CILT Design Principles Interim Report
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1 PROJECT TITLE

Identifying Emergent Design Principles through Analysis of Learning Technology in Action

2 PARTICIPANTS

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3 WEBSITES

We have been putting together a wiki that contains some information, and we will be updating it as the work continues:

http://firefly.ctl.sri.com/wiki/jsp/wiki.jsp?DesignRetreat

There is also a design principles database that Yael Kali is developing, in which the data collected and evaluated during the course of this project will reside. This will be done by April, 2003.

4 PROJECT SUMMARY

A unique opportunity offered itself to the participants of this project: To begin the process of mining a library of educational software and data (including videos of students using the software, summaries of written student work, and design rationale from the development teams) in order to elicit the design principles that successfully support problem-solving. The purpose is to garner lessons from a large educational software development project to share with the learning sciences and other interested communities who develop learner-centered software, as well as with practitioners to inform their selection of educational software. The focus of this project is not on user interface design specifically, but on principles that support problem-solving, learning, and learner-centered design issues. We had three weekend-long meetings in which we did this work.

The educational software library that was evaluated was developed by the Educational Software Components of Tomorrow (ESCOT) project. Each piece of software was accompanied by a context, a set of questions, and a Java applet (sometimes more than one applet) to help students answer the questions. They were posted to the public as part of the Math Forum's Problem of the Week (PoW; http://mathforum.org/pow/), and called ESCOT PoWs (EPoWs). Forty-two EPoWs comprise this library.

Our approach to generating the design principles was to select a representative subset of the EPoWs that would help us focus our efforts. We then collected our expert opinions and built consensus ratings about each of the selected EPoWs. From that, we generated design principles, refined them, and categorized them. The resulting design principles fall into four categories (see Table 1).

Table 1. Sample design principles, their categories, and intended effects

Category	Example Design Principle	Intended Effect
Ease of Applet Use	Leverage standard expectations in the use of conventions	ease of use, more pleasant user experience, less cognitive load
Motivation	Enable early reward for students (e.g. provide easy questions or activities they can do successfully)	get involved in the problem that leads toward producing a solution
Presentation	Make links between representations obvious and ungratuitous	less division of attention, understanding relationships
Support for problem-solving	History of actions	can lead to reflection, strategy tuning, and not wasteful duplication

We did empirical validation of the design principles by watching videos of students using some of the EPoWs. The videos were sampled to include the following:

1. Two high ability 8th grade boys using Fish Farm 1
2. Two lower ability 8th grade girls using Fish Farm 1
3. Two low ability 8th grade students (one boy and one girl) using Fish Farm 1 while working with a pre-service mathematics teacher
4. Two lower ability 8th grade girls using Scale n Pop

These videos were original data sources collected from several research projects conducted by various members of the ESCOT team, including Renninger and Stohl. In each video, students were encouraged to think aloud while working in pairs at a computer with access to paper and pencil. The video images were captured in such a way to observe both verbal and non-verbal information about how the students interacted with the ePOW. The ability to observe students directly interacting with the applets was useful for coding.

Our intention for examining the videos was to locate evidence to support whether or not a design principle (DP) was followed, and whether or not an intended effect (IE) occurred. Thinking about these options as a 2x2 matrix allows us to see four possible outcomes (see Table 2).

Table 2. Coding for student videotape data.

	Design Principle Followed	**Design Principle Violated**
Evidence of Intended Effect Displayed	*FE (followed, with effect)*	*VE (violated, with effect)*
No Evidence of Intended Effect Displayed	*FNE (followed, no effect)*	*VNE (violated, no effect)*

These four outcomes (FE, FNE, VE, and VNE) were used as we coded video segments. Each researcher had a chart that listed each DP, IE, and space for recording descriptions of segments from the video (including timestamps) that provided evidence supporting (FE and VNE) and evidence against (FNE) a design principle (see Table 3 for examples). For the fourth case, when a DP was violated but there was evidence that an IE was achieved, no conclusion could be made about whether the evidence supported or refuted a design principle. Thus, a segment coded as VE was inconclusive.

The videotape data were first reviewed by five of the researchers as a group, in successive 3-minute segments in order to provide evidence for the design principle being effective. During this time, we paused to write down everything we thought relevant after each segment and to discuss what we saw. Second, detailed notes of students' work with the EPoW were compiled in order to evaluate the correspondence between assessed intended effects and evidence of these effects based on student activity (see examples in Table 3.) After we watched a student work session, we compared the codes and evidence generated independently by five members of the research team. For each DP, the codes were shared, compared, and discussed until consensus was reached. Within each video analyzed, evidence was provided for almost all DPs. In addition, all four codes (FE, FNE, VE, VNE) were evident in the analysis of the video segments.

Table 3. Examples of evidence of design principles in several video sessions.

Category	Design Principle	Intended Effect	Evidence	Video Session
Motivation	Enable early reward for students (e.g. provide easy questions or activities they can do successfully)	get involved in the problem that leads toward producing a solution	FE (min 5) They were happy when the balloon released. FE (min 17-18) They were happy when the balloon enlarged for the improper fraction booth.	Scale n pop, two girls
Presentation	Links between representations should be obvious and ungratuitous	less division of attention, understanding relationships	FE (min 11-13) One girl knew to use the sums instead of counting the fish. FNE (min 11-13) The other girl didn't know to use the sums. VNE (min 3-6) The girls expected the other representations to be updated when they did something.	Fish 1, two girls
Support for problem-solving	Everything in there (questions, interface elements, activities) should have a sound pedagogical reason	more coherent, less accidental, better learning environment	VE (whole) The equation didn't seem necessary. FE (min 5-6, 17-18, 20-22) The series of buttons allowed them to make judgments and adjustments before releasing. FE (whole) Because the last question was about numerator and denominator, forcing them to type in only standard fractions was okay. VNE (whole) The decimal new diameter had no good purpose and wasn't used.	Fish 1, two boys

Since the data were not obtained from studies that were designed to validate the design principles, the contribution of the data is to give examples, both pro and con, for specific principles. From these, hypotheses can be generated from which studies can be designed.

We regard these design principles and their validation as a starting point in a conversation. We hope that others will continue this conversation through the web site that houses the design principles as well as in other forums.

The Participants

Five of the project participants also participated in ESCOT, each with different areas of expertise – middle school teacher, software developer, educational technologist, math educator, and project evaluator. The remaining authors, not having been part of ESCOT, brought objective views about the software we set out to evaluate, and had complementary areas of expertise – teacher, math educator, and technology designer.

Specifically:

Jody Underwood (educational technologist), **Chris DiGiano** (computer scientist), and **Hollylynne Stohl** (math educator) were all members of the ESCOT project, serving respective roles. They were each part of teams that designed and developed EPoWs. Dr. DiGiano was co-PI of the project. Dr. Underwood was co-PI of the Math Forum subcontract. She also served as the project coordinator, helping each team complete the design and implementation of their respective applets and tasks.

Suzanne Alejandre (middle school math teacher), **Kristina Lasher** (elementary teacher), and **Annie Fetter** (math facilitator/teacher) are all at the Math Forum. They work on various things related to math, math education, and various technologies including the Internet. Ms. Alejandre was also a participant of the ESCOT project, and was part of teams that designed and developed EPoWs.

Karen Hollebrands is an assistant professor of mathematics education at North Carolina State University. She has engaged in research related to the learning and teaching of mathematics with technology.

Chris Hoadley is an assistant professor of the learning sciences at Penn State University. His work has focused on design in education and technology.

K. Ann Renninger is a professor of education and psychology at Swarthmore College. She served as project evaluator of the ESCOT project and of the Math Forum, and does research on motivation and communities focusing on the Internet.

5 RESULTS AND IMPLICATIONS

After three weekends of generating, refining, and organizing the design principles, we came up with a list of 26 principles, organized into four categories. Each design principle is listed with intended effects. The resulting categorized list is located in Appendix A.

To be clear, we are not:

1. looking at things like general use of an applet (for example, for use with other questions) because we cannot collect data to support our claims.

2. evaluating the EPoWs as to their effectiveness, other than how student data support or show violation of design principles.

3. validating design principles, though we are offering evidence both in support of the presence and absence of design principles for problem-solving.

5.1 The Four Categories of Design Principles

During our last session working with the design principles (dps), we identified four categories that the design principles fall under: *Ease of Applet Use, Motivation, Presentation,* and *Support for Problem-Solving*, each of which is described below. During the categorization process, we collapsed some of the earlier-found dps into others, resulting in a total of 26 principles. The categorized list, along with intended effects, is located in Appendix A. There were a number of principles that fell under the realm of User Interface design, and we did not address those in our list since they are covered extensively in the literature.

Ease of Applet Use: These design principles focus on the intuitiveness of the applet, including the use of standard interface conventions and clear and useful directions. This category has three design principles.

Motivation: These design principles promote motivation, including staying on task, showing excitement about the process, etc. They include such principles as familiar problem context and enabling early reward for students. This category has four design principles.

Presentation: The simplest way to think about these design principles is in terms of proofreading for the intended audience. In a sense, this is the counterpart to the "Ease of Applet Use" category for everything other than the applet. Some principles that are addressed are clarity of the context and the questions and the use of professional conventions. Some principles get at applet implementation issues when they're not about the *use* of the applet, but about the *meaning* of the things in it. For example, the linked representations need to be obvious, or draw attention only to things that support the problem solving. The effect we expected was that the understanding of the problem and all its facets not be impaired. This category has seven design principles.

Support for Problem-Solving: A plurality of the principles falls into this category with its 12 design principles. All these design principles are intended to facilitate problem solving, including things like allowing multiple solution paths, multiple entry points, appropriate feedback, and rewarding strategic thought.

5.2 Interactions between Principles

These design principles do not stand alone, as each EPoW uses a number of design principles. Interactions between the design principles must be considered in the design or in the selection of educational software.

Toward this end, one of our goals is to have a ranking of important design principles. While evaluating the design principles that capture the EPoWs, these interactions were noted. These are some examples of how some design principles are more important than others, though the ordering may not be clear all the time:

1. *User expectations of artifact and interface design are met* vs. *Attention is drawn to the important information*. Fish2 (http://mathforum.com/escotpow/solutions/solution.ehtml?puzzle=41) was designed so that as each fish is scooped out of a pond, a running total is incremented, and a pie chart updated to reflect the ratio of males to females that have been selected. As was documented with students using Fish1, students expect the updating to occur. However, the fish are constantly moving around the pond using animation, and this distracts students from seeing the two representations that show the mathematics of what is occurring, which also keeps the students from solving the problem.

2. *Graphics are great* vs. *Attention is drawn to the important information*. In Hispaniola (http://mathforum.com/escotpow/solutions/solution.ehtml?puzzle=30), a graphic artist developed pictures and animation that help the student fill cups with water, according to the constraints described in the problem. However, students have to pay a lot of attention to the moving around of cups to the spigot and funnel, and therefore cannot pay a lot of attention to the history list that shows them what they have achieved and what they still have to achieve.

3. *History of actions* vs. *Follow conventions*. In Fish2 (http://mathforum.com/escotpow/solutions/solution.ehtml?puzzle=41), a history of actions is recorded, which helps students see trends in their selections. However, you must remember to *save* in order to obtain a history. The latter goes against what one would expect in the interface, given that the history is very helpful in solving the problem.

6 LESSONS LEARNED: COLLABORATION

This has been an extremely successful collaboration. The participants have all been motivated to do the work, and we found different ways to collaborate and to make each meeting rich. For example, at each meeting at least one new person joined us (mostly different representatives from the Math Forum) and that forced us to revisit and explain things all over again. You might think it would get old to keep revisiting what we did, but since a lot of time passed in between meetings, it allowed us to review where we were, ask new questions, and move ahead – always in ways that we felt were invaluable.

Up until now, all of our work has been done face-to-face. At this point in the project, we are starting to write papers from a distance. Since this work is in addition to our regular positions, it may be difficult to move ahead as quickly and in as many ways as we want to. We have used IM for meetings, and this was successful in that we all seemed comfortable with the environment, plus we have written accounts of what transpired during the meetings. We continue to communicate over email in between meetings. We are also using a wiki, but we have not been that active in keeping it up to date.

7 NEXT STEPS

Our immediate next steps are to write articles to publish our work. The plan is to target:

1. AERA 2003 (already accepted). Interactive poster session with other CILT Design Principles teams. Our poster will focus on the process we took and on some results, similar to the ETRD paper, below.
2. *ETRD Educational Technology Research and Development* journal. We have begun work on this already. It will be a thumbnail of what we did over the 3 weekends. Everyone who has been involved in our retreats will be an author. Brief outline: What is ESCOT, what data did we work with, what did we do, some results. Title: “IDEA: Identifying Design Principles in Educational Applets”.
3. Design studies (Hoadley): almost done. He will summarize our work within a larger paper and point to the fuller JLS paper, described below.
4. *Mathematics education*, e.g., IJCML: Int Jrnl for Computers for Mathematical Learning (Stohl, Hollebrands): has begun. This article will focus on support for problem solving around the Fish case, compare with other similar things that have been done in math ed. Two potential papers: Representation dp paper (mathematical thinking and learning); Problem solving dp paper, using Fish and other epows.
5. *Sharing the principles*, e.g., JIME (Underwood, DiGiano): Case description of Fish1 EPoW with other supporting EPoWs to describe the design principles.
6. *Journal of the Learning Sciences* (Hoadley, Underwood): Focus on the process and how you could empirically validate design principles.
7. *NCTM Yearbook 2005*. Use the dps to give ideas on how to select problem-based applets to use with your classes, and how teachers can support student use. The link to the PoWs could be strong. Due March 1. Focus on Representation and Support for Problem Solving dps. This is a maybe.
8. *Computer science education*, e.g., SIGCSE (DiGiano, *later*)
9. Compile published papers into an *edited book* with other similar work. Later.

We will also work with Yael Kali to enter the design principles we generated into the CILT design principles database.

However, having laid out this great plan, there is a caveat. CILT provided us the means to get away from our regular positions in order to do the work that we all wanted to do. While we have started some of the publications listed above, we all are finding it difficult to continue to do this work with all our other responsibilities. Perhaps we should write a larger grant proposal to continue the evaluative work, which would allow us to also do the publishing that we want to do. This is not out of the question; it is just something that we have not yet addressed. In addition, each of us is pursuing next steps in our individual work environments, mostly in informal ways.

8 RELATED RESOURCES

As mentioned before, we have a preliminary wiki (<http://firefly.ctl.sri.com/wiki/jsp/wiki.jsp?DesignRetreat>) where some of our design principles and other resources can be found. In particular, some related resources can be found at: <http://firefly.ctl.sri.com/wiki/jsp/Wiki?RelatedResources>.

In addition, the CILT web site has related design principle seed grant projects: <http://www.cilt.org/seedgrants/visualization/>.

Appendix A: The Categorized Design Principles

Category	Design Principle	Intended Effect
Ease of Applet Use	1. Leverage standard expectations in the use of conventions (e.g., interface design and contextual artifact design)	ease of use, more pleasant user experience, less cognitive load
	2. Use of the applet should be intuitive	students can start right in
	3. Directions should be clear (maybe screenshots) and short.	students quickly oriented
Motivation	1. Familiar problem context	motivation
	2. Use second person voice	immersive, motivating, creates ownership for student
	3. Enable early reward for students (e.g. provide easy questions or activities they can do successfully)	get involved in the problem that leads toward producing a solution
	4. For videogame-like activities, interactivity, high-quality graphics, etc. should match user expectations for playability	get game players to take seriously and students continue with the problem
Presentation	1. Question, cover story and/or introduction should be clear, unwordy, unsuperfluous	students get started quickly because they know what to do
	2. Proofread text, labels, etc, with target users and age range in mind	reduce distractions or snag, increased focus on learning issues
	3. All other things being equal, use professional conventions for content domain	familiarity, enculturation
	4. Make links between representations obvious and ungratuitous	less division of attention, understanding relationships
	5. Use high-quality graphics and other media (e.g., still graphics, audio, animation)	better understanding of the problem.
	6. Draw attention only to things that support the problem solving	more on task, more focus on important issues that will help the student to solve the problem
	7. Make everything described in the question obvious in the applet; align interactive and noninteractive parts	students oriented more quickly. The applet supports student solutions to the questions.
Support for problem-solving	1. History of actions	can lead to reflection, strategy tuning, and not wasteful duplication
	2. Everything in there (questions, interface elements, activities) should have a sound pedagogical reason	more coherent, less accidental, better learning environment
	3. Allow multiple entry points (e.g., ability, experiences, preferences, styles...)	more students might have many ways to get started, get involved
	4. The E-POW supports multiple approaches and multiple solution strategies (e.g., questions and/or applet)	students can use different strategies to solve the problem - more students should be able engage in mathematical thinking

	5. Use dynamic multiple representations appropriately (linked/notlinked, multiple or single sources of control)	develop representational fluency. Facilitate movement toward better understanding of the problem. More students should be able to engage in mathematical thinking.
	6. Give students opportunities to make predictions, commit to them, and examine outcomes	students may revise their solution strategies. Way to make learnable moment
	7. Thoughtful strategic use of the tool should be rewarded more than random use	less try-and-trash, more thinking
	8. Make a pedagogical decision about whether closure is needed.	sense of accomplishment
	9. Applet should give appropriate status feedback (say the right thing at the right time in the right way)	appropriate challenge but doesn't get too far off track.
	10. Programming of the applet supports the level of accuracy necessary for problem solving	less wasteful hairsplitting
	11. Make effort involved in an activity proportional to the importance of what is needed to solve a problem (aside from programming for accuracy)	more likely to stick with the problem. Students attend primarily on relevant factors. Less busywork in the student's mind.
	12. Technology should add value	technology is an integral and essential element in the problem solving process. Students use the technology as an essential part of their problem solving.