to provide a detailed description of the principle, its goals, limitations, tradeoffs and pitfalls. They are also required to connect *pragmatic* principles to *meta-principles*. In this way the database can grow while keeping connectedness between features and principles and between principles in the different levels.

The *Search/Browse* mode enables users to search for features and principles using filters that include any of the pieces of information described above. For instance, a hypothetical browsing path could include a search for all the features in chemistry that are based on inquiry learning, for 10^{th} grade. The user of the database could review the features with these characteristics, review the related design principles connected to features, and finally, review other features from other contexts that are also connected to these same design principles.



Make Thinking Visible is a meta-principle in the database that calls for designing features that assist students to create visual representations of their ideas in order to communicate them to teachers and peers. It *also calls for designing visualizations to assist learner*s understand complex concepts*. This meta-principle represents a cluster of pragmatic design principles. Two of them are: Provide visual aids for the perception of 3D phenomena, and* provide *a visual overview of the inquiry process. Each of these pragmatic principles is connected with several specific design principles which are part of a* software-feature description*. For instance, the pragmatic design principle that calls for providing visual aids is connected to features of the following software: Crystal Lab (developed by Concord Consortium to assist students understand various crystal structures), Geo3D (developed at Weizmann Institute to help students perceive geological structures) and BlockStacking (developed at U.C. Berkeley to help university students develop spatial skills required in engineering). Each of these features in the database includes the specific design principle which explains the rationale that underlies its unique design.The pragmatic design principle that calls for providing a visual overview of the inquiry process is connected to the following features in the database: the WISE inquiry map, (U.C. Berkeley); the Legacy Cycle (Vanderbilt), and the Symphony inquiry wheel. Each of these features helps students navigate within the Inquiry process in a unique manner explained in their specific design principles in the database.*

Figure 1. Multiple connections between Specific, Pragmatic and Meta-Principles in the Design Principles Database



Name of Feature	Category	Subject	Grade			Date	Author
Model-It	Models	Others	Seventh - Twelfth	0	0	Feb 19, 03	krajcik joseph
Review of change over time.	Multiple	Physics	Seventh - Twelfth	0	0	Feb 26, 03	Robert Tinker
Simple, Common Presentation of Empirical...	Data Visualizations	Biology	Fifth - Sixth	0	0	Feb 19, 03	Nancy Songer
PDA Forms	Multiple		Fifth - Twelfth	5	0	Feb 19, 03	Tim Zimmerman
Personally-Seeded Discussions	Asynchronous discussions		Fifth - Twelfth	0	0	Feb 19, 03	Douglas Clark
Real-time display of abastract represent...	Multiple	Physics	Fourth - Twelfth	0	0	Feb 26, 03	Robert Tinker
Pedagogica--a tool for embedding tools a...	Guided inquiry	Others	Fourth - Twelfth	0	0	Feb 26, 03	Robert Tinker
Manipulative animated 3D illustrations i...	Visual Explanations (2D+3D)	Earth Science	Fourth - Twelfth	1	0	Feb 19, 03	Yael Kali
Dynamically linked representations of ra...	Data Visualizations	Math & Geometry	Fourth - Eighth	2	0	Apr 8, 03	Jody Underwood
WorldWatcher Diagram Windows	Multiple	Earth Science	Sixth - Twelfth	0	0	Feb 19, 03	Matt Brown

Figure 2: List of features in the database (partial)

CONTEXT OF THE STUDY

Evolution of the project

The *Design Principles Database* 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 *Design Principles Database*. The project was initiated at the CILT 2000 conference. Participants in the 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 *Design Principles Database* (Kali et al, 2002, Kali et al, 2003). The database was intended to guide conversations in the 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 newly NSF funded

Technology Enhanced Learning in Science (TELS) center, we continue to develop the *Design Principles Database* and use it as a core framework to capture, synthesize, discuss and disseminate the research-based design ideas of TELS technology software innovations.

The Design Principles Online Workshop

The CILT workshop was conducted to support educational technology designers in contributing features and design principles to the *Design Principles Database*. The participants were 24 educational technology researchers in 10 teams. Each team was comprised of a mentor – a leading figure in the field of design, and a mentee – a postdoctoral researcher or graduate student working with the mentor. The teams came from various universities and institutions, mostly in the United-States (including University of California Berkeley, University of Michigan, Northwestern University, Georgia Tech, Penn State University, Arizona State University, and the Israeli Weizmann Institute of Science). The first week focused on sharing features. Each mentor-mentee team was required to contribute a feature from their software to the database, and present it in a teleconference at the end of the week. Following these presentations, multi-institutional groups of two or three teams were formed to synthesize pragmatic design principles that connected the 2-3 teams' features. The second week focused on building these cross-linking design principles. At the end of the second week each group presented the design principles that they synthesized in a summarizing teleconference. The workshop was hosted and supported through *Blackboard*. Using this online environment we provided all of the directions participants needed to enter information into the *Design Principles Database* and it also supported participants' online threaded discussions.

METHODS

Our analysis for this study centers around the use of the online workshop as a means to build community around the Design Principles Database. We briefly describe the data sources and data analysis techniques.

Data sources

To answer the research questions above we use the following data sources:

- Records of the two online asynchronous discussions in the workshop.
- Transcriptions of two 90-minute teleconferences that occurred during workshop.
- Features (21) and Principles (6) contributed by workshop participants to the *Design Principles Database.*
- Transcriptions of three 60-minute interviews with individual participants of the workshop. These interviews were intended to elicit participants' ideas about the synthesis of design principles. Interviewees were asked to compare and contrast

their contributions to the database with other features and principles in the database, which were entered prior to the workshop.

Data Analysis

In order to better understand the ways participants communicated design knowledge we coded and categorized the online records and teleconference transcriptions, and searched for common patterns in participants' contributions to the discussions. The categories that immerged from the analysis include:

- **Describing** a feature (also functionality and context of use)
- **Explaining** a feature (provide rationale, frameworks, beliefs); or asking for explanation of a feature.
- **Linking** or referring to other features (comparing contrasting or asking for comparison)
- **Analysing** a feature (examine a feature in terms of emergent features and principles).
- **Application** (Providing examples related to the application of principles).
- **Theorizing** (posing claims/questions, referring to research in the field, relating the emergent ideas with existing theory)
- **Synthesizing** (grouping, finding commonalities, beginning to describe principle, introduction vocabulary, emergent criteria for principles)
- **Meta discussion** (discussing how principles should be thought about)

In order to gain deeper insight into the ways design-knowledge was synthesized we focused our analysis on three case-study groups. The groups were chosen based on the breadth of the online discussion in which they synthesized their mutual design principles. This discussion was segmented into small increments which were characterized by the manner in which they advance the group discussion toward the goal of synthesizing a design principle. The advancement of the discussion was mapped using a graphic coding scheme in which circles represent design principles, squares represent features, and arrows represent connections between them (Table 1).

OUTCOMES

Our findings can be grouped in three areas: a) the ways participants communicated their features, b) the ways participants synthesized design knowledge and obstacles in this endeavor, and c) strategies for leveraging contributions to the database.

Communicating features

The discourse in week one was characterized mainly by participants' descriptions and explanations of features. This is manifested in the abundance of the *Describe* and *Explain* categories in Figure 3. When asked to share features at the teleconference, participants frequently intertwined descriptions of a feature's functionality and its context of use, with explanations of their rationale in designing it, and their theoretical commitments. This finding supports our design decision to embed the specific principles within the feature-description page in the database.

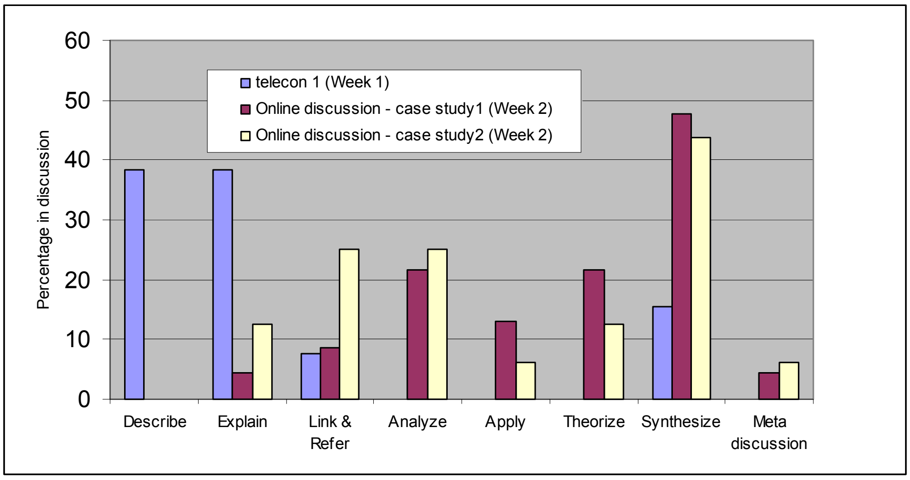


Figure 3. Categorization of sample discussions in the two weeks of the workshop

Synthesizing design knowledge

The discourse in week two of the workshop was characterized by references to other teams' features and by efforts to synthesize design ideas. The example representative discussions provided in Figure 2 indicate that participants were more engaged in comparing and linking their features, grouping features into emergent principles, analyzing features in terms of the emergent principles, providing examples from their own research and from related research, and having meta-discussions about principles. This difference can be explained by the different nature of tasks in week one versus week two. The first week focused on sharing features and the second week focused on a collaborative synthesis of design principles. Thus, much of our analysis focused on the second week, so that we could study the ways participants synthesized their design knowledge.

Our analysis shows that group efforts to synthesize design principles that cut across several mentor-mentee teams yielded different degrees of productivity. Some groups seemed to have convergent discussions that eventually led to well defined and robust design-principles, while other groups' discussions were more divergent. Kali, Spitulnik and Linn (in preparation), provide a detailed analysis of three case-study groups, and the ways participants in these groups synthesized their design knowledge. An example analysis of a convergent discussion is shown in Table 1.

One of our most salient findings, which immerged from the detailed analysis, is the need for groups to negotiate a shared vocabulary. We describe this as an obstacle to building design knowledge, and contrast the ways participants dealt with this obstacle. Groups that were more productive (such as the group in case study 1), made a special effort to negotiate meaning of design ideas. They asked for specific explanations of each other's features; they suggested and refined design principles; they questioned diverse aspects of emergent principles; they searched links of these aspects with their own features and their colleagues' features; they connected emergent ideas with examples and theory; and finally, they had meta-discussions about the way design principles should be thought about. This negotiation brought to gradual development of a common vocabulary within a group, and to gradual refinement of a robust, well-defined design principle. An example of such a negotiation and how it brought to construction of a robust design principle is provided in Table 1.

Leveraging contributions to the database

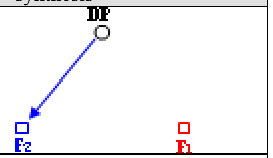
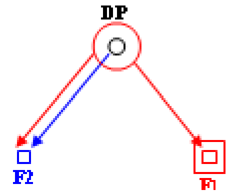
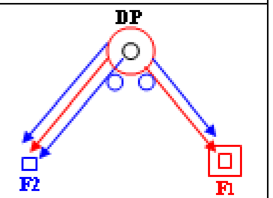
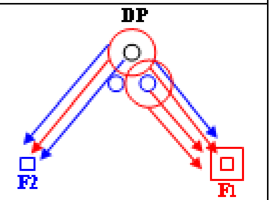
Interviews conducted after the workshop indicate that activities, which require designers (who already put their features and principles in the database) to connect, contrast and find gaps between their ideas and contrasting ideas are highly effective in leveraging designers' contributions to the database. Interviewees were asked to explain how their principle is different from a related principle in the database, whether it contradicts another principle, and whether it can be tied to some of the other features in the database. Careful examination of their answers show that designers made significant *refinements* of their principles (usually in order to clearly distinguish them from other principles). They also *elicited ideas* for new features in their own designs and in those created by other designers. In addition, they *raised questions* that can serve as important research questions in the design field. We anticipate that such type of questioning can stimulate community-wide norms and standards that are likely to make design decisions more evidence-based and ultimately more effective.

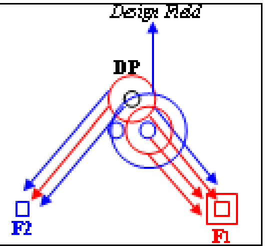
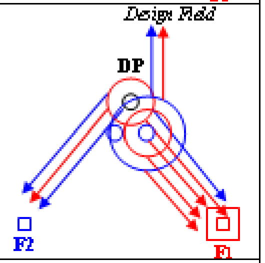
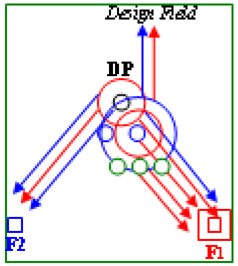
NEXT STEPS

The outcomes of this study indicate that the *Design Principles Database* has the potential to serve crucial functions in enabling the field to synthesize the creative contributions of its members. The database can serve as a medium to document design advances and a conversational prop to support designers' rationale with a language that connects to rich, powerful examples of important accomplishments in the field.

To take advantage of this potential we need more activities such as the CILT design principles workshop that bring designers together to synthesize their knowledge. We also need to explore the role of an editorial board that would look for overarching connections and discontinuities to ensure the quality of the database. We envision the role of the editorial board members as identifying gaps, overlaps and contradictions in the database, and initiating public discussions around them. Such discussions are likely to leverage design principles, elicit new ideas for software features, and raise new research questions that will advance the educational software design field.

Table 1: Ways people synthesize design principles - Case study 1 (convergent discussion)

	Excepts from discourse	Analysis	Graphic Representation of synthesis
Debbie	I think we can gain a great deal by dealing with the Visualization of Complex phenomena that was suggested in the teleconference…. …The complexity of electric circuits resides in their being comprised of many components that together form an interrelated system. So that a change in any one of the components or connections gives rise to changes in all the others.	Debbie indicates how the general design principle relates to own feature (represented as blue arrow from the design principle to feature 2).	
Alice	…Maybe the first step is to understand in what sense these phenomena are complex, since complexity can appear in different forms. … the complexity of DC circuits lies in their being comprised of many components that form an interrelated system, so changes in one component gives rise to changes in others… the source of complexity in our feature is in having many variables changing at once while some of these variables are also interdependent (changes in energy, speed, phase)…. At least on my part I need to think a little more about the question of complexity - in what sense these phenomena are complex.	Alice digs deeper into the design principle (larger red circle around the original circle). She also indicates how the complexity aspect of the principle relates to both features (two red arrows from DP to features). She reveals a gap in understanding of own feature in terms of the suggested principle (larger square around the original F1 square).	
Debbie	The complexity of electric circuits can be related to issues of structure and functionality…Oscillations (both simple and driven) also occur in systems rather than single objects. In fact one such example is an alternating current electrical circuit. …Oscillating systems can have different physical manifestations but still possess an identical underlying mechanism. The ability to generalize the phenomenon is something we would like to promote. To sum up I would like to propose two principles that might usefully guide design: 1) Help students identify meaningful patterns. 2) Promote understanding of micro-macro relations.	Debbie indicates how she sees the relation of the complexity aspect to both features (two blue arrows from DP to features). Her analysis brings her to break the design principle discussed above into two other, more specific design principles (two blue circles underneath the original design principle).	
Alice	I'm glad you brought in the issue of generality and patterns since this is the context in which the oscillator modeling was evolved. We're trying to abstract the pattern of oscillation from other physical occurrences and focus on the underlying pattern… In your first principle you wrote: help students identify meaningful patterns. Did you mean that the design of the feature helps students identify patterns? If so, how can it help them? Is it by reducing some aspects of the physical phenomenon and highlighting some others? In the oscillator model reducing aspects that are not the essence of oscillation (e.g. gravity) help highlight some patterns of oscillation.	Alice suggests how one of the design principles suggested by Debbie relates to her team's feature (red arrow from one of the blue circles to F1). She digs deeper into the new principle by (larger red circle around one of the blue circles). Indicates how the new principle relates to her team's feature (red arrow from the larger red circle to F1).	

Debbie	"Help students identify meaningful patterns by reducing complexity" sounds like a worthy principle and I think we can add it to the database… The question whether this principle is best achieved in a context free environment needs further discussion… For myself, I believe that the student should navigate back and forth between the specific context and the general phenomenon. An environment that "forces"/directs the learner to identify or define the abstract idea that is embodied in a specific manifestation, may go some way towards that goal. This reminds me of a software tool called "Learning about Light" that has a menu item entitled "Powerful Ideas".	Debbie deepens their insight about the revised design principle by raising the issue of context related to their principle and providing some ideas for answers (larger blue circle around the red one). Connects revised principle to existing knowledge in the design field (blue arrow from the revised principle to "Design field").	
Alice	The point that you made about context is a very interesting one. In fact, diSessa's work on p-prims (knowledge in pieces) refers exactly to this point. Students in different contexts will use different pieces of intuitive knowledge (even if for an expert this is the same phenomenon). …In our case, I think that we reduced complexity by eliminating some variables and highlighting others… I agree with you that the student should go back and forth from the representation back to the referent world all the time. And in fact, in the oscillation case this was the case with students we watched (it just happened naturally).	Alice connects the issue of context of their revised design principle to theory (red arrow from the revised principle to "Design field"). Relates the issue of context in their design principle to the team's feature, and provides supporting evidence from her research (blue arrow from the revised principle to her team's feature).	
James (Alice's mentor)	It seems to me that principles best come in chunks of principles, competing principles, and trade-offs. "Abstract the core phenomena" is useful, but countered by "invoke useful resources in everyday knowledge" because you may abstract away any useful phenomenological knowledge…This has a good ring to me. Principles are not scientific laws, so just won't have the universal character. They will always conflict with other principles, so "good" understanding of them means managing the conflicts and trade-offs, not just a principle at a time. In order to make this principle work for me, I have to introduce some different categories of patterns, and introduce a few different ways of "reducing complexity" that have different properties…. Sub-principle: Make interaction possible that will expose phenomenologically such key behaviors. Sub-principle: Make key causal interactions easy to see and understand. Sub-principle: Make the relevant causal entities visible and comprehensible.	James contextualizes the discussion in a theoretical framework about what design principles are and how such discussions contribute to the design knowledge (green frame around all the prior discussion). He goes on and deepens the principle the Alice and Debbie have synthesized throughout the discussion, by providing three sub-principles that explain how the design principle can be reached (three green circles underneath the circles of the synthesized principle).	

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