ONE DIGITAL LIBRARY, TWO UNDERGRADUATE CLASSES, AND FOUR LEARNING MODULES: USES OF A DIGITAL LIBRARY IN CLASSROOMS

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ABSTRACT

The KMODDL (Kinematic Models for Design Digital Library) is a digital library based on a historical collection of kinematic models made of steel and bronze. The digital library contains four types of learning modules including textual materials, QuickTime Virtual Reality movies, Java simulations, and stereolithographic files of the physical models. This paper reports an evaluation study on the uses of the KMODDL in two undergraduate classes. This research reveals that the users in different classes encountered different usability problems, and reported quantitatively different subjective experiences. Further, the results indicate that depending on the subject area, the two user groups preferred different types of learning modules, resulting in different uses of the available materials and different learning outcomes. These findings are discussed in terms of their implications for future digital library design.
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BACKGROUND

Many digital libraries have been developed over the past decade (Borgman, 2002), and the investment in designing digital libraries (DLs) in the United States including the National Science Digital Library (NSDL) and the Digital Library Initiative (DLI) has been significant (Fox & Urs, 2002). The ultimate goal of NSDL is to transform learning in educational and everyday settings for a variety of users, including from kindergarten to twelfth grade, undergraduate, graduate, and lifelong learners (Zia, 2001). However, evaluating how these DL’s are being used remains elusive, especially with regard to their educational impacts. The National Science Foundation (NSF) supported Evaluating Educational Impact Workshop highlighted the intensified interest on this difficult issue (Sumner, Marlino, & Butcher, 2003).

The goal of this project is to explore the potential for integrating the same DL into the curriculums of two different undergraduate classes for the purpose of facilitating learning and knowledge transformation. However, since different classes may have different pedagogical requirements and different user groups may have diverse background knowledge and cognitive styles, using one digital library in different classrooms poses interesting questions: do we need to design different interfaces for different users? Will different user groups learn differently from the same digital library? If the learning outcomes differ for these different users, will that affect their subjective experience? To address these questions, a multi-method data collection plan was
developed, including document analysis, surveys, ethnographical classroom observations, videotaping, software logging, screen capturing, and web log analysis. Borrowing from Jones et al. (1996), data were collected on multiple aspects of uses including context, interaction, attitudes and outcomes. The goals of this evaluation research were to assess contexts, usability problems, learning processes and outcomes, and the subjective experience associated with the uses of the digital library.

The remainder of this paper is organized as follows: the history of the model collection and the different types of learning modules in the digital library are described first, followed by a detailed description of the research methodologies; the paper then describes the findings from the comparison between the evaluations of the KMODDL uses in two undergraduate classes; lastly, the theoretical contribution of this research and the implications for designing digital libraries are discussed.

REULEAUX COLLECTION OF KINEMATIC MODELS AND KMODDL PROJECT

The KMODDL is based on a historical collection of kinematic models made of steel and bronze. Franz Reuleaux (1829-1905), a German professor, created over 800 models of mechanisms to embody the basic machine elements for the purpose of teaching kinematics in colleges. Cornell University acquired a collection of 266 models in 1882. Two hundred and twenty of these models are owned by Cornell's Sibley School of Mechanical and Aerospace Engineering, which is the most complete set of the Reuleaux mechanisms in the world. At Cornell today, Reuleaux models are frequently visited by various groups of students, researchers, and professors in the areas of dynamics, robotics, art, architecture, and historical research. The
models in the Reuleaux collection can enhance creativity and intuitive thinking by encouraging hands-on experience and visual thinking in the classroom (Ferguson, 1992). However, the limited quantity of these historical models and the cost of reproducing them are prohibitive. The KMODDL project intends to provide a web-based system to include “navigable moving images and simulations of mathematical principles related to the machines’ movements”, in order to “restore the objects to their intended classroom use as teaching models of geometric and kinematic principles” (Saylor, 2002). The KMODDL project is supported by the NSF in cooperation with Cornell University Library, and is a part of National Science Digital Library (Saylor, 2002). The KMODDL team includes two professors in the Department of Mechanical Engineering, two professors in the Department of Mathematics, and technical and managerial staff from Cornell University Library. Since 2002, the team has collected textual materials related to the Reuleaux collection, taken still pictures, and developed other digital learning modules. Currently, there are four types of modules in the digital library, including textual materials, QuickTime Virtual Reality movies, Java simulations, and the stereolithographic files of the physical models (See Figure 1). Each of these modules is described briefly below.

Textual Materials

There are two types of textual materials in the collection. The primary textual materials were developed for the purpose of collection, preservation and digitization. These include descriptions of mechanisms and historical texts from the past centuries pertinent to the theories of mechanism and machine design. The team has selected approximately 50 books and other historical documents to be included in the collection. The second type of textual materials, the
instructional materials, was designed specifically for educational outreach purposes. These include tutorials and textual learning modules developed by the professors on the KMODDL team, which intend to explain one specific mathematical or kinematic problem related to kinematic models. The professors continue to develop instructional materials and integrate them into the digital library while simultaneously conducting educational outreach programs in universities, middle schools and high schools. Thus the collection in the KOMDDDL is continuously evolving and being enriched.

QuickTime Virtual Reality Movies

Currently the KMODDL team has developed interactive movies using QuickTime Virtual Reality technology (QTVR). A sequence of still images of each physical model in different positions was taken and combined into an animation movie. If a user clicks and moves the mouse on the movie, the images change according to the direction of the mouse movement. These movies give the users an interactive experience by allowing them to examine the models from various positions and to witness the effects of the movement in detail.

Kinematic Java Simulations

Realistic representations of the kinematic models in images and movies are not sufficient to illustrate the underlying mathematical, geometric, and kinematic rules that determine their movements. The KMODDL also includes simulations in simple forms of lines and joints, allowing the user to pull, push or drag in different ways. There are two types of simulations in the KMODDL: the primary materials are a general type of Java simulation that demonstrates the forces and movements of a model’s mechanisms; the instructional materials are specifically
designed for a course for the purpose of demonstrating a particular problem relevant to the course materials. In both types of simulations, users can change the lengths of different parts of the mechanism and observe the subsequent changes on the motion of the model. These abstract Java simulations encourage users’ interaction while giving users an in-depth understanding of how the mechanisms work.

**Physical Models and Stereolithography Files**

The historical models provide students with an opportunity to gain hands-on experience and facilitate a holistic view of the mechanism, intuitive learning, and creative thinking (Walker et al., 2003). However, for most educational institutions in the world, this historical collection is inaccessible because of physical distance. During the development of the KMODDL collection, the design team discovered a rapid-prototyping technique, which could be used to generate three dimensional models from Computer-aided Design method (Tata, Fadel, Bagchi, & Aziz, 1998). Historical models are measured from different perspectives, producing files in stereolithography (STL) format for each model. These files can be downloaded to a rapid-prototyping fabricator (3D printer). Physical replicas of these models can be generated in plastic forms and the students can operate them in the same way as the historical models (Figure 2). These models can be the substitutes when the historical models are too costly and prohibitive to access. Furthermore, these printed models can be printed in different scales, in different colors, or in different parts to afford new types of teaching and learning. As 3D printers gain more popularity and printing costs continue to decrease, 3D printing technology can bridge the gap between museums and digital libraries by removing obstacles to wider accessibility.

-------------------------------------- Insert Figure 2 here ---------------------------------
The previous discussion illustrates how the development of the KMODDL has been an dynamic and evolving process. For example, the textual materials include not only primary collections, but also instructional materials that are specifically designed for a course. The instructional materials were later incorporated into the core collections and became a part of the primary materials. Additionally, the two professors working with the evaluation team are principle investigators of the projects. They also provide collections to the digital library and market the digital library to local user communities. Their multiple roles actually helped to link evaluation and outreach efforts with the development of the KMODDL so that usability problems could be addressed promptly. Furthermore, the 3D printing technology emerged from the ongoing development and discussions of the project team. The practices of bringing the KMODDL into classrooms and building the KMODDL collection simultaneously has resulted in enhanced development practices and better design.

EVALUATION METHODOLOGY

Various theories have stressed the importance of context and user tasks in evaluating digital library design effort (Bishop et al., 2000). In fact, activity theory posits that the interaction between a user and a tool is always mediated by the activity. The theory argues that the interaction should be positioned within a larger space of motives, community, rules, history, culture, and other aspects of context (Gay & Hembrooke, 2004; Nardi, 1995; Spasser, 2003). The focus of this research is on the uses of a digital library as an educational tool in the specific context of a geometry class and a robotics class for the purpose of fulfilling pedagogical goals. The evaluation has the major objectives of assessing context, usability, learning, and subjective
experience. Different contexts determine various uses of tools (Gay & Hembrooke, 2004); the evaluation of usability can help the development team to improve the design; learning outcomes and positive user experiences are two major goals of digital library development (Pan, Gay, Saylor, Hembrooke, & Henderson, 2004). Bishop et al. (2000) argued that evaluation methodology should include multiple methods and the triangulation of different types of data is crucial. Marchionini, Plaisant, and Komlodi (2003) also stated that one needs to collect multi-faceted data in order to evaluate the uses of a digital library. Thus, it is essential to explore and understand the tasks, scenarios and context, interaction, and outcomes of different uses through multiple data collection methods. Document analysis, surveys, observations, videotaping, software logging, and web log analysis were used to capture the context, interaction, attitude and outcomes (Jones et al., 1996; Jones et al., 1999). Since the design and evaluation of digital libraries is a constructive and evolving process, slightly different research procedures were followed in different stages of the digital library development.

**Uses of KMODDL in Undergraduate Classes**

In the fall semester of 2003, the professor of a geometry class (Math 451: Euclidean and Spherical Geometry) at Cornell University introduced the KMODDL in his classroom. Since the development of the KMODDL was in progress, the professor developed a class web site containing links to the digital learning modules in order to provide a holistic view of the class materials (http://www.math.cornell.edu/~dwh/courses/M451-F03/451web/). The web site also contains Java simulations and textual materials developed specifically for this course based on the historical kinematic models. There were 14 students in the class and 13 agreed to participate in the study, including both graduate and undergraduate students (Pan et al., 2004). After two
initial class demonstrations of the physical models, students were able to interact with the digital materials through a computer and web browser and answer questions related to the course materials.

The KMODDL was also used in a robotics class (MAE 417: Introduction to Robotics: Dynamics, Control and Design) in the spring semester of 2004. Usability problems uncovered from the geometry class were reported to the design team. Specifically, the speed and stability of the kinematic simulation were improved based upon the students’ feedbacks. Since the KMODDL digital library was still under construction, a non-public prototype web site was used for the class (http://kmoddl.library.cornell.edu/proto.php). Similar to the exposure in the geometry class, physical models were demonstrated first, followed by a computer lab session in which the students accessed and studied digital models while working on problem sets related to the course.

Data Collection Methods in Geometry Class

In the geometry class, multiple data collection methods were used to capture the context, interaction, attitude, and outcomes (Jones et al., 1996) (Table 1):

1) Document analysis (Context): Before the class began, the evaluation team collected textbooks, course syllabus, and other class materials. These materials were evaluated to determine the structure and style of the class so that the evaluation of the KMODDL would be appropriately situated in that context (Patton, 2001).
2) Videotaping and observations (Context and Interaction): During the two class sessions when the students interacted with the historical models, the evaluation team videotaped both the professor’s demonstration and the students’ responses. A researcher also sat in the classroom, observed the class session and wrote down notes about classroom activities. The goal was to understand the context of the class and also to capture the students’ responses to the physical models.

3) Process Tracing (Interaction): In the class session when the students accessed the digital learning modules, three methods were used simultaneously to capture the students’ interaction. In addition to the videotaping and observation mentioned above, screen capturing software Camtasia (TechSmith, 2003) was used to capture user behavior on the computer screen into a movie file, including the computer display, mouse movements and clicks. Two students shared one computer and the discussion between them were encouraged. A microphone was placed in front of the computer so that this natural verbal protocol was recorded in the Camtasia movie file. The data from these three sources were triangulated to provide a detailed picture of the interaction between the students and the digital library.

4) Surveys (Attitude and Outcome): A usability survey and a self-evaluation survey were administered in the study. During the lab session in which the students accessed the KMODDL, the evaluation team distributed a survey asking the students to comment on the difficulties they encountered, what they liked about the learning modules, and suggestions for their improvements; at the end of the fall semester, the self-evaluation survey asked students about their opinions regarding the usefulness of the four learning modules on both learning outcomes and subjective experience. The three aspects of learning outcomes include: A. stimulation of interests and curiosity; B. help to understand; and C. help to remember. The
subjective experience was evaluated through seven aspects of hedonic values of technology: outstanding; exclusive; impressive; unique; innovative; exciting; and interesting (Hassenzahl et al., 2001).

5) Interview (Context, Attitude and Outcome): A final interview with the instructor was conducted at the end of the semester in order to obtain the professor’s view on the context, the usability problems, and the learning outcomes of the KMODDL.

Data Collection Methods in Robotics Class

In the robotics class, the evaluation methods changed slightly given that the development had progressed and the context and the requirements of the course were different. The screen captured movies were replaced by two surveys in order to assess learning effects more objectively. Videotaping was eliminated since the team discovered that videotaping didn’t contribute significantly to the insights gained from ethnographic observations (Table 2).

1) Document Analysis (Context): Similar to the method used in the geometry class, context was assessed through document analysis on class materials.

2) Observations (Context and Interaction): The professor introduced the physical models in a lecture session. A researcher sat in the class, observed and took notes about the professor’s demonstration of physical models and the students’ responses. One week later, the researcher also observed and took notes during the lab session when the students accessed the digital models in the KMODDL.
3) Surveys (Attitude and Outcome): After the students had accessed the digital library, they were asked to respond to a usability survey similar to that used in the geometry class. In order to evaluate learning effects more objectively in the robotics class, a pre-test and a post-test survey were used to assess the students’ understanding of various kinematic models. The pre-test survey asked the students to explain how two of the models worked and their applications in the real world. After they used the digital library, a similar survey was distributed to test the learning effects from exposure to those models. The professor then graded their responses in order to assess the potential learning outcomes of the DL materials on the students’ understanding of the models and their functions. The grading follows a scale of 0-2 (0: understand nothing; 1: understand a little; 2. understand a lot). Similar to that used the geometry class, a self-evaluation survey was administered at the end of the semester to the students asking questions regarding their subjective experience of using the four different learning modules and how these tools did or did not help them to learn.

4) Interview (Context, Attitude and Outcome): Similar to that in the geometry class, a final interview with the instructor was conducted at the end of the semester in order to obtain the professor’s view on the context, the usefulness and usability problems, and the learning outcomes.

Analysis Methods

The following paragraphs detail how the four goals of this research -- different contexts of use, usability problems, learning effects, and subjective experience, were analyzed through the multiple data sets collected:
1) The context of the two courses was assessed through document analysis on class materials, and ethnographical observations in class sessions;

2) In the geometry class, usability problems with the digital library and modules were assessed in the lab session through two different methods. First, in the usability survey the students were asked to respond to questions about things they liked, usability problems, and their recommendations for various learning modules. In addition, the evaluation team analyzed user behavior and their verbalizations through critical incident analysis (Carroll, Koenemann-Belliveau, Rosson, & Singley, 1993) on the screen captured movies. According to Carroll et al., (1993), a critical incident is an event observed during task performance that is a significant indicator of some factors defining the objective of the study. Critical incidents were used to evaluate both usability problems and learning incidents. Since two students were sharing one computer and their discussions were encouraged, the natural think aloud protocol helped to identify usability problems that the students might not otherwise have articulated. In the robotics class, usability problems were assessed through the usability surveys which asked the users’ opinions about things they liked, usability problems, and possible improvements.

3) Learning can be assessed through either the outcomes of learning or the process of learning. Outcomes of learning are always difficult to assess in educational settings because of the extreme difficulty of controlling all the variables that have an effect on learning and isolating only the variable of interest ( Jones et al., 1996; Jones et al., 1999). In the geometry class, learning was assessed through critical incident analysis on screen captured movies and the learning questions on the self-evaluation survey. In the robotics class, learning was assessed through pre- and post- surveys and the learning questions on the self-evaluation survey at the end of the semester.
4) In addition to the usability issues and learning, the team also evaluated the students’ subjective experience. The hedonic value of technology has been recognized in recent years as an integral part of the use of technology (Hassenzahl, Beu, & Burmester, 2001). Digital libraries should not only help the users to learn, but also give them an enjoyable and exciting experience. In both classes, this component of the evaluation was assessed through classroom observations, and the analysis of the open-ended questions about the users’ subjective experience in the self-evaluation survey.

In general, the notes from document analysis, observations, and texts from transcribed interviews, and screen captured movies were analyzed using NVivo (Gibbs, 2002). The survey questions in Likert Scale were analyzed through averages and T-tests. These data sets were triangulated and matched with each other to provide a more complete picture of the uses of the digital library. The comparisons between the evaluation results were performed in different ways: quantitative responses from the self-evaluation survey were compared to determine different learning effects, subject experience, and preferences toward the four different modules; content analysis on open-ended learning questions on the self-evaluation survey was performed to gain different views of different user groups.

Comparison of the Evaluation Results of Two Classes

The comparison of the uses of the KMODDL in two classes is detailed below according to the four goals of the research: assessing contexts, usability problems, learning processes and outcomes, and subjective experience.
Comparison of Contexts

The goals, styles, and pedagogical requirements of the two courses are different. The geometry class is an advanced undergraduate class on Euclidean and spherical geometry. The professor introduced the KMODDL in his class in order to connect geometry with its applications. The course focused on the understanding of abstract mathematical and geometric rules, and the goal was to expose the students to the real application of geometry and discovery through manipulation of the KMODDL. The professor adopted the Moore method of teaching, emphasizing learning geometry using reasoning, intuitive understanding, and insightful personal experience (Henderson & Taimina, 2001). In the Moore method of teaching mathematics, the students need to work through and discover mathematical rules on their own without traditional lectures and collaborations between them (Jones, 1977). In the class, the students were given a series of inviting and challenging problems, and encouraged to write down and discuss their reasoning and understanding. The professor also developed a Java simulation for the course in order to teach the principle of inversion which is embodied in the straight-line mechanism.

Alternatively, the robotics course followed a more traditional lecture style of teaching, with challenging homework assignments, computer programming problems, exams, and a major design project, in which the students needed to design a robotic arm. The class focused on design-based issues, requiring an understanding of kinematics and the integration of mathematics, physics, and geometry. In the interview, the professor indicated that the goal of the class was to expose students to hands-on experiences in order to facilitate intuitive understanding and creative thinking. The focus was on applying knowledge to design in creative ways.
In general, the goal of one class was conceptual and theoretical, while the other was more applied and practical. The teaching styles of two classes were also different: one focused on personal experience and the Moore method of teaching; the other one was more conventional in its approach with its lecture-style presentations and materials, challenging homeworks, computer assignments, and design projects.

Comparison of Usability Problems

In the geometry class, usability problems were assessed through the usability survey and critical incident analysis on the screen captured movies. The usability survey indicated that the first major difficulty the students had was the slow speed of the Java simulations. In addition, direct manipulation created many problems. For example, the users could not move smoothly on the simulations and certain default values could not be changed. Typos and grammatical errors in the textual materials were also reported. Other comments indicated that the interface was confusing and not intuitive. Overall, because of existing usability problems, the students sometimes got distracted from the content of the materials and instead they focused their attention on how to make the simulations work. The suggestions for improvements were primarily related to display issues, for example, adding more numerical or visual displays to make geometrical rules more easily understandable. Critical incident analysis on the screen captured movies in the geometry class also uncovered many usability problems. While some of them confirmed the responses from the usability survey, others were additional problems revealed from the video analysis. In total, 81 usability critical incidents were identified in seven screen capturing videos. On average 11.4 usability problems occurred during a single interaction session. These problems were categorized as one of three types of usability problems: (1) mental
model discrepancy (37 critical incidents): this occurred when what the user expected was different from what actually happened, or the users’ understanding of the simulation or the digital library was different from its actual function. These usability problems can be solved by providing more direct instructions; (2) speed (23 critical incidents): this problem occurred when the Java simulations responded slowly; (3) Bugs in the software (21 critical incidents): this type of problem occurred when the simulation or the browser froze up or crashed.

In the robotics class, the usability problems were assessed through usability surveys distributed during the lab session. Usability problems uncovered from the geometry class were reported to the design team and the speed and stability of the kinematic simulation were improved and the grammatical errors of the textual materials were corrected. As a result, complaints about the speed and the grammar errors decreased dramatically. However, certain usability problems were still present and new usability problems emerged. The students reported that they were frustrated by not being able to manipulate or rotate QTVR movies and Java simulations freely, and that the animations would stop from time to time. In addition, the students expressed the need for directions on how to manipulate the Java simulations. They suggested providing directions on how to use the simulations, making animations for all the models, providing various speeds and multiple angels for viewing, and enlarging the size of the animations. The students liked the clear, interesting, and understandable textual materials, and disliked the lengthy text and the long waiting time for opening up Adobe Acrobat reader for files in Portable Document Format (PDF). Furthermore, they suggested that the development team should add links to the textual materials, give more examples with practical implications, and make the texts more structured and detailed.
In general, by comparing usability problems, the results reveal a decrease in bugs in the simulations and grammatical errors in textual materials. The interaction between users and the Java simulations continued to be a major complaint.

Comparison of Learning Processes and Outcomes

In the geometry class, classroom observations and critical incident analysis on the classroom demonstration of physical models and screen captured movies were used to capture the learning process. The self-evaluation survey was used to assess learning outcomes. In the class demonstration of physical models, classroom observations and videos of the demonstration showed that the students were interested and stimulated during the introduction to the physical models and their history. They showed their interests by smiling and standing up from their seats. It shows that the physical models were especially useful for stimulating and engaging the students’ interests. The quantitative measurements in the self-evaluation survey (Figure 3) show that the digital modules were rated more useful in facilitating students’ learning than were the physical ones. Among them, the instructional material of Java simulation of inversion was rated the most useful, followed by textual materials. Physical models were rated third and QTVR movies were rated the least useful. Java simulations on inversions were specifically designed for this course and closely related to the goal of demonstrating the rules of inversions. This suggests that the digital modules will be most useful if they are adapted to fit the purpose and context of the class materials. Responses to the question, “what do you like about the K-MODDL” suggested that the students were in favor of the ability to manipulate the digital modules, which gave them a sense of playfulness, hands-on experience and real-time responses. In addition to the
surveys, learning critical incidents were discovered through the verbalizations and behavior of the users on the screen captured movies. Those “ah-ha” moments indicate that new connections are being made between different pieces of knowledge and mental obstacles being conquered (Parker, Webb, & Dsouza, 1995). Among seven captured screen movies, there were five sessions that contained learning incidents. The most common incidents were the discovery of rules through manipulation. For example, a couple of students discovered the condition under which a circle could be inverted to a straight line. One student even discovered a new geometrical rule in one mechanism that was not mentioned either by the professor or in the class materials, indicating that direct manipulation can lead to creative thinking and self-discovery. However, a special case of “hedonic problem” which inhibits learning was uncovered. One student in the class was enjoying the Java simulation to the extent that he was playing with the simulation and virtually ignoring the task of understanding the geometrical rules governing the movements of the mechanisms.

In the robotics class, a pre-test and a post-test survey and a self-evaluation survey were used to evaluate the outcomes of learning. The pre- and post- tests indicated that 6 in 14 responses showed improved understanding on a four-bar linkage mechanism, and 2 in 14 showed improved understanding of a universal joint mechanism, suggesting that the learning outcomes were not very robust. The four bar linkage mechanism is intuitive with relatively few linkages; the universal joint is more implicit and its functions are more difficult to understand. This result indicates that even varied representations and hands-on experience may not be enough to enhance learning for more intricate or complex models. In the self-evaluation survey distributed
toward the end of the semester, the students indicated that they liked the physical models followed by QTVR movies and Java simulations. Physical models were ranked highest on “stimulating their curiosity, and “remember kinematic rules”. QTVR movies were ranked highest on “helping them to understand kinematic rules”. Textual materials were rated the least useful in helping them to learn. Figure 4 illustrates the students’ subjective evaluation of the learning effects of the four different modules.

A comparison of the responses to the open-ended questions on the self-evaluation surveys shows that six in the geometry class and two in the robotics class mentioned “visualization” as a useful feature of the KMODDL in helping them to learn. In the geometry class, the Java simulation specifically designed for the class was rated the most helpful. In the robotics class, the students reported that the physical models and QTVR movies helped them for design, for example, some students commented: “… it makes you think of other design methods apart from the popular ones”; and “the models help us discover new ways of doing things that we might not otherwise think of”. The results suggest that the physical models and QTVR movies were more useful in facilitating creative thinking for designing mechanisms. Thus, different formats are suitable for different pedagogical requirements and learning purposes. The goals, styles, and pedagogical requirements of the two different courses determine the students’ different learning experience and outcomes with the different modules in the KMODDL.
Comparison of Subjective Experience and Preferences

In the geometry class, classroom observations, critical incident analysis on the classroom demonstration of the physical models and screen captured movies, and the self-evaluation survey were used to assess students’ subjective experience. During the web access session, students engaged in hands-on manipulation of the digital modules even before the session started. The animated discussion between students sharing the same computer also indicated their high levels of interest and enthusiasm. Open-ended questions in the self-evaluation survey asked about the students’ general experience with these models. Most students gave positive responses (10 in 12) when asked about their experience. However, the students gave different opinions regarding the digital models and the physical models. Physical artifacts allowed them to “experience beautifully crafted models”, but the digital ones really helped them understand and learn by “eliminated realistic details” and “focusing on underlying mathematical and kinematic rules.” As in one student’s words: “…the physical ones were more fun than educational”. In the self-evaluation survey, seven questions on the hedonic value of four types of the models were used to determine the experience of the users (Hassenzahl et al., 2001). Java simulations dominated four of them and were rated most “outstanding”, “innovative”, “exciting”, and “interesting”. Physical models were rated most “exclusive”, “unique”, and “impressive”. In general, simulations had the highest hedonic values followed by physical models and the textual materials. QTVR movies were rated the least fun and interesting among all four learning modules (Figure 5). Interestingly, when compared with the students’ reports on learning effects, those modules rated highly on learning outcomes were also rated high on hedonic values.

--------------------------- Insert Figure 5 Here ---------------------------
In the robotics class, classroom observations and the self-evaluation survey were used to assess students’ subjective experience. The students showed great interest as indicated by their high level of concentration while introduced to the physical models and their related history. Six students stayed after class to further explore the physical models. At the end of the semester, students were surveyed on their assessment of the hedonic value of various digital and physical modules (Figure 6). Clearly the students prefer physical models and QTVR movies. Physical models were ranked the most unique and interesting. QTVR movies were rated the most “exciting”, “impressive”, and “outstanding”. In general, the physical models and QTVR movies rated equally well on average hedonic value followed by the Java simulations. Textual materials were given the lowest score on all the hedonic measurements. Similar to the geometry class, the modules which were rated high on learning outcomes were also rated high on hedonic values.

----------------------------- Insert Figure 6 Here ----------------------------------

By comparison, the two groups of students had different preferences and ratings for the different modules. The open-ended questions in the self-evaluation survey queried students about their general experience with the models. Thirteen geometry students and 16 robotics students returned the self-evaluation survey. The numbers of positive and negative responses from the two classes were about the same. In both classes the number of positive responses was four times more than the number of negative responses, indicating that in general both groups of students had a positive experience. They used similar keywords to describe their positive experience, for example, “fun”, “interesting”, “exciting”, “very good”, and “very nice”. However, the negative responses were different from each other. There were six complaints about the lack of access to the physical models in the robotics class while there was only one similar complaint in the
geometry class. On the other hand, ten complaints about usability problems associated with
digital models came from the geometry class, while only one came from the robotics class. These
findings are consistent with how students rated their preferences for the different modules
discussed earlier. In addition, the results show that both groups of students enjoyed the modules
that helped them to learn.

IMPLICATIONS AND DISCUSSIONS

One very clear finding from this evaluation was user preferences, learning outcomes, and
the affective values associated with learning experiences, were different depending on the class
subjects, goals and objectives. The geometry class students enjoyed the Java simulations the
most and considered the digital models more useful in helping them to grasp and understand
class materials and fulfill pedagogical goals, while the students in the robotics class preferred the
physical models and asked for gaining access to them. Physical models and QTVR movies
facilitated intuitive understanding and hands-on experience in the robotics class, while Java
simulations and textual materials helped the geometry students to learn abstract geometrical and
kinematic rules. The customization and personalization of information systems has been
promoted widely. This research demonstrated that in order to design interfaces for different user
groups, it is necessary to take their cognitive styles and knowledge background into
consideration. Even based on the same historical models, different representations will suit
different user groups. Kennedy (1998) concluded that no educational tool is effective for
everyone. For example, although physical models can be produced through rapid-prototyping
tools, the results of this study have suggested that the physical models may not be necessary for
certain groups of users. Considering the high cost of rapid-prototyping even a single physical
model (about $300), this has important practical implications. Past research has also indicated that there are a number of situations in which computer simulations are preferred to other tools including when the process to be investigated takes place in reality too quickly, too slowly, or it is too complex to be observed or experienced (Min, 1995). Since abstract geometrical rules cannot be directly observed, rendering the physical models will be less useful than the Java simulations which by their nature allow student to extract the underlying rule.

The relationships among usability, learning, and subjective experience are another interesting finding from this research. For example, good usability is a necessary condition for learning, since frequently some students were busy trying to figure out how to make the simulations work, instead of reflecting on the mechanism and linking the simulation to the geometrical rules. Effective learning in turn results in a positive subjective experience. The students enjoyed the modules which helped them to learn. However, good usability is not a necessary condition for a positive experience. Some students were amused by unusual shapes in the simulation, which were actually bugs in the program. In addition, a positive subjective experience can also be detrimental to learning: one student was enjoying playing with the Java simulation of inversion without reflecting on the rules of inversion. The relationships among these three factors -- usability, learning, and subjective experience -- pose interesting questions for the design of digital libraries. Making the models engaging, while leaving space and time for reflection and connecting the models with pedagogical goals, is important consideration for the future design.
Besides different context, usability problems, learning effects and subjective experience, this research also reveals the dynamic and evolving nature of the design, uses, and evaluation of a digital library (Bishop et al., 2000). More specifically, this is characterized by the following aspects: 1) the dynamic uses of a digital library and the blurred boundary between the digital library and other digital sources. The professor of the geometry class created a class web page with links to various digital models from the digital library. The learning modules were from the KMODDL however the main homepage was designed by the professor specifically for his course; 2) The dynamic building of collections and the blurred boundary between primary and secondary materials. The professor designed Java simulations and textual modules specifically for this course based on the historical collections explaining the mechanisms in geometric and mathematical terms. All the modules have been added to the digital library and have become the primary materials. Our research results demonstrate that the digital modules were most useful when they were adapted and redesigned for the specific pedagogical goals and the context of the class. There is no clear boundary between the collections in a digital library and their derivative learning materials; 3) The multiple roles of team members. The professors on the team provided content for the digital library, used the digital library and related modules in their classes, and worked with evaluators to design and execute the evaluation plan. Their multiple roles helped to translate lessons learned from the outreach and evaluation efforts directly to the development; 4) The dynamic nature of evaluation. The research methods were slightly changed after improvements were made on the KMODDL and lessons learned from the previous evaluation effort. Screen capturing was dropped from the research methods since usability problems had been revealed and improvements in the interface had been made. In general, the research shows that the materials in the KMODDL should be used dynamically by tailoring the number of
learning modules and the interface of each module when they are introduced in a course. In addition, integrating educational outreach and user community involvement with the collection development process is essential to the successful use and development of digital libraries in educational settings.

While the virtues of 3D printing will need to be assessed relative to the learning context, where appropriate, 3D printing technologies are a potentially powerful extension for digital learning. We are currently studying the uses of 3D printing technology in educational settings. Working with the Museum of Science in Boston, the team is exploring the potential of using 3D printing to exchange physical artifacts in both formal and informal learning environments.

ACKNOWLEDGMENTS

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REFERENCES


<table>
<thead>
<tr>
<th>CIAO! Element</th>
<th>Date</th>
<th>Methods</th>
<th>KMODDL Related Class activity</th>
<th>Research Goals</th>
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<td>Document Analysis</td>
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<td>Context Interaction</td>
<td>Nov 6\textsuperscript{th} and Nov 11\textsuperscript{th}</td>
<td>Observations</td>
<td>Introduction of KMODDL</td>
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<td>Interaction</td>
<td>Nov 13\textsuperscript{th}, Nov 18\textsuperscript{th} and Nov 20\textsuperscript{th}</td>
<td>Videotaping</td>
<td>Demonstration of physical models and introduction of related history</td>
<td>Understand the use of physical models in classroom</td>
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<td>Nov 20\textsuperscript{th}</td>
<td>Software logging and screen capturing</td>
<td>Use of digital models in KMODDL digital library</td>
<td>Understand the usability problems and learning effects of KMODDL</td>
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<td>Attitude Outcome</td>
<td>Nov 20\textsuperscript{th} and Dec 2\textsuperscript{nd}</td>
<td>Surveys</td>
<td>Discussions of homeworks on KMODDL</td>
<td>Assess students’ subjective evaluation on usability and learning</td>
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<td>Context Attitude Outcome</td>
<td>Dec 20\textsuperscript{th}</td>
<td>Interview</td>
<td>End of the course</td>
<td>The professor’s view on the context, the learning effects and usability problems of KMODDL</td>
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Table 2. Major research steps in the evaluation of robotics class

<table>
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<td>Demonstration of Physical models and Introduction of related history</td>
<td>Understand the use of physical models in classroom</td>
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<td>Interaction</td>
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<td>Surveys</td>
<td>KMODDL accessing session</td>
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<td>May 21&lt;sup&gt;st&lt;/sup&gt;</td>
<td>Interview</td>
<td>End of the course</td>
<td>The professor’s view on the context, the usability issues and learning effects of KMODDL in classroom</td>
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</table>
Figure 1. Four types of learning modules in KMODDL
The historical model of slider crank mechanism       Rapid prototyping of the historical model

Figure 2. Rapid prototyping for historical models
Figure 3. Learning effects of different modules in geometry class
Figure 4. Learning effects of different modules in robotics class
* The last item is the average hedonic value.

Figure 5. Comparison of different modules on hedonic values in geometry class
Note: the last item is the average hedonic value.

Figure 6. Comparison of different modules on hedonic values in robotics class