Chapter 1

Introduction

Software can assist the craftsman[1] in many ways: in the design of craft objects, learning the basics of a craft, and in handling the computational aspects of craft-work that might be difficult otherwise. One of the more interesting aspects of software enhancement of craft is the design of computational tools to enable the learning and practice of a craft by children.

Adapting computation for craft learning is like any other type of programming–the programmer must know and respond to the needs of the user, and must handle the aspects of the user's tasks that are appropriate. The question then becomes: what are the tasks and the user needs to support craft learning for children? In order to answer this question it is necessary to look both at craft in general and at the specific craft for which the software will act as a learning tool.

By virtue of their large numbers and quality, pop-up books have become a part of children's culture. The making of pop-ups is a craft that has seen limited practice by children and seems a natural candidate for computer enhancement.

In this dissertation, a framework of craft practice and learning is developed that can be used to examine the design and application of software for children's craft activities. A particular craft, paper engineering or the production of pop-up books and cards, is examined using the framework, and a software tool for children to use in this activity, Popup Workshop, is described.

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[1] The term *craftsman* will be used throughout this study as opposed to *crafter* or *craftsperson*. It is the most common term, and is not intended to be gender-specific.

1.1   Motivating Problem

Like many children I liked to play with toys that were purchased for me, but I also liked to make things. My particular joys were small plastic animals, people, and buildings. I soon discovered that it was more fun to make buildings so that they were my own creation and I often wished that I could do the same with the animals and people. Making your own toys has an appeal that the readers of this thesis have probably experienced in some form.

Children learn within a physical environment, play with physical objects, own physical objects, and enjoy making objects to trade, as gifts, and as treasures to be kept as they grow up. Their creations adorn our refrigerators and hold our paper clips. Some of these objects are made by following directions or patterns. But the most striking are often designed by children themselves within a setting that is presented to them, by handing them crayons and a blank piece of paper rather than a pre-printed picture to color, for instance.

By designing their own objects, children learn both general principles of design and details about the domain in which the design takes place. However, design is a complex issue, difficult to teach, difficult to analyze, and

> Any attempt to describe something as complex as how children or adults design is fraught with difficulties. Not enough is known about an activity that is dependent on both the characteristics of the designer and the context within which designing takes place. [57, p. 32]

Children can use some help in designing and making physical objects, but often tools are made for adults and come with few instructional materials or materials that may be difficult for children to use. Small fingers have trouble holding tools or drawing straight lines, and although simple objects may be easy to make in a given medium, more complex designs can take a long time to get right causing frustration and disappointment. Children can benefit from computer software that helps them over some of these difficulties, but that does not take away the fun and surprise of making something that can be held in the hand and played with directly.

1.2   Children and Paper Engineering

If the reader has not recently looked at the dazzling array of pop-up books available, a trip to the bookstore is in order. These pop-up books and cards are not only amazing works of art, but often mathematically interesting and challenging.

Pop-ups are enjoyed by children and adults. Pop-up books sell well, in spite of their expense and fragility. They range from simple but well-designed books for young children to amazing artistic creations. However, few children try to make pop-ups on their own and even though there are several good introductory books on paper engineering for children, it does not seem to be an activity that is common. But then neither is this an activity common among adults. Pop-ups can be very simple to design and produce and do not have to be complex to be amusing and creative. It is possible that the reason few children make pop-ups is that they are never told that they can; pop-up books are seen as something that is bought, not made.

An activity that involves such interesting objects should be usable in a classroom context as well. Pop-ups are useful manipulatives for teaching mathematical concepts; Simmt[108] has used geometric single-sheet pop-ups in the classroom to introduce concepts such as growth patterns, limits, iteration and fractal dimensions. She describes this as a variable entry activity that "offers a rich space for mathematical exploration and discussion about the nature of mathematics" [108, p. 108]. Another variation on this approach, not for the classroom but for teens or adults, is Uribe's book [122] that illustrates fractals, iteration and self-similarity using pop-up cards that can be cut out and constructed by the reader. Pop-up books can also support learning in art and writing. Many projects for the classroom using pop-ups can be found in Johnson[58] and Bohning, Phillips and Bryant [9]. It can be seen from these examples that making pop-ups is instructive in several disciplines, about which more will be said in Chapter 3. In constructing a pop-up, art blends with mathematics. In constructing a book, writing blends with art.

Making pop-ups involves paper, and paper is a good material to work with. Paper is strong, common, and cheap. Children are familiar with its properties. They are also familiar with and

fond of pop-ups. Therefore, they will be using a familiar material to make something they will enjoy. The domain is varied, yet constrained. There are a limited number of elements, simple combinations of folds, cuts, and attached pieces, that can be combined. Yet, as any glance at actual pop-up books indicates, there is a great deal of space for innovation.

Even in the present day pop-up books are designed by hand, whether by adults or children. But there are good reasons for building a tool to help children in this process. The task of constructing pop-ups can be quite frustrating. Often mechanisms must be removed, remade, fiddled with, and refined in order to make them open and close smoothly and properly. The constraints involved in many mechanisms are hard to learn and involve parallel lines, equal angles, and other measurements that are difficult for children to make. Also some mechanisms must be quite smooth, straight, and regular or they will bend or seize.

Having a pattern to follow helps, but patterns produce standardization. If children can combine many mechanisms together in a variety of ways that will function correctly, the process of creating a complex pop-up can be eased and innovation encouraged. In addition, the use of software to design pop-ups allows interesting possibilities for children such as importing the designs into other programs to decorate them, sharing designs, and printing multiple copies of a pop-up.

It is important to note that this is design applied to physical objects. A pop-up design program would be a failure if the user did nothing but stare at a screen. These objects beg to be made, read, manipulated, and played with.

1.3   Pop-ups as a Domain for Computation

Popup Workshop is not the first attempt to produce a tool for the construction of popups, although it is the first such tool to concentrate on children as users. Unfortunately, the only other available software for paper engineering handles only the small subset of pop-ups in a domain called origamic architecture. Other work has either produced research software that is not available to the general user, theoretical work, or software that demonstrates only partial

solutions to the problems of the domain. A detailed view of the research in this area is included in Chapter 4, but it is worth pointing out some of the more interesting technical challenges here, as they were a driving force in producing Popup Workshop.

Pop-ups are produced from a 2D material that is cut, folded and glued into a 3D form that will collapse back into two dimensions when the book or card is closed. In order to produce a useful tool, the interface must show both forms, the original 2D sheets of paper and the 3D result. In other examples of this type of software, the 3D form is manipulated, rather than the 2D form. Producing a simple, intuitive interface to manipulate 2D pop-up designs was a requirement.

An additional complication is to provide an animation of a pop-up opening and closing, which is of great use to the designer. Several mathematical solutions have been proposed for this problem for various pop-up element forms. The problem is exacerbated by the possibility that elements can be placed not only on the page, but on other elements. A simple method that allows the user to examine and manipulate a 3D representation of the pop-up was required.

Finally, pop-ups must be saved in some file format to allow them to be imported into other programs, shared between users, or opened in the software and re-worked.

1.4   A Framework of Craft

There are many unknowns when designing computer software to support children's design activities. There is little known about which tools might be appropriate to help children design physical objects. For example, a tool should help them over the problem areas, but not take away too much of the value of the design activity. By taking away some of the effort, is the learning process shortchanged? By transferring some of the work from physical object to screen, is too much of the value of making a physical object destroyed?

Software is used in many craft activities and programmable tools such as sewing machines, milling machines, and laser cutters have changed the way in which many craftsmen approach materials. Drawing and image manipulation programs are used in the production of art objects. The decoration of commercial pop-up books, and the illustration of other children's books often

relies on such software. The focus of this work is more specifically on software developed to aid in the learning or practice of a particular craft, rather than in general tools that can be used in a wide variety of work. Such a system is unusual in that it deals with tangible objects as a product, rather than with virtual objects like a file or image. What are the rules by which such software should be designed and evaluated?

In order to answer this question, the nature of craft itself needs to be investigated. This dissertation proposes a framework for craft consisting of three interrelated competencies. First, knowledge of the craft is obtained from observation, reading, or perhaps talking to another craftsman. Second, skill comes from practice of a craft. Finally, appreciation allows for the judgement of the work of others, and its incorporation into the craftsman's own practice. This framework can be used to examine crafts in general, or any particular example. Paper engineering will serve as the particular example for the purposes of this dissertation.

1.5   Research Question

The research question that provides focus for this work is:

Can a computer-aided design system be created that will enable children to design and make pop-ups and that will support the craft of pop-up making—its skills, knowledge and appreciation?

This questions addresses not only the ability of such a system to help children learn the craft, but to be further supported in the craft as their competencies improve. The framework developed in the course of this dissertation encompasses three competencies, knowledge, skill and appreciation, that are used as a basis for the development of the system as well as the assessment of its success in user testing.

1.6   Research Approach

The methods used to address the research question fell into two distinct areas. First, the software was designed, implemented and tested informally with a number of users to determine

basic usability. Second, more intensive user testing allowed a longer time to assess how children used the software and what they produced.

Java was chosen as the language for the software primarily on the basis of portability. Development was incremental using source control, with a simple viewer being designed first. This early viewer took point positions of the pop-up that were hard-coded and converted them to a 3D representation. The editor was added and allowed the user to make simple $90°$ elements (those using no additional sheets of paper besides the base page). Later additions included the ability to save pop-ups in multiple formats, support for more complex elements, and a better Viewer Window using Java3D. During development, paper engineering literature, and pop-up books themselves were studied to help guide the process.

Informal testing took place over the development cycle of Popup Workshop. Besides the developer another graduate student used the program, and an undergraduate intern who used the software to produce a set of pop-ups to test Popup Workshop operation on multiple operating systems. Several children from a local elementary school each produced a single pop-up, as did older students in a summer program. These early tests not only found bugs, but helped to guide the format of the later user tests. The software was made available to the public through the Web, and over a period of 3 years was downloaded by over 1200 users.

It was realized from the early informal testing that children should spend enough time with the program to make several pop-ups. Testing was done with 5 children ranging in age from 6 to 12, who spent over 40 hours total making 42 pop-ups. The pop-ups were made in an environment in which the children had access to a wide variety of hand tools, materials, commercial pop-up books, and instruction books. Pre- and post-tests included having the children discussing how a sample set of pop-ups were constructed and functioned. They were asked questions about their background at the beginning of testing and their reaction to the software when testing was complete. They were asked to compare two pop-ups with the same subject. Two cognitive tests were administered to the children in the first and last sessions in the areas of visualization and spatial orientation. Finally, an email follow-up questionnaire was answered by the children a few

months after testing. Users were videotaped, and pre- and post-tests, the tapes and the pop-ups produced were analyzed to observe how their knowledge, skill and appreciation were affected, as well as their reaction to the software itself.

1.7   Reader's Guide and Road Map

This dissertation is divided into two segments. Chapters 2 through 4 discuss craft in general and paper engineering in particular. These chapters present the framework used to analyze the user tests, examine how pop-ups are made, and survey previous research in this area. The reader desiring to proceed directly to the description of the system created for this research, the user testing done with the software, or the conclusions and contributions of this work may wish to skip to Chapters 5 through 8.

Chapter 2 discusses craft in general, its definition, value, and computational enhancement. A framework for the study of craft activities is developed in this chapter that is used throughout the dissertation in analyzing paper engineering activities, developing the design of a tool to aid children in learning pop-up making, and assessing the use and value of the tool.

Chapter 3 describes the practice of paper engineering by first investigating the history and development of the craft, and then proceeds to examine pop-up making in terms of the framework developed in Chapter 2. Finally, the value of paper engineering as an activity for children is examined, both as an individual craft and as a classroom activity.

A detailed look at the elements that comprise pop-ups is taken in Chapter 4, including a taxonomy of pop-up element forms and a review of relevant research relating computation and paper engineering. This research, the details of pop-up composition, and the craft framework are merged to create requirements for a software system to aid children in learning pop-up design.

Chapter 5, building on the requirements from Chapter 4, describes the computational system created in this research, Popup Workshop. This includes a description of the user interface and details of the internals of the software.

In Chapter 6, user testing with the system is described. The users and procedures are

detailed, and the results noted not only in terms of general use of the system by children, but also using the craft framework to analyze the user experiences.

Chapter 7 compares and contrasts the use of the system by twin sisters. This gives a more detailed look at the construction of a few pop-ups, and emphasizes the variety of styles that children can bring to this craft.

Chapter 8 summarizes the conclusions and contributions of this work.

There are several appendices that present information that is best separated from the main body of the dissertation. These appendices are referenced at appropriate places in the text, but it is worth mentioning that Appendix A is a glossary, containing terms used in the craft of paper engineering, and may be of use to the reader at any point.