CHAPTER FOR LEARNING OBJECTS

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EXECUTIVE SUMMARY

This chapter focuses on a case study that compares and evaluates different instructional design employing a set of learning objects. Based on a historical collection of steel and bronze models, KMODDL (Kinematic Models for Design Digital Library, http://kmoddl.library.cornell.edu/) contains four types of learning objects: textual tutorials, interactive QuickTime Virtual Reality movies, Java simulations, and stereolithographic (STL) files. The four learning object types have been used in the context of an undergraduate geometry class, an undergraduate robotics class, a middle school technology club field trip, and a middle school technology class. Following the CIAO! (Context, Interaction, Attitude, and Outcome) model of evaluating educational technologies (Jones et al., 1999), the research team have evaluated the four types of learning objects in the four learning scenarios. Multiple data collection methods (Bishop et al., 2000) were used, including observation, videotaping, screen-capturing, interview, focus groups, and surveys. The research shows that the educators’ strategies for integrating digital objects into their curriculum depended on their subject area and the educational level of their students and, significantly, that these differing strategies resulted in different uses of the available materials by the students, as well as in different learning outcomes.
LEARNING OBJECTS IN CLASSROOMS

INTRODUCTION

As an emerging concept that bears great potential to revolutionize classroom instruction, the learning object has attracted increasing attention from various fields in recent years (Wiley, 2001; Koohang, 2005). Connecting instructional design with learning objects is essential for making learning objects useful in classrooms and has been shown to facilitate learning (Wiley, 2001; Krauss & Ally, 2005). However, precisely how learning objects support student learning has not been widely researched to date (Orrill, 2000). There have been remarkably few empirical studies evaluating the educational impacts of learning objects (the examples include Cochrane, 2005; Krauss & Ally, 2005). This research uses multiple methods to evaluate the educational impacts of a collection of learning objects. The goal is to explore and understand the different learning processes, outcomes, and experiences associated with a single array of learning objects, when these are deployed in the context of different instructional design, different subject areas, and different educational levels. The remainder of this paper is organized as follows: the authors reviews the previous research on instructional design and learning objects first, followed by an introduction to KMODDL project; then it details the instructional design in four learning scenarios; lastly, the chapter describe the results in depth and concludes the chapter by outlining the conclusions and implications.

INSTRUCTIONAL DESIGN AND LEARNING OBJECTS

Recent studies of learning objects have shifted from a technological perspective to an educational perspective (Wiley, 2001). As a new concept by way of which educators
might view instructional resources in digital format, learning objects need to demonstrate their value in facilitating student learning. This section reviews recent advances in this area.

According to Mergel (1998), three learning paradigms have influenced instructional design: behaviorism, cognitivism, and constructivism. Founded by Pavlov and followed by Watson, Thorndike and Skinner (Dembo, 1994), behaviorism focuses on observable behavior in response to stimuli; cognitivism focuses on the association of new knowledge and old knowledge and views learning as the reinforcement of new mental constructs; constructivism focuses on learning as self-constructed knowledge, not as transfer of knowledge from a teacher to a student. These different learning theoretical perspectives have led to different types of instructional design practices. However, the paradigms are not mutually exclusive; rather they capture different aspects of learning (Mergel, 1998). In simple terms, behaviorism led to measurable and systematic approaches to instruction; cognitivism informs learning by stressing breaking down tasks into small components; constructivism stresses multiple representations of reality and thus suggests that standard and uniform measurements might not be appropriate for diverse learners. This last approach encourages team-based and hands-on experience.

The classic book on instructional design edited by Reigeluth (1983) reviews eight instructional design models, including the prescriptive model of instruction, the behavioral approach to instructional design, the Algo-Heuristic theory of instruction, structural learning theory, inquiry-based learning, component display theory, elaboration
theory, and the motivational design of instruction (see Reigeluth, 1983 for a detailed description of the eight models). However, one needs to identify different learning requirements and obstacles in learning in order to adopt appropriate approaches for the actual instructional design.

Wiley (2001) argues that in order to design useful learning objects for education, educators need to consider appropriate combinations and granularity of learning objects. The value of learning objects lies in the way that they can be rearranged and recombined in different sequences according to users’ background knowledge and varying educational levels. The size of a learning objects – be it a whole curriculum, a simulation, or a picture – is an important consideration in instructional design. Sequencing and combining different learning objects into meaningful instructional materials is best informed by instructional design theory. Theory can also provide guidance on appropriate scope and scale of learning objects (Reigeluth, 1983).

In what follows, this chapter describes the educational uses of a learning object digital library. In four educational settings, the professors and teachers used different types of instructional design to integrate four types of learning objects into their curriculum. Different learning processes, learning outcomes, and experiences resulted.

THE KMODDL PROJECT

KMODDL (Kinematic Models for Design Digital Library, http://kmoddl.library.cornell.edu/) is a collaborative project of the Cornell University
Library and Cornell faculty members in mathematics and mechanical engineering. Built with the support of the National Science Foundation and the Institute of Museum and Library Services, the core of KMODDL is Cornell’s Reuleaux Collection of Mechanisms and Machines, an important collection of 19th-century machine element models. The digital library contains four types of learning objects based on these and other machine models: textual tutorials, interactive QuickTime Virtual Reality movies, Java simulations, and stereolithographic (STL) files (Figure 1). The STL files represent a special type of digital object – these files can be downloaded to a rapid prototyping machine to “print” working 3D plastic replicas of the original models. The four learning object types have been used in the context of an undergraduate geometry class, an undergraduate robotics class, a middle school technology club field trip, and a middle school technology class.
FOUR EDUCATIONAL USES OF KMODDL

Following the CIAO! (Context, Interaction, Attitude, and Outcome) model of evaluating educational technologies (Jones et al., 1999), the research team have evaluated the four types of learning objects in four learning scenarios. Multiple data collection methods (Bishop et al., 2000) were used, including observation, videotaping, screen-capturing,
interview, focus groups, and surveys. The four types of educational settings that used the
learning objects – an undergraduate geometry class, an undergraduate robotics class, a
middle school field trip, and a middle school technology class – are described below.

**Undergraduate Geometry Class**

In the Fall semester 2003, the professor of a geometry class (Math 451: Euclidean and
Spherical Geometry) at Cornell University introduced KMODDL in his classroom. Since
the development of the KMODDL web site was in progress, the professor developed a
class web site containing links to the learning objects in KMODDL 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 contained Java simulations and textual materials based
on the historical kinematic models developed specifically for this course. There were 14
students in the class and 13 agreed to participate in the study, including both graduate and
undergraduate students (Pan, Gay, Saylor, Hembrooke, & Henderson, 2004). After two
initial class demonstrations with the physical models, students were able to access digital
materials through a computer and web browser in the lab and use them to help answer
questions related to the lab lesson.

**Undergraduate Robotics Class**

KMODDL was also used in a robotics class (MAE 417: Introduction to Robotics:
Dynamics, Control and Design) at Cornell University in the Spring 2004 semester. Usability
problems revealed in the geometry class had been reported to the design team
for improvement, and by the time KMODDL resources were used in this second
classroom context, the speed and stability of the kinematic simulations had been improved in response to student feedback. A non-public prototype website was used for the class (http://kmoddl.library.cornell.edu/proto.php) since the KMODDL website was still under construction. Similar to the approach taken in the geometry class, physical models were demonstrated first, followed by a computer lab session in which the students accessed and studied digital objects while working on problem sets related to the objects.

**Middle School Technology Club Field Trip**

In order to evaluate the use of KMODDL in middle schools, a field trip was organized to Cornell University’s Information Science Building on June 15th, 2004. Six middle school students (8th graders) participated in the study. There were three steps in this field trip. First the students were introduced to KMODDL and Cornell Human-Computer Interaction group in the conference room. Next they were given the opportunity to play with seven models from the historical Reuleaux collection; next they went to the computer lab to play with digital representations of the three models they had been shown in the conference room. Six students were paired up and each pair shared one computer. During the final step, the students went back to the conference room, where they were asked to draw a shape of equal widths, to recognize several similar kinematic models, and to talk about their experience and opinions regarding the digital and physical models.

**Middle School Technology Class**

KMODDL’s evaluation team introduced the kinematic models to a video design middle school class in March 2005. An educator and an evaluator from Cornell brought around
10 models (including two 3D printed models) into middle school technology classes. The students heard a short presentation on the history of Cornell University’s Reuleaux Collection of Kinematic Models. They were then divided into teams of 2-4 and each team worked out a video project to show how the model works and to relate something about its history, its inventor, and its mathematical and scientific context, utilizing information available from KMODDL. At the final stage of the project, each team was asked to present their videos and answer relevant questions about the model.

**DIFFERENT INSTRUCTIONAL DESIGNS IN FOUR EDUCATIONAL SETTINGS**

The goals, pedagogical requirements, and styles of the four educational settings were markedly different. The geometry class is an advanced undergraduate class on Euclidean and spherical geometry. The professor adopted the Moore method of teaching, which attempts to replace lectures with inquiry-based learning (Jones, 1977). He emphasized learning geometry using reasoning, intuitive understanding, and insightful personal experience (Henderson & Taimina, 2001). In an interview, the professor of the geometry class noted that he introduced 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 through KMODDL. To accomplish this, the students were given a series of inviting and challenging problems, and were encouraged to write and discuss their reasoning and understanding. The professor also
developed a Java simulation for the class to teach the principle of inversion of circles, which is embodied in the straight-line mechanism featured in the KMODDL collection.

The undergraduate robotics course followed a traditional lecture style of teaching, with challenging homework assignments, computer programming problems, exams, and a major design project, in which the students had to design a robotic arm. The instructional design of this course follows something closer to a behaviorist stream of learning, focusing on evaluating measurable outcomes (Mergel, 1998). The class focused on design-based issues, requiring an understanding of kinematics and the integration of mathematics, physics, and geometry. In an 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 emphasis was on applying knowledge to design in creative ways.

The third session, the middle school field trip to Cornell University, was obviously aimed at students of a very different level of cognitive development. This session, set in a more informal educational setting, was shorter in duration than the undergraduate seminar sessions and focused primarily on increasing the students’ interest. The teacher instructed the students about the history of the models and asked them to browse through the learning object digital library. She then asked the students to solve a problem of drawing an arbitrary shape of equal width from the inspiration of the models.
In the fourth setting, the middle school technology class, teaching followed a more constructivist approach: the teacher used the format of a group project (the video production) and inquiry-based learning to encourage the students to construct their own meanings from the models (Jonassen, 1991). The teacher also asked each group to answer three questions in their final video: who invented the model? where is the model used or where could it be used? what is model’s math and science connection? The teacher gave the student groups two weeks to finish the video using the iMovie application, present their videos, and answer the three questions in class.

The goals and instructional design of four educational settings were quite different, as befit their distinct subject areas and educational level. The goal of the undergraduate geometry class was conceptual and theoretical, while the undergraduate robotics class was more applied and practical. The middle school student field trip had the goal of stimulating student interest, more than conveying particular concepts; the middle school technology class aimed to bring students to a deeper understanding of technologies, as well as to change their attitude toward technology and engineering as possible career choices. The instructional designs of the four settings matched their divergent goals. The undergraduate geometry class focused on personal experience and followed the Moore method of teaching; the undergraduate robotics class was more conventional in its approach, with its lecture-style presentations and materials, challenging homework, computer assignments, and design projects. The middle school student field trip encouraged browsing of physical and digital models; and, finally, the middle school technology class followed a strategy of team-based and inquiry-based learning.
RESEARCH METHODS

In evaluating educational technologies, the context and user tasks are extremely important (Bishop et al., 2000). 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). The focus of this research is on the uses of learning objects as an educational tool in four different educational contexts. 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 multifaceted data in order to evaluate the uses of technologies. Jones and his colleagues proposed to evaluate educational technologies through Context, Interaction, Attitude, and Outcome (CIAO!) (Jones et al., 1999). 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 in this study to capture the context, interaction, attitude and outcomes (Jones et al., 1996; Jones et al., 1999; Pan, Gay, Saylor, & Hembrooke, in press). Similar research methods were followed in observing the four educational settings and sessions. The following is a description of the most complete procedure of the data collection and analysis. In some educational settings, some steps were skipped because of changing needs regarding development of the learning object digital library, and because of the differing demands of the actual settings.
1) Document analysis (Context): Before each teaching session began, the evaluation team collected textbooks, the course syllabus, and class materials. These materials were used to understand the structure and style of the class, so that the evaluation of KMODDL would be appropriately situated in that context (Patton, 2001).

2) Videotaping and observations (Context and Interaction): During the class sessions, when the students interacted with the physical models, the evaluation team videotaped and audiotaped both the professor’s demonstration and the students’ responses. A researcher also sat in the classroom, observed the class session and took 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 objects, 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 mouse clicks. Two students shared one computer and discussion between them was encouraged. A microphone was placed before the computer so that this natural verbal protocol was recorded along with 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 KMODDL web site. The researchers skipped this method in the undergraduate robotics course since usability problems have already been gathered for undergraduate student user group and the development team has made significant changes to the learning objects and the digital library interface.
4) Surveys (Attitude and Outcome): Surveys were used in three of four educational settings. In the two undergraduate classes, during the lab session in which the students accessed KMODDL, the evaluation team distributed a survey asking the students to comment on the difficulties they encountered, what they liked about the learning objects, and suggestions for improvements (the usability survey); at the end of the semester, a second survey (the final survey) asked students about their opinions regarding the usefulness of the four different physical and digital models on both self-evaluated learning outcomes and subjective experience. The three aspects of learning include: A. stimulation of interests and curiosity; B. help to understand; and C. help to remember. Seven aspects of subjective experience were evaluated. Students were asked to rate the learning objects as: Outstanding; Exclusive; Impressive; Unique; Innovative; Exciting; and Interesting.

In the middle school technology class, the students' attitude toward engineering was measured through a standard questionnaire (Gibbons, Hirsch, Kimmel, Rockland, & Bloom, 2004). The actual questionnaire used in the classroom was shortened for the purpose of reducing the time needed to fill out. At the first class session (March 16, 2005) the students were asked the complete questionnaire a first time. On the day the students presented their videos (March 30, 2005), the same students were asked to complete the same questionnaire a second time, in order to detect changes of attitude. Surveys were not used in the middle school field trip because of the limited time.
5) Focus Groups (Attitude and Outcome): In the middle school technology class, the students were asked about whether and what they learned using the physical models and the learning objects in the digital library. The numbers of positive, neutral, and negative answers were recorded and compared to show learning outcomes.

**COMPARISON OF LEARNING PROCESSES AND OUTCOMES**

In the undergraduate geometry class, classroom observations, critical incident analysis on the classroom lecturing, and screen captured movies of the students’ interaction with KMODDL site were used to capture different aspects of the learning process. The final surveys were used to assess self-evaluated learning outcomes. In the class demonstration of physical models, the students were interested and stimulated during the class that introduced the physical models and their history. They showed their interests by smiling and standing up from their seats. The physical models were especially useful for stimulating and engaging the students’ interest. The quantitative measurements in the final survey show that the digital learning objects were rated more useful in facilitating students’ learning than were the physical ones. Of the learning objects, the Java simulation of inversion (instructional material) was rated the most useful in terms of helping students grasp the principles of inversion. The textual materials were rated next most useful. Physical models were rated third and QTVR movies were rated the least useful among the four learning objects (Figure 2). The Java simulations on inversions were specifically designed for this course by the professor and were precisely keyed to the goal of demonstrating the rules of inversions. This suggests that the objects 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 KMODDL?” suggested that the students appreciated the ability to manipulate the learning objects, 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. These “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, some students discovered when 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 of digital simulations can lead to creative thinking and self-discovery. However, a special case of learning inhibition was uncovered, which is termed the “hedonic problem.” 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 applying geometrical rules to the movements of the mechanisms.
In the undergraduate robotics class, a pre-test and a post-test survey and a final survey on self-reported learning and subjective experience were used to evaluate the outcomes of learning. In the pre- and post-tests, six in fourteen responses showed improved understanding of one model (a four-bar linkage mechanism), and two in fourteen showed improved understanding of the other model (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 intricate and its functions are more difficult to understand. This result indicates that even varied representations and experience may not be enough to enhance learning for more intricate or complex models. In the final 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 for “stimulating their curiosity,” and for helping them “remember kinematic rules”. QTVR movies were ranked highest
for “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 learning objects.

Figure 3. Learning effects of different learning objects in robotics class

A comparison of the responses to an open-ended question from surveys (“what do you like about the object?”) shows that six in the geometry class and two in the robotics class mentioned “visualization” as a useful feature of 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 considered all the learning objects helpful but not very pertinent, and not closely related to class materials. This group of students reported that the models helped them to design. For example, some students commented: “the models help us discover new ways of doing things that we might not otherwise think of.” The results suggest that the Java simulations may foster the visualization of geometrical concepts and rules by providing detailed description of mathematical and kinematic rules, visualizations and manipulative experience. Alternately, 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.

In the middle school field trip to Cornell University, the observations and screen capturing movies showed that the students were more interested in real world applications that related to their everyday lives. Some real world examples the instructor gave to the students (for example, a special Chinese ring and Mazda engines) were apparently too distant from their real lives so they were not very interested. If applications were introduced with which the students had direct experience, they would presumably be more likely to understand and comprehend. The task of drawing a shape with equal widths was too difficult for the students. KMODDL texts were too long; the students responded that they were boring and confusing. Tutorials (both Reuleaux triangle and Geneva wheels) were too difficult. Some students like to read textual material while others do not. The students were interested in the physical models but in a superficial way; they did not know what they are used for. The students had various background knowledge; some knowledgeable students seemed much more engaged than the other students and thus learned more than the others. The students were able to relate similar models to one another.

In the middle school technology class, learning was measured through questions posed during the presentations and the critical incident analysis of the screen-captured movies. Two cases were found where the students understood how the mechanism works through movies or simulations. In the focus group discussions, students were asked whether or
not they learned from the physical models and from the website. 82.1% of students expressed positive learning outcomes from the physical models while 41.1% indicated that they learned from the website. By this measure, at least, the learning effects of physical models appear to be much greater than the website. When they were asked what they learned from the physical models, students used the following expressions: they learned “different cams,” “different types of motion,” the models can be used “in cars,” “in clocks,” “in steam engines”; some models have “same idea, different forms”. From the website, they learned “different uses of the model,” “how engines work,” “what models do,” their “inventors,” “history,” “what they are used for,” and “how they work.” In the final presentation, almost all of the teams could answer the three questions the teacher raised: who invented the model? where is the model used and can it be used? what is the model’s math and science connection? However, some of their answers to these questions were imprecise. For example, James Watts improved steam engines but he was not the inventor; there is a difference between the Reuleaux Triangle and the Wankel engine, which uses the Reuleaux triangle. For these open-ended questions, the students sometimes had trouble find precise answers using KMODDL’s textual resources. Their understanding of the kinematic models stayed at a superficial level.

In addition, as described above, the students’ attitude toward engineering was measured through a standard questionnaire, which they completed at the start of the first session and at the end of the last. The results of the two surveys were then inputted and coded. Among fifteen student participants who filled out both questionnaires, five showed an increase in their positive attitude toward engineering; one showed no change; and nine
students showed a decease in their positive attitude toward engineering. Therefore, the questionnaire didn’t show significant positive improvement of their attitude. There might be different reasons for this result: 1. the effects of physical models on the students’ attitude toward engineering were not great enough to generate significant changes of attitude in two weeks; 2. the major project was a video project, so the students’ focus was on the video production instead of related engineering concepts; 3. there are many intervening elements in determining the students’ answers to the questions, for example, different stages in the semester and the general atmosphere in the middle school may influence the students’ attitude, but they may not be controllable. In the future, two survey measurements across a longer period of time, for example, two years, might be used.

In general, undergraduate students in a geometry class enjoyed using the Java simulations and learning geometrical rules from simplified representations. For the robotics students, these objects furnished holistic and hands-on experience that could facilitate creative design. The middle school students who were exposed to the original physical models as well as the digital objects on a field trip enjoyed the physical models, but failed to gain concrete knowledge from them because of limited access time; in the middle school technology class, the students increased their understanding of kinematics but failed to show changes in their attitude toward engineering.
COMPARISON OF SUBJECTIVE EXPERIENCE AND PREFERENCES

In the undergraduate geometry class, classroom observations, critical incident analysis on the classroom demonstration of the physical models and screen captured movies, and the final survey were used to assess students’ subjective experience. During the web access session, students engaged in hands-on manipulation of the learning objects 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 final survey asked about the students’ general experience with these models. Most students gave positive responses (10 in 12) when asked about their experience using these models. However, the students again 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 final survey, seven questions on the hedonic value of four types of the models were used to determine the experience of the users (Hassenzahl, Beu, & Burmester, 2001, 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 objects (Figure 4). Interestingly, when compared with the students’ reports on learning effects, those objects rated highly on hedonic value were also rated highly on learning impact.
In the robotics class, classroom observations and the final survey were used to assess students’ subjective experience. In the robotics class, the students also 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 objects (Figure 5). 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.” The two are rated equally high on the “exclusive” measurement. 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

![Figure 4. Comparison of different learning objects on hedonic values in geometry class](image-url)
all the hedonic measurements. Similar to the geometry class, the objects which were rated high on hedonic value also rated high on learning effects.

![Graph showing comparison of different learning objects on hedonic values in robotics class]

Note: the last item is the average hedonic value.

Figure 5. Comparison of different learning objects on hedonic values in robotics class

By comparison, the two groups of students had different preferences and ratings for the different objects. Furthermore, the open-ended questions in the final survey queried students about their general experience with the models and whether or not they thought that these models had helped them to learn. The responses were coded in NVivo (Gibbs, 2002), with each response coded into one or more categories. Thirteen geometry students and sixteen robotics students returned the final 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: “fun,” “interesting,” “exciting,”
“very good,” “very nice,” etc. However, some 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 objects discussed earlier. In addition, the results show that both groups of students enjoyed the objects that helped them to learn.

In the middle school field trip to Cornell University, the students were interested when introduced to the physical models. Some of them were bored when accessing digital models. They were not very excited when viewing the animations and pictures compared with responses from undergraduate classes. The students were more interested in “cool stuff” (3D printing technology and how a gyroscope works), which was not a part of KMODDL, but something unique and uncommon, or something they had experience with. The students preferred physical models since they could really see what was going on; with various usability problems with the QTVR movies, it was difficult to see the functionalities of the mechanisms.

In the middle school technology class, the students’ subjective experience was measured through critical incident analysis (Carroll, Koenemann-Belliveau, Rosson, & Singley, 1993) and the focus group discussions. Ten positive incidents were found where the students showed their enjoyment of the website. There were sixteen incidents of negative
experience (boredom, frustration, or confusion) on the website. However, in the focus group discussion, the students were asked if they enjoy the physical models and the websites. Among all 56 students, 82.1% indicated that they enjoyed working with the physical models; 76.8% indicated that they enjoyed working with the website (see Figure 3 and Figure 4). When they were asked what they enjoyed about the physical models, they used the following statements: the models are “interesting,” “cool,” “wonderful,” “amazing,” “weird,” “old,” “mechanical,” “hands-on,” and “complex,”; “they move,” “they make noises,” “they spin,” “they are really complex to learn,” and they have “lots of concepts.” Regarding the website, they mentioned the following reasons why they enjoyed working with the website. Through the movies and simulations they could “make them move,” “change the size,” learn “how things work”; the site is “organized,” “easy to use,” contains “lots of information,” they are “cool” and “interactive,” “they move,” you can “drag” and it “goes fast.” Students’ enjoyment of the website had to do with its interactivity and its presentation of novel and old information. Furthermore, the students consider the usability problems encountered on the Web as normal. The fun of interactive movies and simulations outweighed the difficulties they had. Thus, in general, they had a positive experience.

In general, all the students enjoyed the learning objects which helped them to learn. The students in the geometry class enjoyed Java simulations more than other learning objects; while undergraduate students in a robotics class preferred the physical models and interactive QuickTime movies. Middle school students in two educational settings
enjoyed the learning objects even though sometimes they were bored and frustrated by the levels of abstraction and complexity of the learning objects.

CONCLUSION AND IMPLICATIONS

Through evaluating the learning effects of four different types of learning objects in four different classroom settings, this research demonstrates that different types of instructional design fit different educational needs, which depend on factors such as subject areas and educational levels. The research shows that the educators’ strategies for integrating learning objects into their curriculum depended on their subject area and the educational level of their students and, significantly, that these differing strategies resulted in different uses of the available materials by the students and in different learning outcomes. This multi-stage study also informs us about the way to adopt appropriate combination and granularity when designing learning objects for different user groups (Wiley, 2001).

Combination and Sequencing

Different user groups in different areas prefer different types of learning objects. In this research, the geometry students enjoyed Java simulations more than physical models, since the simulations are abstracted model of the physical ones and could help the students to understand the geometrical rules. On the other hand, students in robotics class prefer physical models since they can give them a holistic and hands-on experience and thus facilitate creative design. Thus, different combinations of learning objects are suitable to different user groups in different subject areas. In addition, scaffolding
methods are needed to provide learning objects to middle school students when teaching higher levels of concepts. The middle school students are interested in real world applications of knowledge and theories. Therefore, starting with learning objects which are closely related to their everyday lives and adding in abstract concepts later will help students at this level become interested first and then proceed to conceptual thinking.

**Granularity**

In the undergraduate geometry class, the professor set up a home page and linked to different simulations, texts, and tutorials in the learning object digital library. These are learning objects of different granularities. While simulations are the smallest units of learning objects, the tutorials actually contain texts, multiple pictures, and simulations. Thus, in designing learning objects, flexible granularities are needed to let the users combine objects in different ways.

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