DESIGN FOR LEARNING: PRODUCT DESIGN AND ENGINEERING FOR A KNOWLEDGE-BASED SOCIETY

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ABSTRACT

As changes in the society and economy lead to greater demand for products that include and enhance learning in all facets and stages of life, demand will increase for products that build upon the diversity of ways in which people learn and use knowledge. In response what is needed is product design and engineering that addresses an ergonomics of learning – designing products and strategies for using them that make effective use of ways in which individuals learn. In this paper, I use as examples hands-on science exhibits to illustrate the development of products designed and engineered for learning. The goal is to create products and experiences that are able to engage people in learning, provoke their questions, lead them to insight and understanding, and reinforce their critical thinking skills. Expanding the basis for design in this way presents a challenge that calls for academic courses and programs that take full advantage of the incipient convergence of learning theory and practices with neuroscience, the need for opportunities to learn throughout life, and improving technologies for nearly ubiquitous communication, coordination, delivery, and display of information. I propose the establishment of a university course or program on "Design for Learning" to help prepare students to address this challenge successfully. A Design for Learning program would combine engineering and design with cognitive science, motivational psychology, education, specific content areas (e.g., science, math, geography, history, reading), art, and business. This would also create an alternative academic and career path for students, one which combines technical challenges and educational impact.

Keywords: learning, education, product design, science exhibits, computer games, toys

1 DEFINITION AND PURPOSE

1.1 Purpose and definition

My purpose in writing this is to promote the explicit incorporation of current learning theory and educational practice into product design and engineering, ultimately leading to products that have significant positive impact on the way a broad spectrum of people in society encounter and use opportunities for learning throughout their lives. To bring about that conjunction of education, design, and engineering, I propose that "Design for Learning" becomes a recognized area of study in engineering and design programs at the undergraduate and graduate levels. Design for Learning would combine engineering, design, and education lectures and discussion, with practical experience in planning and executing projects for communicating ideas, learning processes, and developing skills in specific content areas.

1.2 Rationale

Design for Learning fills a significant gap in the design and engineering education spectrum. Many universities and corporations devote substantial efforts to research and education on design and engineering of the human/device interface, management of knowledge networks, and cognitive and physical ergonomics. Nearly all of these programs are primarily concerned with optimizing the design of a mechanical or computer interface for ease and efficiency of use. There are also excellent programs that focus on learning and education, including learning in informal situations, which includes learning in museums, after-school programs, home, and play. What is missing is the confluence of the insight into learning, the creative and aesthetic problem-solving approach product design, and the tools and methods of engineering. That confluence is what should occur in a program on Design for Learning.

1.3 Precedence and significance

Excellent programs and courses on product design and engineering have been operating in many universities for decades. Several programs, including Umeå Institute of Design in Sweden [1], TU Delft in the Netherlands [2], Loughborough University in the UK [3], and those I am most familiar with at Stanford [4, 5] and MIT [6] in the US, have graduate or undergraduate programs and research groups concerned with product design, technology, education, and learning. Design for Learning builds on those programs and devotes the focus of the course or program to products for learning. The purpose of new courses on Design for Learning is to provide future engineers and designers with knowledge of our evolving understanding of learning as it pertains to the needs of the users of products. With that knowledge they will be better able to create designs that facilitate learning. At the same time, the courses provide students from other fields with insight and experience in design and engineering that will enrich their work in developing educational materials and activities for specific content areas. This cross-fertilization will enrich both students and faculty from many disciplines.

2 SCOPE AND BENEFITS

2.1 Scope

A single semester course by itself is insufficient to provide the depth of understanding and range of ideas needed for students to become proficient in design and engineering of products for learning. Ideally a series of interrelated courses offered by different departments or programs would be organized to form a coherent extended program on Design for Learning. But to begin with, even one well-developed course may provide sufficient impetus to launch students into their own further explorations.

2.2 Outcomes for students

After taking a course in Design for Learning students should have, at a minimum, an understanding of cognitive science and educational practice, in both formal and informal settings, coupled with a solid knowledge of design considerations and engineering requirements applied to products for learning. They will apply their understanding and build their skills by designing and testing an original product. In a broader program that extends beyond a single course, a student should be able to fully integrate an understanding of the complexities of cognitive science and learning theory and knowledge of current issues in education with fluency in state-of-the-art design and engineering.

2.3 Benefits to the university

Design for Learning offers the university benefits both internally and externally. Internally the benefits are in attracting new students into a new, interdisciplinary, non-traditional field with a combination of technical strengths and educational value. This offers industry and society uniquely qualified graduates of the program. In turn, this means that industry has an investment in supporting the work of the students in the program who may be part of the future workforce for the industry.

3 CONTENT

3.1 Course structure

The course will combine lectures, class discussions, student presentations of projects, and critiques of existing products for learning. A significant portion of the work in the course will be student projects. Students, either individually or in small groups, will choose a project to design from concept through prototype. The project must carry forward an original idea for an exhibit, toy, game, or activity that contains a significant opportunity for learning. The prototype must be in a form that can be shown to the class. With it, there must be data and analysis of evaluation with inexperienced users who represent the target audience.

3.2 Current ideas about learning

An obvious starting point is to ask what constitutes learning and how does it occur in different populations and in different content domains. Through lecture, discussion, and readings, students will explore these questions. The key ideas that they will consider in light of design include the following:

- Developmental levels
- Likely prior knowledge of the content and how that can be ascertained
- Effects of prior knowledge – whether naïve, misconceived, or incomplete -- on the users' learning process
- Intrinsic and extrinsic motivation for learning
- Effects of environment or situation in which product is used
- Impact of social and cultural contexts on learning by an individual or in group situations
- Types of learning – skills, procedures, content, concepts
- Learning styles and the implications for design of learning experiences
- Evaluating learning in informal situations

3.3 Categories of products

Categories of products that have the potential for inviting and enhancing learning include museum exhibits, consumer electronics with explicit learning objectives (e.g., Leapfrog's reading skills products, Educational Insights' geography information products), computer games, events, demonstrations, and theater productions. In the domain of video and computer games, "serious games" and games that have purposes beyond just entertainment, including learning and training – have recently received more explicit attention [7, 8, 9].

3.4 Applying insights into learning to design

How can an understanding of learning be translated into more effective design for learning? This central question will be addressed through discussion and demonstration of examples, as well as through student presentations of case histories of products and evaluation of their impact on learning.

In considering the choice and design of a product for learning, the first question is, what is the idea or skill or process that the product is intended to convey and what learning outcomes are desired? Then the work focuses on the choice of medium, what the user interface is, how the interface engages the user with the central idea, and how the product and learning outcomes are evaluated and the design refined. These considerations are listed below along with examples to illustrate the points. Two hands-on science exhibits, among the scores of exhibits which my staff and I developed and produced for more than 200 science centers and other institutions worldwide, are used as examples below. Science centers has been an interesting proving ground for incorporating a growing understanding of the learning process into the design of physical and electronic products. The empirical evolution of explicit criteria to meet design requirements for learning and robust operation in a science center are valuable lessons to incorporate into the education of designers and engineers.

3.4.1 Focus on the most significant idea

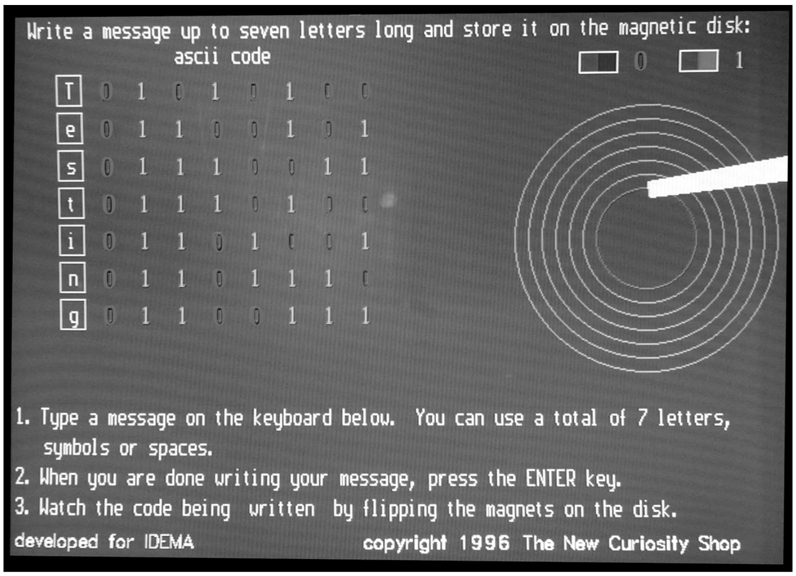
Determining what the central, most significant idea is and bringing that to the fore of the user's experience is both crucial and very difficult. It's essential to resist the temptation to expect people to notice and remember several points for each experience. That they rarely, if ever, do so is one of the challenges of designing devices for use in informal, as distinct from structured and sequential, learning situations.

3.4.2 Find the appropriate metaphor and match the medium to the message

The first exhibit I will use as an example is what we called the Giant Magnetic Disk Drive™ (see Figure 1), or GMDD, copies of which are in Mirador in Santiago, Chile and The Computer History Museum, San Jose, California.

Figure1: Giant Magnetic Disk Drive exhibit – The world's slowest, lowest density magnetic storage device

The central idea of GMDD is that magnetic storage of information is accomplished through the binary orientation of magnetic regions. We chose to use the medium itself to illustrate the message. It is a metaphor in physical terms. The medium is a disk with seven tracks, each representing one byte of information and containing eight small magnets. Each magnet can be in one of two horizontal positions – green or red side up, thus representing either 1 or 0. Up to seven symbols can be entered on the keyboard, the eight bits representing each symbol are displayed on the screen, and the visitor then can have the exhibit write the data to the disk. This happens by moving the disk under the read/write head, which has a simple, visible electromagnet that flips each magnet to the required orientation, i.e., red or green side up. This is shown in Figure 2. The electromagnet in the head also serves to read back the data, which is then shown on the screen as the head passes over each bit.



Details of the Giant Magnetic Disk Drive™ Exhibit

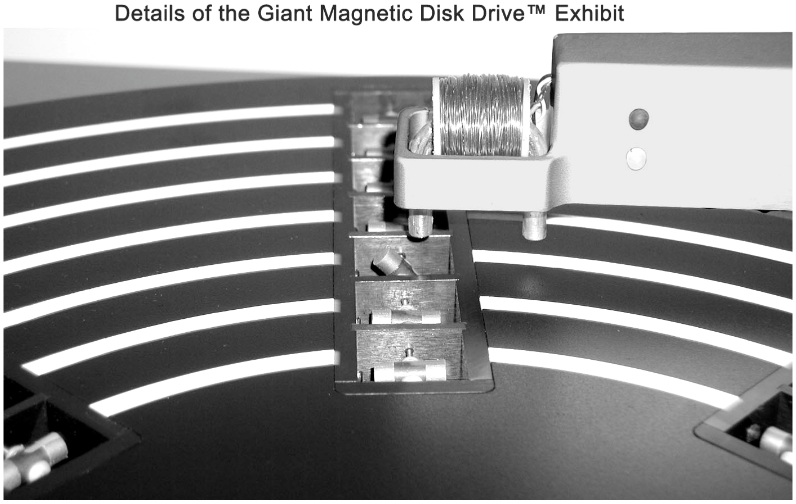


Figure 2: Top: screen view after writing seven letters (0 is red, 1 is green).
Bottom: Magnet in track 5 being flipped by head electromagnet from red to green

3.4.3 Parse complexity into distinct conceptual layers

This is like peeling a conceptual onion — layers can be peeled away by first seizing a broad idea and then finding refinements of that idea and corollaries embedded in adjacent examples. The GMDD exhibit conveys the central idea of magnetic storage of information, but a real magnetic storage disk in a computer does not contain little magnets physically flipping around. In order to convey the idea behind a real computer disk effectively, we separated the idea of storing data in the orientation of magnets, as in the GMDD, from the change in direction of an invisible magnetic region in the medium of a disk. For the latter idea we used a small block of magnetic medium that users could slide back and forth between a magnet and a compass placed 30 cm apart. The user could set the direction of the magnet and slide the block under the magnet. When the block was moved under the compass, the compass changed its direction to match the magnet's direction, showing that the medium retained the information from the magnet.

3.4.4 Use real phenomena and objects wherever possible

An important part of the GMDD is known as the "data destroyer". It is a small magnet that can be positioned over the giant disk and can manually flip any of the magnets in the first track. Flipping even one magnet and reading the data again shows that the data has been altered. In other words, it makes it clear that the data is really stored on the disk purely in the orientation of the magnets and that bringing a magnet near the disk can destroy the information. It is not a "fake" system run by a computer. Children find delight in discovering that it is OK to mess up the data in this case, but that they must not bring a magnet near their school or home computer disk.

Real objects and events play an important, and sometimes critical role in learning. In many cases, a more abstract representation of an object or event is not understood as clearly or remembered as well. Often a representation can be manipulated, as in a computer game world, but the relationship to reality remains tenuous or is disregarded.

3.4.5 Provoke questions and engage users in a process of inquiry and experiment

Ping Pong Pinball™ (PPPB) is an example of using counter-intuitive events or misconceptions to provoke questions. In the PPPB exhibit, a ping pong ball is shot up into a maze by the explosive combustion of hydrogen and oxygen gas. The user simply cranks for 10 – 30 seconds to produce electricity from a hand generator, releases the gases produced (the 2:1 ratio of hydrogen to oxygen is clearly visible) under a ping pong ball and ignites the mixture with a sparker. The ball can be launched 10 m vertically, if the space is available (see Figure 3). That alone is enough to generate great interest. What provokes even more questions is a second ball, which can be launched mechanically by hitting a paddle. Children hit the paddle very hard and expect to launch the ball as high or higher than by the combustion of the gases. They are very surprised to find that they can reach less than 1 m. The difference lies in the power, not the force or energy supplied. This provokes many questions and further engages the users, leading them into a process of inquiry and experiment with this and related exhibits. The New Curiosity Shop has produced several versions of this exhibit since the initial version was developed in 1986. It has intrigued visitors in 26 institutions including science centers in Florida, Arizona, Georgia, Illinois, New York, Chile, Kuwait, Singapore, Malaysia, Indonesia, and England, and aboard a cruise ship in the Caribbean.

Figure 3: Ping Pong Pinball™ – single user or cooperative exhibit illustrating ideas of chemistry, combustion, work and power and energy, and hydrogen as a clean fuel

3.4.6 Make written information and instructions optional

PPPB has written instructions and information placed close by. But most museum visitors are not interested in standing in front of the exhibit and reading the text. Nearly all users ignore the written information and jump directly into using the exhibit. That is not a problem if two conditions are met through design. One is that the exhibit is designed in a way that allows access and success in operation without instruction (see point about testing, below). The second is that the experience provokes questions that impel most users to read the information or ask others.

3.4.7 Test early and often and use feedback to refine designs

Testing prototypes is an essential, integral part of the process of design for learning. Testing prototypes with representative users can be used to elicit answers to four critical questions: 1) Can the users successfully operate the device or engage in the activity with minimal or no coaching or instruction? 2) Do users become engaged in activities that are relevant to the central idea? 3) Does the central idea seem apparent to the users and do they understand and remember it after use of the exhibit? 4) Do users see connections to and make use of related exhibits strategically placed nearby?

In developing PPPB, several iterations were needed to refine the interface. In this case that meant positioning the generator (#1), valve (#2), and igniter (#3) numbered as indicated, so that people were able to operate the exhibit without needing instruction.

By observing users and listening to their comments as they used PPPB prototypes, it became clear that one important idea was not evident to most users. Initially most users did not notice the 2:1 ratio of gases produced by the water as they cranked the generator. Adding a red/green diode under the bubbles not only made the bubbles more dramatically visible, but also indicated which direction the crank was turning (i.e., polarity on the wires from the generator). The diode called more attention to the difference in volumes produced and led to more people experimenting with the direction and amount of cranking.

4 CONCLUDING REMARKS

The impetus for suggesting the course comes from my own long process of trial and errors in designing and building interactive learning programs and exhibits on science and technology. I hope that Design for Learning will be implemented in several institutions in the near future. Design for Learning will bring together important, evolving insights into the learning process, creative and aesthetic innovations of design, and powerful tools and methods of engineering, in order to successfully address the increasing need for lifelong learning opportunities in a knowledge-driven society.

REFERENCES

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[4] Stanford University, USA; particularly the Product Design program http://design.stanford.edu/

[5] Stanford University, USA; Learning, Design, and Technology program in the School of Education http://www.stanford.edu/dept/SUSE/ldt/

[6] Massachusetts Institute of Technology, USA; Media Lab, particularly projects such as the Lifelong Kindergarten; http://llk.media.mit.edu

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