A Digital Library of Printable Machines: Models for Collection Building and Educational Outreach

A Proposal to the Institute for Museum and Library Services (IMLS)
Submitted by the Cornell University Library (revised 22 September 2004)

Introduction

The Cornell University Library (CUL), in partnership with Cornell's College of Engineering, and the Museum of Science (MOS) in Boston, seeks the support of the Institute for Museum and Library Services for a research project in the framework of the Model Programs of Library-Museum Collaboration program. The proposed 18-month project, "A Digital Library of Printable Machines: Models for Collection Building and Educational Outreach," will research and develop the use of stereolithographic ("3D printing") technology to create working physical replicas of mechanical artifacts that can be exchanged electronically between the project partners and manipulated by museum visitors, students, and other users of the collection. The "Printable Machines" project will greatly expand the scope of an openly accessible digital collection now being built by CUL as a resource for teaching and learning about the history and theory of machines, the Kinematic Models for Design Digital Library (K-MODDL). The project will integrate an important set of mechanical models from the MOS holdings into K-MODDL and create an adaptable program of educational activities and materials to enhance access to the MOS and CUL materials for the general museum public, middle school students and their teachers, and university communities.

Research activities in the context of the proposed "Digital Library of Printable Machines" project investigate three research questions, the first two dealing with the use of mechanical artifacts and their digital representations in two distinct learning environments (middle school classroom and museum), and the third addressing management of digital representations of physical objects in a library environment:

I. What are the effects on learning of the integration of digital and physical experiences provided by historical mechanical artifacts, 3D printed machines, and computer simulations?

II. What different types of learning experiences do users have using printable machines in the museum and classroom settings? Are different types of learning better suited to one or the other of the two distinct contexts?

III. What terminology, descriptive protocols, and asset management practices will enable original artifacts, digital representations, and printable machines to be accurately and appropriately found, accessed, and utilized by users within a library environment?

Investigation of questions I and II will follow procedures discussed in part 1 of the Research Plan (p. 11, below); part 2 of the Research Plan (p. 19, below) addresses question III.

Kinematic Models for Design Digital Library (K-MODDL)

The "Printable Machines" project builds on this nascent CUL digital initiative, which is funded by a two-year (2002-2004) National Science Digital Library (NSDL) collections grant from the National Science Foundation. K-MODDL (http://kmoddl.library.cornell.edu/) is a collaborative effort of Cornell librarians and faculty in mathematics and mechanical engineering to create a digital library of mechanical models for teaching the principles of kinematics – the geometry of pure motion. K-MODDL includes:

- still and navigable moving images of a rare set of 19th-century mechanical models, designed by the German engineering professor Franz Reuleaux, with systematic descriptions,
- computer simulations of mathematical relationships associated with the mechanisms' movements,
- historical and contemporary documents related to the collection of mechanisms,
- and sample teaching modules that employ the models and simulations in the classroom at the undergraduate, high school, and middle school levels.

Printable machines

K-MODDL allows users to explore kinematic motion by manipulating moving photographic images of machine artifacts, as well as abstract computer models of mechanisms. What cannot be experienced with a digital collection, however, is the physical handling of the models – and physical embodiment is essential for an intuitive appreciation of many critical concepts of motion and force. The K-MODDL team is exploring the use of rapid prototyping technology to reproduce physical models as 3-dimensional "prints" from digital files. These replicas are based on computer-aided design (CAD) drawings of the Reuleaux models, captured in stereolithography (STL) format. STL files can be exported for printing on a rapid prototyping fabricator. Rapid prototyping builds a working physical object in a sequence of thermoplastic layers from a filament-wound coil that is heated and extruded through a nozzle.

A clock escapement mechanism: original Reuleaux model (left) and rapid-prototype model (right).

Stereolithographic technology converts between information and artifact and thus exemplifies an intersection of library and museum work. The "Printable Machines" project focuses on the uses of stereolithography for disseminating physical objects in a context of digital library-museum collaboration.

1. National impact

While some in the research community have integrated rapid prototyping technology into digital collections,[1] the proposed project represents the most systematic and holistic attempt to date to bring

[1] See the NSF-funded e-Skeletons Project at www.eskeletons.org and John Kappelman, et al., "e-Skeletons: The Digital Library as a Platform for Studying Anatomical Form and Function," *D-Lib Magazine* 5.9 (Sep. 1999): http://www.dlib.org/dlib/september99/kappelman/09kappelman.html .

digital library best practices to bear on a collection of 3D-printable objects, and to utilize the technology in a large-scale combined collection-building and outreach effort. The project will provide U.S. cultural institutions with a significant practical model and research results on ways that digital libraries can enhance access to digital and physical representations of museum artifacts for educational purposes. The “Printable Machines” project leverages NSDL investments, amplifying the impact of the NSDL and IMLS projects.

The project team is convinced that research and development in the “3D printing” aspect of the project can contribute to a “normalization” of rapid prototyping technology in museum and library work and lay the groundwork for other digital library initiatives that utilize this technology. Moreover, the project will contribute research findings and practical experience to emerging discussions in the library and museum communities on how to organize and provide long-term access to various types of 3D data, discussions which, up to now, have only peripherally treated stereolithographic data.[2]

2. Adaptability

The “Printable Machines” project will adapt the K-MODDL resource for use in an interactive museum setting and enhance its utility in the classroom. Resources created as part of the “Printable Machines” project will be designed for re-use and exchange among the project partners and in the various project settings (museum, university, library, website, public school classroom), and our model can be further adapted by other projects that provide access to artifacts and information. The project takes a multifaceted approach to curating an educationally valuable artifact collection, enhancing its usability for multiple communities, and providing outreach. The project provides a well-documented methodology and a framework based on standards that is extensible to diverse fields. The project will provide early, groundbreaking research on and demonstration of the provision of *physical* access to artifacts via distributed *digital* libraries. The growing body of STL files, along with the increasing availability and lower prices of 3D printers in universities and other institutions, will increase the value of this research for other cultural institutions.

3. Design

The “Printable Machines” project will meet the following objectives:

<u>Digitize the Clark Collection of Mechanical Movements</u>: Produce still images of each model in MOS’s Clark Collection, as well as digital video to illustrate their motions. Complete extensive metadata to classify and describe the Clark models and explain their educational merit and scientific significance. Integrate these records into K-MODDL.

<u>Create printable machines</u>: Produce stereolithographic (STL) files for a minimum of twelve of the Clark and Reuleaux mechanisms; make these available via K-MODDL. “Print” replicas of the models and specially designed manipulatives for outreach and display.

<u>Provide access to machine models in the museum</u>: Customize a web-based interface for the digital library for use with an interactive exhibit at MOS. Develop museum programs for the general public and for middle school visits, including exhibits, materials, and activities that integrate the digital library interface, original artifacts, and “printed” 3D manipulatives.

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[2] See Jeremy Rowe, "Developing a 3D Digital Library for Spatial Data: Issues Identified and Description of Prototype," *RLG DigiNews* 6.5 (15 Oct. 2002): http://www.rlg.org/preserv/diginews/diginews6-5.html#feature1 . Also, Humanities Advanced Technology and Information Institute (U of Glasgow) and National Initiative for a Networked Cultural Heritage, *The NINCH Guide to Good Practice in the Digital Representation and Management of Cultural Heritage Materials,* Version 1.0 of the First Edition (Oct. 2002): http://www.nyu.edu/its/humanities/ninchguide/ .

Provide access to machine models in the classroom: Work with middle school teachers to develop and disseminate learning modules that deploy the digital library and "printed" manipulatives.

Expand the digital library: Build on the existing K-MODDL database infrastructure to accommodate the new collection.

Conduct research: Carry out research on the use of mechanical artifacts and their digital representations in learning environments, as well as on the management of digital representations of physical objects in a library setting.

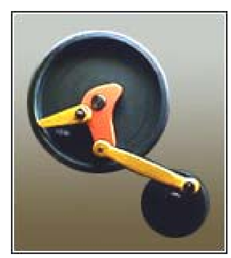
Evaluate the program: Carry out formative and summative outcomes-based evaluation to document the project's benefits. Compile a final report documenting lessons learned, sustainability of the collection, and the potential for its adaptation and expansion.

The objectives are discussed in detail below.

3.1. Digitizing the Clark Collection of Mechanical Movements

The Museum of Science owns a collection of working models of mechanical movements and combinations of drive mechanisms built by American engineer William M. Clark in the early 1900s. Originally numbering over 200, these working models were displayed as the *Mechanical Wonderland* in New York in 1928 and at the Century of Progress Exhibition in Chicago in 1933. Today, 120 of these mechanical models remain in working order and on display at the Museum of Science in Boston. The models include gears mechanisms, pulley systems, cutaways, and cross sections of a variety of machines. They illustrate methods of converting rotary to rectilinear motion and rectilinear into oscillating motion, and solutions to a variety of other mechanical tasks. Clark published photographs and descriptions of these models in 1933 in a *Manual of Mechanical Movements*. The models remain of interest today to a range of visitors, from young children to mechanical designers and tinkerers.



The Museum's collection is displayed behind glass in cases that each houses sixteen of the models. A single visitor-activated switch on each case animates all sixteen mechanisms in that case. Over the years, the Museum has replaced the original drive mechanisms that animate the models, allowing them to remain fully operational. Some cosmetic touch-up will be required on some of the models before they are photographed and a few will need some parts repaired.

CUL staff will photograph the Clark models in Boston and produce the video sequences that allow users view the mechanisms in motion. Professor Francis Moon will describe each of the Clark mechanisms, writing abstracts for each model record in the K-MODDL database and producing longer explications of selected mechanisms. Moon's historical and theoretical descriptions of the models in the Reuleaux collection are part of the core content of the existing K-MODDL database and his expertise will be indispensable in integrating the Clark models into the expanded version of the resource. Moon's preliminary research has traced the Clark mechanisms to 19th-century designs published by the American Henry Brown, and many to much earlier examples from British and Continental machine theory.

3.2. Creating printable machines

Together with Moon, Professor Hod Lipson will select a minimum of twelve of the Clark and Reuleaux mechanisms to be made available as STL printable machines. Lipson will supervise Cornell engineering students in creating the STL files and will also direct the production of the 3D prints, which will make use of a rapid prototyping fabricator housed at Cornell's College of Engineering. The printable machines can be faithful replicas of the original artifacts, but they need not be limited to this. As the needs of the museum and classroom programs crystallize, 3D manipulatives can be designed and printed that simplify, enlarge, combine, or disassemble mechanisms to meet specific educational goals. The mechanisms in the Clark and Reuleaux collections are machine *elements*; a possible activity involving manipulatives would allow users to assemble a more complex machine from multiple mechanisms.

The Cornell team will assume responsibility for the printing and delivery of the stereolithographic models (3D printed machines) to the museum site. Ideally we would like to provide the museum with a 3D printer so that they could do the printing themselves from STL files available on the K-MODDL website. We are negotiating with a company that manufactures 3D printers about the possibility of providing MOS with a machine as a philanthropic gesture. If this effort is not successful, the Cornell team will print the models the museum needs on the 3D printer that is already owned by and in production at Cornell and deliver the models to Boston by carrier.

3.3. Providing access to machine models in the museum

Over the last two years, the Museum of Science has developed a long-range strategic plan that makes a strong commitment, for the next decade, to informal technology education addressing the full range of goals for technology education represented in *Standards for Technological Literacy*, published by the International Technology Education Association in 2000. Massachusetts is the first state in the U.S. to have statewide engineering and technology content standards in its K-12 Curriculum Framework; in response, MOS is adapting its school visit programs and developing resources to support the state's Science and Technology Framework before, during, and after class visits to the Museum. Two efforts currently underway to implement new technology education activities in the Museum will benefit from the proposed collaboration between the MOS and CUL:

<u>Interpretations</u> are informal activities led by Museum staff and volunteers at demonstration counters and activity carts throughout the Museum. These are aimed at a general public.

<u>Design Challenges</u> are exhibit hall activities that school groups can drop in on while visiting the Museum's exhibit halls, and participate in without prior reservations. These activities provide school-age visitors with a design challenge and the materials to design, build, test, redesign, and retest their projects.

Both programs will provide opportunities for our school and public audiences to explore the three different representations of machine models. Each effort will take place within close proximity to the mechanism exhibit so that it can serve as a resource for visitors during these interactions. The interpretation and design challenge activities encourage critical thinking, cooperative learning, and kinesthetic explorations – three skills that will be served to varying degrees by each of the three modes of displaying the Clark Collection mechanisms.

In the interpretation program visitors will interact with a skilled educator who will facilitate the exploration of these models through the theme of simple machines. The goal for this interpretation is to have visitors understand that a complex mechanism is made up of easily understood simple machine components. Each of the Clark Collection mechanisms on display – in all three modes of accessibility – can be described as a combination of interacting simple machines, such as wheel and axel, pulley, lever or inclined plane.

An interpreter based in the exhibit will introduce visitors to these simple machines through touchable, working models that are available to visitors to manipulate. After that initial introduction visitors can investigate the mechanisms on display to find how these simple machines are combined to create the working mechanism. We expect that each of the three modes of display – the digitized model, the working mechanism, and the printed replica – will yield different information to our visitors as they set out to “construct” the mechanism from it’s individual machines.

In the design challenge visitors will engage in a more in-depth activity, once again using the various model modes as a resource on mechanics. While the interpretation encouraged visitors to reduce each complex mechanism to its individual components, the design challenge will ask visitors to use these simple machines to construct a mechanism that can accomplish a specific task. The design challenge environment – a comfortable table and chair arrangement conducive to explorations twenty to thirty minutes in length – will include materials such as gear boards, pendulums, ramps, and levers.

A Museum educator will introduce the concept of simple machines to the design challenge participants. After the group understands the palette of simple machines available for their use they will be asked to design a mechanism that accomplishes a certain task, such as moving an object or turning a wheel. The selected task will be one that is featured in the Clark Collection, so at the completion of their challenge they can learn how someone else solved the same challenge using the same components.

3.4. Providing access to machine models in the classroom

In her work on the NSF-funded phase of the K-MODDL project, Dr. Daina Taimina has developed learning modules for middle school technology and mathematics classes and successfully tested them with students and teachers in the classroom. IMLS support will allow Taimina to extend these efforts and integrate printed 3D manipulatives into the curriculum materials and activities. Taimina will:

- advise MOS on the use of kinematic mechanisms for middle school mathematics education,
- work with Ithaca-area middle school teachers to build on the learning modules developed for the KMODDL grant, incorporating Clark mechanisms and materials and activities developed for the MOS outreach program, and
- offer teacher workshops to disseminate materials and activities produced as part of the IMLS grant.

3.5. Expanding the K-MODDL infrastructure

In the current, NSF-funded phase, K-MODDL engineering/programming has focused on core functionality associated with digital collection building, including but not limited to: database design and administration, the development of a web-based data entry interface for ingest, search and browse functionality for end users, and the development of an OAI interface for metadata harvesting. The majority of this work will be completed prior to the end of the current project phase. IMLS support will allow CUL to build on our solid infrastructure with a stronger focus on the needs of the end user.

The IMLS “Printable Machines” project makes the K-MODDL resource adaptable for use in use in varied learning environments and by multiple communities. Engineering/programming staff will work closely with evaluators to profile our target audiences, conduct task analyses, develop user scenarios, establish user performance requirements, and document usability goals and objectives. Subsequently, engineering staff will focus on rapid prototyping and design walkthroughs aimed at improving the user experience. Programmers will shift their focus from server-side to client-side functionality including but not limited to: more robust (and more usable) search and browse interfaces, improved navigation and information architecture, audience-specific "views" of the data, and improved integration of multimedia content.

We conceive of the “Printable Machines” project as an important step toward a long-term vision of projecting digital library services directly into diverse learning environments. One of the ways this may be accomplished is by developing "device-independent" content. The number of different kinds of devices that can access the Web has grown from a small number with the same core capabilities (web browsers on PC's) to many hundreds with a wide variety of capabilities. Currently mobile phones, smart phones, personal digital assistants (PDA's), interactive television systems, voice response systems, kiosks and even certain domestic appliances can all access the Web. Web content and applications can be authored, generated or adapted for a better user experience when delivered via many different web-connectable devices. Adapting materials for the kiosk-based display at MOS is an ideal way for K-MODDL and CUL to begin to address issues of device-independence. We hope to leverage what we learn toward development of a PDA-based display of the Reuleaux Collection of Mechanisms at Cornell University.

3.6. Research

The research agenda for the “Printable Machines” project is laid out in the Research Plan (parts 1 and 2), below.

4. Management Plan

The Principal Investigator will have overall responsibility for operation of the Digital Library of Printable Machines. The Project Manager will carry out the day-to-day responsibilities with the support and participation of the Project Professional Team. The Professional Team is comprised of: faculty who are experts in content, instructional design, and 3D printing; librarians who are expert in digital libraries and digital preservation and archiving; and our programmer/web designer. The Project Manager will also coordinate the involvement of the Project Partner, the Museum of Science (Boston).

The Project Executive Team, made up of the Principal Investigator, Project Manager, Cornell faculty, and a Museum representative, will meet biweekly (MOS by conference call) to coordinate activities. Other Professional Team members will be responsible for coordinating their activities with the Executive Team and will be called in as needs arise.

The Partnership Statement between CUL and MOS describes specific partnership activities and reciprocal responsibilities. It will be the responsibility of the signatories to that agreement to ensure that the obligations laid out in it are met. The Principal Investigator and Project Manager are responsible for monitoring progress toward fulfillment of these obligations.

5. Personnel

Cornell University:

John M. Saylor, Cornell University, is the Principal Investigator. His activities include overall project planning, financial management and monitoring, sharing responsibility for the outcomes-based evaluation, and maintaining the research agenda.

Kizer Walker, Cornell University, is the Project Manager and will be responsible for the day-to-day coordination and management of the project. He will also be sharing responsibility for the outcomes-based evaluation.

Francis C. Moon, Cornell University, is a Co-Principal Investigator and the faculty member in Mechanical Engineering with the content expertise needed to accurately describe the mechanics of the models and their utility for educational purposes at the undergraduate level.

Hod Lipson, Cornell University, is a Co-Principal Investigator and the faculty member in Mechanical Engineering and Computer Science who is an expert in 3D rapid prototyping printing. He will coordinate the work of undergraduate students for the creation of stereo lithographic files (STL) used in printing the models.

Daina Taimina, Cornell University, is a mathematics educator and research associate. She will develop learning modules from the MOS Clark models for middle school technology and mathematics classes. In this project, Taimina will integrate printed 3D manipulatives into the curriculum materials and activities, and disseminate the research findings of the educational effectiveness of using these tools.

Ron Rice, Cornell University, is the web designer and database programmer. He is also an expert in digital video and photography and as such will be responsible for coordinating the image digitization of the MOS (Boston) models.

Nancy McGovern, Cornell University, will direct and perform the digital library research associated with integrating digital replicas of artifacts such as the Clark models into the Library's systems for collection management, description, and delivery.

Richard Entlich, Cornell University, will assist Nancy McGovern on the activities stated above.

Geri Gay, Cornell University is Faculty Advisor and HCI Expert. Gay is Professor and Chair of Department of Communication and the Director of Human-Computer Interaction Group in Cornell University. Professor Gay will supervise HCI team to conduct usability testing and user evaluations studies.

Helene Hembrooke, Cornell University, is the team's Cognitive Scientist. Hembrooke is Research Associate at the Human-Computer Interaction Group at Cornell University. She will work with Pan and Gay to design rigorous user studies and conduct user evaluations.

Bing Pan, Cornell University, is the User Study Researcher. Pan is Post-Doctoral Associate in the Human-Computer Interaction Group at Cornell University. He will work with Hembrooke and Gay at Cornell and researchers at MOS to carry out usability testing and user evaluation studies.

Museum of Science (Boston):

The **Program Developer** will develop program components using the Clark models, digital models and touchable printed models and will present those programs to visitors in the Museum during the summer and fall of 2005.

The **Research Associate** will consult with the Program Developer during program development and early program implementation stages and supervise the work of the research assistant.

The **Research Assistant**, under the supervision of the Research Associate, will conduct research and evaluation activities during the fall of 2005, and analyze the data and write a final report in the winter of 2006.

6. Advisory Board

Role:
The Advisory Board's primary role is to advise the Project Team on research concerning the management of digital representations of physical artifacts in the library environment. The Advisory Board will also be solicited for advice on all other aspects of the project.

Activities:
The Advisory Board will be supplied with the complete project proposal and apprised of monthly developments. The Team will solicit comments and advice with the monthly updates.

The Advisory Board operates by mailing list (closed discussion group with archive), to be set up by the Project Team. Face-to-face meetings will be held at the 2005 and 2006 annual Webwise Conference and at least one telephone conference will be held between the two Webwise Conferences. Other forms of electronic communication will be used as necessary

The Advisory Board has no formal voting procedures and operates on a principle of consultation, striving towards consensus.

The Advisory Board will have five members. Four of the five have been identified and have agreed to serve:

1. Jeremy Rowe, Ed.D., is Head of Media Development and Director of Research, Strategic Planning and Policy for Information Technology at Arizona State University. Rowe is also Associate Director of Arizona State's Institute for Computer, Information Sciences, and Engineering and Co-Director of the Partnership for Research in Spatial Modeling (PRISM) at ASU. Particularly in his work at PRISM, Rowe is a leader in efforts to develop modeling and analytic tools and strategies for integrating 3D data into digital libraries. See bio at http://www.public.asu.edu/~jeremy/JXRNSFVITA.htm.

2. Thomas Moritz, MLIS, is Harold Boeschenstein Director of Library Services at the American Museum of Natural History. Moritz is an important voice in the digital library and museum communities. His work focuses on the integration of natural history information and the successful application of this integrated information to research, education, and biodiversity conservation. Moritz was Principal Investigator on the Mellon-funded AMNH Digital Library Project, which produced the "American Museum Congo Expedition (1909-1915)" website (http://diglib1.amnh.org/). See bio at http://www.amnh.org/science/bios/bio.php?scientist=moritz

3. James Ferwerda, Ph.D. is Research Associate in the Program of Computer Graphics at Cornell University. He has worked and published extensively on realistic image synthesis and 3D modeling in the digital environment.

4. Thornton Staples is currently the Director of Digital Library Research and Development at the University of Virginia Library and is the Project Director for the Fedora Project. Previous positions include: Chief, Office of Information Technology at the National Museum of American Art, Smithsonian Institution; Project Director at the Institute for Advanced Technology in the Humanities, University of Virginia; and Special Projects Coordinator, Academic Computing at the University of Virginia.

7. Project Evaluation

We envision our project providing long-term, medium-term, and short-term benefits in four broad areas:

- Various user groups (academic researchers, college and university students, museum visitors, high school and middle school students, learners in the general public) will learn key concepts about kinematics understand the importance of the history and theory of machines from the expanding resource.

- The project will break important ground for the library, museum, and educational communities in demonstrating the use of stereolithographic technology to transport physical versions of cultural artifacts by digital means.

- The digital library, museum, and broader cultural heritage communities will gain an expanded knowledge base around the management of 3D objects and related resources, and the integration of digital and physical objects in a digital library environment.

- New links will be forged among the library, museum, academic research, and educational communities that will strengthen our project and foster further communication and collaboration beyond this project and its immediate participants.

The Principal Investigator and Project Manager for the “Printable Machines” project will attend Outcome-based evaluation (OBE) workshops held by IMLS and will coordinate the overall project evaluation. We look forward to developing a plan for defining and measuring specific outcomes within these intended areas of impact.

The evaluation effort is embedded in and intertwined with the formal user research outlined in our Research Plan, part 1, above. As described in the Research Plan, Cornell’s Human-Computer Interaction Group will conduct the user research. OBE methods will inform the user studies, which will focus on learning effects and subjective experience for a subset of user groups: students in the middle school classroom and middle school age and family-group visitors in the museum. Research in the baseline stage will inform the appropriate outcome measurements; these will be further tested in the user evaluation stage. Subjective experience and learning effects represent broad categories of intended outcome; specific outcomes will be elaborated in the course of the research (see also the Research Plan, part 1). In brief, the following table gives tentative measurements and indicators of subjective experience and learning effects:

Table: Indicators of Outcomes

Outcome categories	*Data Sources*	*Indicators*
Subjective experience	Observations, surveys, interviews, and screen capturing movies in the user evaluation step	Number of critical incidents; hedonic evaluation on various digital and physical models; degree of enjoyment measured in surveys and interviews
Learning effects	Observations, surveys, interviews, and screen capturing movies in the user evaluation step	Number of critical incidents; interviews; improvement of understanding and learning degrees measured in surveys.

8. Dissemination

We propose to disseminate information on the project through:

- participation in appropriate IMLS and NSF digital library meetings, e.g. the Web-Wise Conference
- presentations at national library, museum, engineering, and mathematics conferences
- publications by project participants
- press releases about the project
- brochures and other promotional materials, and
- the project website

9. Sustainability

CUL is committed to the sustainability of the contents of K-MODDL. Building on this resource assures a stable foundation for the products of the IMLS award. Incorporating the MOS collection into a high-profile CUL digital resource will expose the Clark models to educators and learners worldwide; broader recognition of their importance will contribute to the sustainability of the physical artifact collection. Digital library research proposed as part of the “Printable Machines” project will address break new ground in addressing digital preservation issues surrounding 3D data and digitized artifacts. This research will contribute to the sustainability and long-term preservation of this project and related ones.

The “Printable Machines” project will research, develop, test, and model new ways of linking collections of artifacts and collections of information. It will build on an important new multidisciplinary and multimedia resource for teaching and learning about the history and theory of machines and adapt it for use in multiple formal and informal learning environments. It will bring an important historical collection into the K-MODDL resource. IMLS support will strengthen existing relationships and forge new ones among academic librarians, museum curators and educators, university teaching faculty, and public school teachers. And the project will document and disseminate research results on a number of pressing issues surrounding the integration of artifactual and digital collections and ways of making these collections accessible through outreach.

A Digital Library of Printable Machines - Research Plan, part 1 of 2

Digital and Physical Learning Objects, Online and On-Location: A Plan for Comparative User Study Activities

1. Background

One of the three main research areas recommended at the September 2003 IMLS workshop on “Opportunities for Research on the Creation, Management, Preservation and Use of Digital Content” is the integration of digital and physical experience, which includes the integration of online and on-location experience (Caplan, Barnett, Bishoff, Borgman, Hamma & Lynch, 2003). Our research as part of the proposed “Printable Machines” project will build on research conducted in this area using materials in the Kinematic Models for Design Digital Library (K-MODDL), the Cornell University Library resource that is the basis for the “Printable Machines” project. Our previous research on the uses of K-MODDL in classroom settings has demonstrated that user groups learn differently from the different types of digital and physical models included in K-MODDL. Broadly speaking, the computer simulations of mechanisms facilitate abstract understanding and learning, while the physical models on which they are based facilitate holistic understanding, visual thinking and creative design. These different learning emphases correspond to the needs and preferences of student user groups in distinct subject areas and educational levels. Upper-division undergraduates using K-MODDL in the context of a geometry responded more readily to abstract representations of computer simulations for in-depth understanding of geometrical rules; students in an upper-division undergraduate robotics class commented that the original physical models enhanced their creative thinking and visual experience; the middle school students were intrigued by the original physical models, but had difficulties understanding their functions and uses in real world. The research also showed a positive correlation between learning effects and subjective experience: the students enjoyed the models that they found useful for learning (Pan, Gay, Saylor, Hembrooke & Henderson, 2004; Pan, Gay, Saylor & Hembrooke, under review).

The stereolithographic models that are the centerpiece of the “Printable Machines” project are different from the original artifacts used in our research to date. The original models are made of steel and bronze and have the look and feel of actual machinery, instead of the plastic feel of 3D printed models. However, the quantity of the historical models is limited and the cost of reproducing them in steel and bronze is prohibitive. The stereolithographic models can be printed in ways that simplify, enlarge, combine, and disassemble mechanisms to meet different educational goals. Based on our previous research and along with the development of the “Printable Machines” infrastructure and educational programs, this study explores the user experience and learning using original physical models, 3D printed models, and computer simulations in two different educational contexts: the middle school classroom and the science museum.

2. Goals and Research Questions

The research team for user studies on this project includes the Human-Computer Interaction (HCI) Group at Cornell University and the research department of the Museum of Science in Boston (MOS). Working with middle school teachers in the Ithaca, New York, area and educators at MOS, the research team will develop class materials for middle school students and educational programs for museums based on the integration of the three types of physical and digital models, according to scaffolding strategies. We will explore how the learning experience differs in the two contexts, and how the digital and physical experience can complement each other. Our previous research demonstrated that physical kinematic models are useful in facilitating holistic learning, visual thinking, and creative design, while computer simulations help the understanding of abstract geometry and mathematical rules (Pan et al., under review). In this research, we will explore the effects of the differences and integration of the user experience of the original physical models, 3D prints, and computer simulations on learning. Specifically, we will address the following goals and research questions:

I. What are the effects on learning of the integration of digital and physical experiences provided by historical mechanical artifacts, 3D printed machines, and computer simulations?

II. What different types of learning experiences do users have using printable machines in the museum and classroom settings? Are different types of learning better suited to one or the other of the two distinct contexts?

The following section provides a conceptual framework for addressing these questions and discusses the major constructs in this research.

3. Conceptual Development

Following Activity Theory, it can be proposed that there are three major components in the activity of learning: learners/users, tools/artifacts, and contexts (Gay & Hembrooke, 2004). The goal of transforming knowledge is fulfilled through the interaction among the three components (Figure 1). In the proposed research, learners are middle school students and museum patrons; tools are the three types of physical and digital models (historical models, 3D replicas and computer simulations) based on the kinematic collections; the contexts are the science museum and middle school classroom. In order to design useful tools/objects and evaluate their impact, understanding the dynamic interactions among learners/users, tools/artifacts, and contexts is extremely important. Assessing any one of the components will involve the analysis of the interactions among the three.

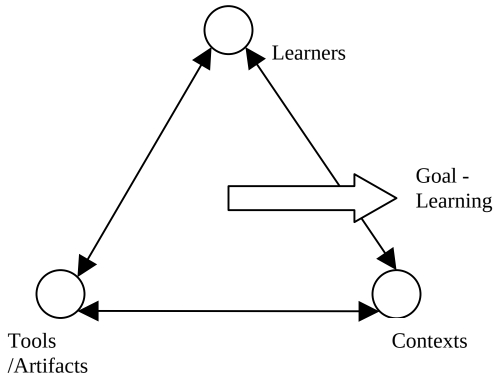


Figure 1. A reduced activity theory framework

3.1 Experience

Experience is closely related to satisfaction and emotion. Dewey defined experience as the totality of a person's acting, sensing, thinking, feeling, and meaning-making in a setting (Wright & McCarthy, 2003; Sengers et al., 2004). Emotional experience is dynamic and involves complex mental and physical processes that are experienced as a whole. Lazarus, Kanner, and Folkman (1980) suggest that emotions are experienced in "fleeting episodes," which makes them different from moods that are longer lasting and more stable, and emotion fluctuates as the experience unfolds. Because of the dynamic nature of experiences, researchers have attempted to use the Experience Sampling Method (ESM) and identify variables that can best capture such dynamic processes (Larson & Csikszentmihalyi, 1983). When conducting ESM, subjects are asked to fill out brief surveys regarding their activities and feelings from time to time in response to alerts issued randomly or in a scheduled manner. Recently ESM has been used in the area of technology evaluation (Consolvo & Walker, 2003). However, ESM may be too interruptive in certain contexts, for example, in classrooms.

Emotion can also be viewed as the outcome of cognitive appraisals. For the proposed research, two measurements of experience will be adopted to measure users' experience in the classroom and in the science museum: subjective experience evaluation of various hedonic values on different models (Hassenzahl, Beu & Burmester, 2001), and observation and Critical Incident Analysis[3] (Carroll, Koenemann-Belliveau, Rosson, & Singley, 1993) on the observed and captured interaction between users and different models. Interactions with the computer simulations will be recorded via screen capturing movies; verbal protocols and videotaping will document users' interaction with the physical models (Pan et al., under review).

3.2 Learning Effects

Learning is the acquisition of knowledge or skill, and this acquisition can be assessed through measuring the outcomes of learning or the process of learning (Jones, Scanlon, Tosunoglu, Morris, Ross & Butcher, 1999; Jones, Scanlon, Tosunoglu, Ross, Butcher and Murphy, 1996). There are three levels of learning outcomes: acquisition of specific knowledge and skills can be viewed as short-term outcomes; changes in

[3] A critical incident is an event observed within task performance that is a significant indicator of some factors defining the objective of the study.

behaviors are often considered to be intermediate-term outcomes; changes of values, conditions and status are long-term outcomes (McNamara, 1996). Though most researchers favor evaluating outcomes of learning with data collection strategies of surveys, standardized student achievement measures and attitude measures (Kulik, 1994; Mitra & Hubllett, 1997), process-oriented evaluation through analysis of the interaction process is more useful in the early stages of design (Mathison, Meyer & Vargas, 1999). Furthermore, quantitative outcomes of learning are always difficult to assess in educational settings because of the extreme difficulty in controlling all the variables that affect learning and in isolating only one variable – such as the use of computers (Jones et al., 1996; Jones et al., 1999). In this research, we will employ quantitative and qualitative measurements to assess both the outcomes and process of learning for different users interacting with the three model types in the two learning contexts. Quantitative measurements will be obtained through testing on course materials. Qualitative measurements track changes of mental models and cognitive capability; qualitative measurements will be obtained via surveys, interviews, and Critical Incident Analysis (Flanagan, 1954; Pan et al., 2004) of the users' interaction with the digital and physical models.

3.3 Usability

Usability is the measure of the quality of a user's experience when interacting with a product or system. Usability is usually associated with the following dimensions: ease of learning the system, system efficiency, ease of remembering the system, freedom from errors, and subjective satisfaction with the system (Nielsen, 1994). In this project, we need to assess the usability issues related to both the 3D printed models and the digital representations in the two learning contexts (middle school classroom and science museum). Usability problems can be assessed through self-reporting and observations (Pan et al., 2004). User's explicit feedback on usability problems can be attained throughout the design process through surveys and interviews; additionally, screen captured movies of users interacting with the digital models and the videotaping of their interaction with physical models will be analyzed following the Critical Incident Analysis method (Flanagan, 1954; Pan et al., 2004).

4. Research Methods and Procedures

The Cornell HCI Group will work closely with professors at Cornell University and middle school teachers around the Ithaca, New York, area to examine the effects of integrating digital and physical models in middle school classes. At the same time, researchers at MOS will conduct research and evaluation on two educational programs (Interpretations and Design Challenges) based on printed machine models. A mixed-methods approach will be adopted to accommodate different contexts of learning and the multiple dimensions of learning effects (Marchionini, 2003). To address the proposed research questions, subjective experience and the learning effects of integrating digital and physical models will be compared between two user evaluation studies. During the development process, the HCI group will also conduct user modeling and user testing to ensure good usability of the infrastructure (the web site, digital models, and 3D printed models), as well as the usefulness of the educational programs in the middle school and museum settings. Along the development timeline, there are two major steps of research: user testing and user evaluations (See Table 1 for an overview of the research steps).

Table 1. Major research procedures

Research Steps	***Timeline***	***Middle School Context***	**Museum of Science Context**
User Testing	Months 1 to 12	**A1:** Two rounds of usability testing along with the development of infrastructure and learning programs in middle schools.	**B1:** Two rounds of usability testing along with the development of infrastructure and educational programs in the museum.
User Evaluations	Months 6 to 18	**A2:** In two technology classes, an initial evaluation of students' learning and experience in classrooms will be conducted *without* the integration of physical and digital models. **A3:** A second evaluation of students' learning and experience in classrooms will be conducted during and after the introduction of physical and digital models.	**B2:** A middle school student group and a family group's experience in visiting the museum's historical collections will be assessed *without* manipulative 3D printed models and computer simulations. **B3:** Another middle school student group and family group's learning and subjective experience will be assessed with the integration of historical models, 3D replicas and computer simulations.

Research question I, which explores the integration of digital and physical experience, can be addressed by comparing the two sets of user evaluation studies A2 with A3, and B2 with B3; research question II, which examines the use of models in different learning contexts, can be addressed by comparing the results of A3 with B3. Cornell's HCI group will conduct research steps A1, A2, A3, and B1 (with staff support from MOS); Researchers in MOS will carry out research steps B2 and B3. The following paragraphs detail the research steps for both the HCI group and researchers at MOS.

4.1 Research Procedures in Middle School Classrooms in Ithaca Area

During the development stages of the educational programs in Ithaca, Cornell HCI group researchers will work with the project team members in the Cornell University Library, with instructors in area middle school classes, and with educators at MOS to ensure good usability of the digital library infrastructure and the usefulness of the educational programs. In the user evaluation studies, baseline data will be collected first in two middle school classrooms that will *not* have the combination of digital and physical models; at the evaluation stage, another user study will be conducted with instructors and students when they are using both the physical and digital models.

4.1.1. Research Step A1 and B1

We propose to conduct user testing along with the development of the infrastructure and educational programs. The methods are user studies with screen capturing and verbal protocol, surveys, and interviews. We will test the educational programs with real users in the museum and middle school classroom contexts to capture usability problems and further test their experience and learning outcomes.

4.1.2 Research Step A2

Working with teachers and students in the Ithaca area, Dr. Daina Taimina (Cornell, Mathematics) will design learning modules on kinematics for middle school technology classes that employ digital and physical models. We will identify two classes that will adopt the kinematics learning modules. A mixed-method approach will be pursued to capture learning activities and student experiences in these two classes. We will conduct a user study before the introduction of the digital and physical models, capturing student experience with the subject matter using observation, videotaping, surveys, and interviews. Learning processes will be assessed through the Critical Incident Analysis on videotaped classroom activities (Flanagan, 1954). The goal of the baseline research is twofold: to examine learning styles and assess the number of learning incidents on one hand, and on the other, to explore and define quantifiable learning outcome measurements, for example, the levels of interest and motivation in surveys, and students' scores on classroom testing.

4.1.3. Research Step A3

In the two different classrooms, we will assess learning effects and subjective experience when the students are using the original physical models, 3D replicas, and computer simulations. There are three main issues we wish to address in this user evaluation study: (1) User preferences and subjective experience with the different model formats; (2) The different learning effects of the three model formats; (3) Ways in which the digital models and tactile 3D printed models complement the users' experience with the original physical models: how do users integrate the three model formats and how does this affect learning? Similar questions will be addressed in the museum context, so that the two learning contexts can be meaningfully compared. User experience, learning processes, and learning outcomes will be documented through videotaping of classroom activities, screen capturing with verbal protocol, surveys, testing on course materials, and interviews with students and educators. Those outcome measurements identified from the baseline research will be further tested during this stage. Learning incidents will be identified from videos of classroom activities and screen capturing movies (Pan et al., under review). Intermediate learning outcomes in terms of the acquisition of knowledge and skills will be identified from surveys and interviews.

4.2 Research Procedures in MOS

Researchers at MOS will coordinate with the Cornell HCI group to conduct two rounds of user testing during the development of the web sites, physical model displays, and educational programs in the museum context.

In the user evaluation stage of the study, a user study on two groups of patrons – a middle school student group and a family group – will be conducted to assess their experience viewing the untouchable historical kinematic models currently on display at MOS. After the introduction of two educational programs in the context of the "Printable Machines" project, a further user study will be conducted to assess the effects of integrating the physical with the digital experience. Each program will make use of the three model formats that are the focus of this study. The Interpretation program will be designed to inform visitors about simple machines by exploring their parts and how they function. The Design Challenge program will focus on engaging museum visitors in the engineering design process, using the gear models as inspirations for creative thinking. Examining visitors' use of the models as learning tools within each of these programs will provide further insights on the value of the three model formats for different groups of museum patrons.

4.2.1. Research Step B2

To investigate the museum visiting experience *without* the integration of physical and digital models, a combination of quantitative and qualitative research methods will be used. Observation, surveys, and interviews will reveal learning effects and subjective experience of visitors viewing the untouchable historical models. Researchers will also explore and examine appropriate outcome measurements for further testing.

4.2.2. Research Step B3

After the development and introduction of the Interpretation and Design Challenge educational programs, a second MOS user study will address these programs, focusing on visitor preferences for the different model formats, the learning experience that each model format offers, and the ways in which simultaneous availability of digital simulations, 3D printed models, and original physical models supports the museum learning experience. A middle school student group and a family group will be recruited for the user evaluation of their visiting experience with the Interpretation and Design Challenge programs. Similar to the middle school study, the questions to be addressed through this part of the museum research include: (1) User Preference: Which of the three model formats do visitors prefer and why? Does the preference vary depending upon learning style, age, ability/disability, etc.? How does this preference influence the users' learning process? (2) User Learning: How do visitors learn from the different types of models? Is what the visitors articulate different depending upon the model format? Is there a difference in the way visitors integrate these different models into their learning process? (3) Multiple Models: How do the digital and tactile reproductions of the historical models support the users' experience with the historical gear models? Does visitor interaction with multiple model formats result in a more robust or different understanding as compared to visitor interaction with just the historical models?

To conduct this user study, research and evaluation staff at MOS will collect both quantitative and qualitative data. Ethnographic observations will afford us the opportunity to examine visitor use and manipulation of the different models and to understand how this use is incorporated into the learning experience. Videotape recordings of user conversations will provide further insights into the learners' thoughts as they use each of the three models formats (Ash, 2003). Surveys and interviews on users' previous knowledge of kinematic principles will provide more information on learning effects and subjective experience. Quantitative measurements of time spent on task with each model and the number of learning incidents identified will provide easily comparable data indicating user preferences for the different model formats (Serrell, 1998). The comparison between baseline research and the user study can reveal the effects of digital and physical experience on facilitating learning and an enjoyable museum experience.

Analyzing data collected across the two educational programs in the museum will yield further understanding of the similarities and differences of visitor use, preferences, and perceived value of the models.

Data collected following the research procedures discussed above will allow comparison of user experiences with different model formats (digital and physical), as well as comparison across two learning contexts (museum and middle school). These two axes of comparison correspond to the research questions we have posed: question I (integration of digital and physical experience) can be addressed by comparing research steps A2 with A3, and B2 with B3; question II (learning contexts) can be addressed by comparing steps A3 with B3. We expect our findings will be of broad interest to the museum and digital library communities, as well as others concerned with the role of learning objects in the learning process and with human interaction with digital and analog technologies.

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A Digital Library of Printable Machines - Research Plan, part 2 of 2

Physical and Digital 3-D Objects as Library Objects: An Exploratory Approach for a New Family of Formats

It is a central goal of a library to develop access to all of its collections in ways that meet the expectations of a wide array of user needs and interests. If 3D objects in all formats are to be integrated into library collections and practice, these objects must be described and presented in ways that allow users to retrieve the 3D materials they were looking for in either physical or digital formats. What will accurate, relevant, and reliable searching of these materials require? Our research will seek to define the spectrum of physical and digital 3D object representations, creating a conceptual framework that can fit any 3D cultural heritage object or be supplemented to account for it. The desired outcome a system of search and retrieval for 3D information that will consistently satisfy user needs. The core research question for this area of exploration is:

> What terminology, descriptive protocols, and asset management practices will enable original artifacts, digital representations, and printable machines to be accurately and appropriately found, accessed, and utilized by users within a library environment?

1. Background and scope

Physical 3D objects have not been universally or uniformly integrated into the traditional library environment. These artifacts are classified, managed, and accessed in varying ways and, in many cases, not at all. Recently, we have seen digital 3D objects coming into more mainstream use with more viable and accessible formats. In the past, these formats have largely existed within specialized research and development settings. The size and complexity of these formats could not be widely supported by the capacity and functionality of common workstations. Evolving technologies are able to provide these formats to an ever-widening audience. This is an active area for development with an expanding and evolving set of enabling file formats and rendering methods, little of which the digital preservation community would yet accept as standard or normalized formats. As these formats emerge from the laboratory, this is an ideal time to begin exploring the means for adopting and adapting existing access and preservation models developed for other formats to these materials. We need to better understand the functionality, anatomy, and potential use of these formats to be able to place them appropriately within the library environment to be harnessed most effectively in educational and research contexts.

The K-MODDL approach bridges a range of physical and digital 3D objects. The examples developed by the K-MODDL project provide a testbed and potential model for leveraging the characteristics of these formats that will enable or inhibit preservation and access for collections that include 3D materials and related resources in libraries and other cultural heritage settings. The combination of physical and digital formats that populate the lifecycle of capture and use constitutes a family or class of formats because:

- There may be more interdependencies between physical and digital 3D objects than typically exist between other physical and digital representation pairings
    - A user may want to consult comparable physical artifacts while accessing digital representations and physical surrogates
    - Though the printable artifacts may serve as surrogates for original artifacts, users (researchers, educators, and students) may prefer to have access to both the physical surrogate and the digital representations because each may play an important role in learning
- Some digital 3D objects require multiple files in multiple formats for display.

A common definition of “3D” is “having a three-dimensional form or appearance”;[4] “3D graphics” has been defined as “a displayed representation of a scene or an object that appears to have three axes of reference: height, width, and depth (x, y, and z in Cartesian Space).”[5] Both of these definitions provide room for many different kinds of objects to fall reasonably within their scope. There are more and more projects working on 3D object imaging and representation, all of which use the term “3D” in varying and potentially ambiguous ways. For example:

- K-MODDL is digitizing versions of mechanical models for teaching the principles of kinematics – the digital representation enables access to the models, provides a viewable demonstration of the model’s functionality, and allows users to generate a printable version .
- The PRISM project at Arizona State University creates digital wireframe images of physical 3D objects with an emphasis on identifying searchable common shapes for comparative purposes.[6]
- The Computer Graphics research group at Cornell is interested in rendering materials within 3D images in measurably realistic and authentic ways so that paper looks like paper, etc.[7]

These are just three examples of 3D projects that have significant scientific applications as well as important implications for preservation and access - each requires different types of documentation, produces varying file formats and digital objects, and requires different types of metadata for ongoing use.

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[4] See http://www.webster-dictionary.org/definition/3d.
[5] See http://3dgraphics.about.com/library/glossary/bldef-3Dgraphics.htm.
[6] See for example an explanation of the project in “Acquisition, Representation, Query and Analysis of Spatial Data: A Demonstration 3D Digital Library” in the proceedings of the 2003 Joint Conference on Digital Libraries (JCDL'03), May 27 - 31, 2003, Houston, Texas USA; and in *RLG DigiNews*: http://www.rlg.org/legacy/preserv/diginews/diginews6-5.html#feature1
[7] See “Three varieties of realism in computer graphics” in the *Proceedings SPIE Human Vision and Electronic Imaging,* 2003; and **“**A model of visual adaptation for realistic image synthesis” in the *Proceedings of the 23rd annual conference on Computer graphics and interactive techniques,* 1996.

K-MODDL and the various resources that will be added to it in connection with the "Printable Machines" project fit within this broader spectrum of the 3D object classification. This is a preliminary perspective on objects that would populate this spectrum:

- Original physical artifacts
- Digital representations
  - Video of physical 3-D object in action (dynamic)
  - A 3-D image of a scene or the environmental context for one or more physical 3-D objects
  - A 360° perspective on a digital representation of a 3-D object, either through a video representation or software that enables more direct interaction between the user and object through the digital representation
- Physical printable surrogate

2. Products and Approach

One objective of the "Printable Machines" project is for digital representations and replicas of mechanical models to be fully integrated into the library's systems for collection management, description, and delivery. To do so, we need to explore the following aspects:

- a taxonomy to provide appropriate terminology to manage 3D objects as library objects
- descriptive and metadata requirements that will build on the taxonomy and utilize the terminology
- a preliminary investigation of the preservation issues in this rapidly changing domain that will be informed by the content, context, and structural elements of the taxonomy and descriptive protocols.

Taxonomy and terminology

A taxonomy is defined as:

> the science of classification according to a pre-determined system, with the resulting catalog used to provide a conceptual framework for discussion, analysis, or information retrieval. In theory, the development of a good taxonomy takes into account the importance of separating elements of a group (taxon) into subgroups (taxa) that are mutually exclusive, unambiguous, and taken together, include all possibilities. In practice, a good taxonomy should be simple, easy to remember, and easy to use.[8]

We propose a means to refer to and uniquely identify the various representations of the models from the original artifact to digital representations (static and dynamic) to printed replicas. We will devise a taxonomy that encompasses the versions of the model representations and recommend appropriate terminology for use with these and similar kinds of objects. This work will entail an analysis of the characteristics of the iterations of these objects, a review of similar library examples, a literature search in relevant domains, and an adaptation of analogous taxonomies. We have access to the 3D projects referenced above and we will identify a representative set of other 3D projects to create an extensible taxonomy that will either encompass the corpus or 3D work, or clearly allow for supplements to the taxonomy to cover the breadth and depth of this work. Classic taxonomy development will form the basis for devising the 3D object taxonomy for use within libraries and archives, with reference to work on 3D classifications within mathematics, computer science, and spatial representation domains.

[8] See http://whatis.techtarget.com/definition/0,,sid9_gci331416,00.html, for example.

Description requirements and metadata

The digital representations of the models have 3D characteristics, but may not possess the elements in each incarnation to be accurately defined as 3D objects. To achieve dynamic digital representations that demonstrate the movement of the models, images of the model may be displayed in video software, but, in that case, the objects are specialized moving images; other representations are interactive, allowing users to control the movement of the models. Using the information embedded in the taxonomy, we will explore the metadata requirements for finding and accessing these objects so that users will know what to expect when they request the objects. The result will be a detailed scenario that expresses the requirements and the means for delivering these objects via a common library delivery platform. We will map the requirements of 3D objects to METS, the most prominent current format for digital archive development, and consider the implications of standards pertaining to the range of formats identified for digital 3D objects. We will consult the representatives of various delivery platform systems available to us at Cornell, e.g., ENCompass, Luna Insight, DLXS, and DSpace, to review and revise the scenarios, and hold at least one focus group with potential library users to explore preferences, priorities, and perceptions surrounding 3D objects.

Preservation implications

The digital representations of these models will require the management over time of some digital formats with which we have less familiarity and for which we lack accepted digital preservation approaches. We will prepare a white paper on the issues that emerge during the project pertaining to digital preservation. The white paper will address the preservation implications for the relevant file formats, rendering software, and retention of look and feel, for example.

3D digital representations are in such early and rapidly changing stages of development that the exploration of preservation implications for these formats will start with a definition of the range of formats being created, exchanged, used, and envisioned by representative 3D projects. Familiar formats may be used in specialized ways that have implications for preservations, especially from the perspective of preserving look and feel. For example, representing the operation or function of 3D objects such as the models that are the focus of K-MODDL may use video formats in specific ways. The video formats may be part of but not all of the intended representation.

The development of the white paper will be influenced by the work of the Global Digital Format Registry (GDFR)[9] and related initiatives; the work of the Florida Center for Library Automation (FCLA)[10] on preservation plans; and the work of Caroline Arms and Carl Fleischhauer at the Library of Congress on analyzing formats for digital content. The intention is to contribute a solid starting point for the ongoing evaluation of 3D objects for preservation and access.

[9]See http://hul.harvard.edu/gdfr/.

[10] See http://www.fcla.edu/digitalArchive/daInfo.htm.