

**Popup Workshop: Computationally Enhanced Paper
Engineering for Children**

by

Susan Lee Hendrix

B.A., University of Nebraska, 1969

M.S., University of Nebraska, 1981

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Michael Eisenberg

Tamara Sumner

Date _____

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Hendrix, Susan Lee (Ph.D., Computer Science)

Popup Workshop: Computationally Enhanced Paper Engineering for Children

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Computational enhancement of craft work has been attempted for a variety of crafts. These comprise an unusual branch of software development because of their relationship with physical objects produced by users. One craft which has seen no general computational enhancement usable by children is paper engineering. Paper engineering is the production of pop-ups, 3-dimensional forms that pop into shape when a page is opened, and that fold away when the page is closed. This is an interesting craft for children since pop-up books have become a mainstay of children's culture, and have many applications in teaching mathematics, writing, and art.

This dissertation describes the design, implementation and testing of a software application, Popup Workshop, that was designed to enable children to learn how to make pop-ups. Features of Popup Workshop include the ability to make a variety of pop-up elements, the automatic enforcement of the geometric constraints necessary to keep the elements smoothly foldable and allow for changing elements, and the use of a constraint system to allow animation of the 3D representation of the pop-up being designed. A framework of craft learning and practice is developed consisting of the competencies of knowledge, skill and appreciation. This framework is applied to paper engineering to guide the design and testing of Popup Workshop and to assess the changes seen in five young paper engineers who used the software.

Dedication

Growing up in small-town Nebraska, it was my good fortune to know many strong women who became my role-models.

I fondly remember Marie Rutledge, a small-town postmistress. Helen Shaw went to college at a time when few women would have, and became a local pharmacist. Her daughter, Ann Marie Shaw, earned a Ph.D. of her own. My grandmother Rachel Parker was a school teacher in a one-room schoolhouse at the age of 16. And my mother, Betty Hendrix, battled MS to live almost 20 years longer than the doctor's predictions.

These women worked hard and found joy in the small pleasures of life: children, books, food, nature, cats, and conversation with a friend. They survived the loss of husbands and children. Some lived through a depression and two world wars. They set high standards. I still remember my grandmother's raised eyebrow, or Helen's "by the gods" when I said something poorly thought out or phrased.

To all these women, and others over the years, I dedicate this work.

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Chapter 1

Introduction

Software can assist the craftsman¹ 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.

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 pop-ups, 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 question 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.

Chapter 2

Crafts, Children and Computing

Craft is a complex subject, an intersection of makers, materials and methods. It comes with its own cultural baggage, with the perspective of the craftsman herself as well as of those who make up the larger community in which she works. As this study is concerned with the practice of a craft (paper engineering) by children using a software tool, we begin with the uncertainties and difficulties posed by the subject of craft in general, and establishes a framework in which craft learning can be examined in an organized fashion. For instance, craft can be defined in many different ways, and can include many different activities and products. Because of these complexities and multiple perspectives, it is appropriate to limit and organize this subject, and choose a framework for observations of the effect of computation on craft design before proceeding to the more specific area of paper engineering that concerns us.

Craft can be not only be poorly defined, but undervalued. Indeed, in the modern world a person can live quite comfortably without ever owning or using a hand-made object; the value of craft activities and products therefore might not be apparent to many. For many people, the word *craft* carries the connotation of the production of useless items, an activity with which to occupy those who would be otherwise idle, as occupational therapy, or the making of ugly kitsch. Yet, at the same time, the fact is that mankind used to make everything by hand, and a common feeling exists that a handmade object has more value and significance than a mass-produced object. The same person who feels that craft has no place in modern life can also possess the desire to produce something beautiful, unique and useful. Many parents encourage

their children to produce crafts, while expecting them to grow up to be accountants, doctors or lawyers, and not potters or weavers. There is a conflict in the way craft is commonly viewed.

This conflict, viewing craft as both elevating and lowly, is not new. It probably arose as soon as a particular craft was separated from the mass of people, for instance the evolution from the production of pots by everyone for personal use to the village potter. Perhaps it is human to rank order everything, but this partition often placed the craftsman in a higher or lower position in the culture.

...it is by no means certain that early potters were universally respected for their skill...The anthropologist George M. Foster, investigating the status of the potter in a contemporary Mexican village, found that those who practiced the craft both deprecated themselves and were looked down upon by non-potters. "Here you find us in all this dirt," one of his potter-interviewees said to him. [69, pp. 28–29]

Similar stories can be told about other crafts. Blacksmithing was considered a form of magic in early societies, and the smith god exists in many mythologies, as Hephaestus of the Greeks and Ama-tsu-mara in Japan for instance. Blacksmiths can be raised above the general population in status. However, in some cultures, and often for the same reason (that they are considered to practice a form of magic) blacksmiths are outcasts.

The Masai think they bring death and disease. The Wachagga, another African tribe, both fear and venerate them, but think they are particularly undesirable as sons-in-law, since in the case of divorce they are reputed to be able to make their wives sterile. [69, p. 39]

With the coming of the industrial revolution, craft was superseded by machine production for items in everyday use. This caused craft items to become rarer, and valued more for their beauty and uniqueness than for their usefulness. Because of this, however, craft items that are not beautiful or unique (and there are a great many of those produced, as a visit to any craft fair will show) have even less value. The gap between these two notions of craft has grown.

Technology changed both the way in which craft was viewed and its place in society. But technology in one way or another has always influenced craft. In the case of weaving, for instance,

the earliest practice was derived from basket-making, and simply consisted of making mats of fibers without the aid of a loom. The earliest looms, in the neolithic, were probably vertical looms with the threads tied to weights such as stones to keep the correct tension on them. Other types of looms were developed, such as horizontal looms (similar to the vertical loom except for orientation) and backstrap looms, in which the weaver's body keeps tension on the threads. With all of these technologies, weaving is fairly slow, but they can produce better quality fabrics than weaving with no loom [129]. With the development of the floor loom with treadles and harnesses in early China the use of foot treadles freed the weaver's hands, and the speed with which fabric could be produced was much greater. But the introduction of powered looms such as the Jacquard loom in the early 1800s removed the skill of the individual craftsman from the process altogether [90, 69]. Thus it can be seen that the tools used, the technology employed by the craftsman, can change the craft and its products in major ways, even to the extent of converting the craft to an industrial operation. Some technological innovations can aid the craftsman or enhance the craft object. Conversely, some can inhibit the practice of the craft, or make the objects produced more ordinary or less attractive. How can we know what effect will occur? This question is particularly appropriate when proposing another sort of technological change, adding computation to the practice of a craft.

This chapter considers the questions of craft's identity, value, and relationship to computational enhancement. Although this may seem to be a winding detour on the path to the heart of this dissertation, the development of software to help children learn to make their own pop-ups, it is instructive to situate this work in the broader world of crafts and their enhancement. This serves not only to reinforce the value of the craft of paper engineering for children and the difficulties faced in developing software for its practice but also provides guidance when developing the analytic craft framework that will be used throughout this document.

This chapter begins with a definition of craft and its relationship to industry¹ on the one

¹ The word *industry* will be used in the sense of mechanical or factory production of objects, as opposed to simply referring to labor in general.

hand, and to art on the other. With that established, it moves on to examine the value of craft, in particular with respect to children. It then establishes a framework for examining how craft is learned, dividing the subject into three competencies: skill, knowledge, and appreciation. Finally, it uses that framework to look briefly at the ways in which computing can aid or inhibit that learning process.

2.1 What is Craft?

Craft can be described in several ways. The word *craft* is used by members of many professions including writers, teachers, and actors to simply mean *skill* or *practice*, as in *the craft of autobiography* or simply *The Craft*. The word craft is used to describe any skillful means of production, not only of objects, but of activities, such as teaching or music performance.

It is more useful for the purposes of this discussion to begin with another, more limited definition and describe craft first and most importantly as *the production of physical objects*. Limiting the discussion to physical objects, as opposed to activities or virtual objects (those that only exist in the producer's mind or on a computer screen) will simplify and bound this inquiry. This restriction is not intended to indicate that production of activities is not craft, simply that it is not the subject of this investigation. This definition is still very broad, however, and not all object production is craft. However, with this simple definition we have eliminated music, dance, and virtual objects (at least until they are printed or otherwise made material.)

Skill is an integral part of making objects, but craft can occur in the absence of skill. When a beginner produces a craft object, it is still craft, even when the production is not skillful². For this reason, the simple definition does not mention skill as a prerequisite of craft. Although it is not a requirement, skill is still an important component and measure of craft learning and practice as will be shown in Section 2.3.

Of course, not all man-made objects are craft. There are still two important distinctions

² I have a pot made by my daughter when she was in first grade. It does not hold water and is lop-sided but it is still craft.

to be made. First, the term craft is not commonly used for those objects that are made in mass quantities or, more accurately, by machine processes. Second, we do not commonly talk about craft in terms of art objects. That is, most people do not consider fine art to be crafts. But as we shall see, neither of those distinctions are necessarily simple to make.

2.1.1 The Relationship Between Craft and Industry

This definition of craft as *the production of physical objects* is not complete, as we still need to distinguish craft from industrial production. A man-made object may not be a craft object, because it is factory-made and these machine-made objects are not ordinarily thought of as craft. But the dividing line is a fuzzy one. For instance, some pottery is made with traditional methods, but in an assembly-line process, with an electric-powered wheel, and machine tools used to dig the clay. Are these pots craft objects despite the use of several people in production, power tools, or non-traditionally produced raw materials?

We could simply say that *craft is the production of physical objects by hand*, but most, if not all, craftsmen use tools. There are very few instances of crafts without tools; basket-weaving is the only one that comes immediately to mind. The use of hand-tools (hammers, chisels, scissors, etc.) in manufacture does not bar an object from being labeled *craft* in common parlance. But does the use of power tools, a lathe or a computer do so? The line should be drawn somewhere between the factory produced object and the object made without tools. It is important to establish where this line lies in the enhancement of any craft by adding tools, including computation. As was previously noted in the example of weaving, a change in tools can enhance the craft's possibilities (the invention of treadle looms) or destroy the nature of the craft entirely (the introduction of Jacquard looms).

A useful dividing line between craft and industry is the presence of hand-control. This is well-phrased by McCullough: "Continuous control of process is at the heart of tool usage and craft practice. Processes can be indirect, and mechanical and powered, so long as they are under manual guidance." [71, p. 66] The Jacquard loom is an excellent counterexample, as the loom

is under programmable rather than manual control. So the previous definition of craft can be rephrased as *the production of physical objects by manual means*. In this new definition, manual means includes hand tools, power tools guided by hand, and computer methods of design if guided by the user. In addition, many artisans can work on a single object and, so long as each has control in her part of the process, this will be considered craft.

The use of machine-dug clay for pots has been mentioned, and pots made from that clay are commonly considered craft. This definition makes no distinction as to the type of raw materials used in a craft or the method by which those raw materials were produced. Craft encompasses all materials, whether natural or man-made: glass, metal, paper, wood, paint, concrete, and even found objects. Fabric hand-woven from thread that is mechanically spun is still craft. In another example, a basket woven from plastic strips originally used to join soda bottles is no less a craft object than a basket woven from reeds.

2.1.2 The Relationship Between Craft and Art

What is it that distinguishes craft from art? Suppose that plastic strips were used to make a wall hanging, an object with no practical use, as opposed to a basket. Some might say that this is no longer craft, but art. Others would say that the object was only art if it were made from canvas and paint. Choice of material is frequently the key to whether an object is fine art—and sought for the museum wall—or craft—and used on the table. Ceramics, fabric and glass are craft; paint and canvas are art. But what about stone? To many people, in the form of a statue, stone is art, but hollow it out and serve a salad in it and it becomes craft. Paper used for a sketch is art; paper used to make a book is craft. As these examples show, the material employed is seldom useful for this distinction.

The age of the object can be used to make this determination. Here there are difficulties as well. A classical Greek vase is placed in a museum and considered art, but at the time it was made, it was craft. Perhaps all man-made objects might attain this status with passing centuries, but art works can be new as well, and that makes using age alone as a distinguishing trait of art

insufficient.

The difference between art and craft is culturally defined, as well. Originally “there was no distinction between art and craft in Japan, and the terms *bijutsu* (art) and *kogei* (craft) are translations of Western concepts.” [70, p. 398] Even within a culture, the definition changes over time. All of what we consider art was originally craft, and craft can come to be considered art [5]. For example, painting began as decoration in the homes of the rich, as well as public and religious buildings, and was practiced by craftsmen who considered what they did as craft.

Side by side on primitive scaffolding, sculptors, glass artisans, painters, and metalsmiths collaborated to embellish monumental cathedrals...[P]ainting, at the beginning of the Renaissance, was not a particularly status-laden art form...the cost of materials bestowed value on a product, not necessarily the skill with which it was executed. Some patrons even paid for paintings by the square foot. [31, pp. 7–8]

Beginning in the Renaissance, the divorce of jobs requiring the hand from those that were mental and theoretical (and the consideration that the latter were somehow more elevated) began to influence the world of craft, leading to a hierarchy of craft. For example, painting was seen as more refined than sculpting, since painting used tools that were closer to those of the scholar than the mason, and by using color and perspective more closely approached the ideal. Finally the arts were separated from craft altogether, at least in art theory [31]. This separation became more than theoretical over the next centuries [69], that is why many modern cultures still consider artists to be above “mere” craftsmen. (At the same time, there exist commercial artists, who fit more comfortably into the mold of craftsmen, and are considered lower in status for this reason.) Similar changes occurred more recently in photography. Photography was initially considered a mechanical means of recording prosaic images, and later went through several periods of stylistic change just as painting has done, to become an art form for museum walls. Indeed crafts turn into arts and back again frequently, through the process of art absorbing new materials, artists “freezing” their technique into a craft, or craftsmen declaring their status as artists [5].

The case can be made that craft is more uniform in the sense that craftsmen place great

emphasis on following certain technical standards and artists do not, or at least artists attempt to rebel against standards as a matter of course and that “...it might be said that breaking the rules is a driving force for the artist, while following the rules...is important to the craftsman.” [84, p. 26] Most craftsmen are concerned with skills and technical excellence; they are focused on workmanship. They are also involved in a tradition, that imposes its own standards on their work.

In their work they are less concerned with design, with the creation of new texts, than they are with technique, with ways of working the stone. Their emphasis is on artistic action, on the process of creation. What matters is the performance of skill. [53, p. 6]

They can be involved in a tradition that imposes its own standards and patterns on their work. “Each craft is the rich repository of many years of practical experimentation and knowledge by men and women whose very lives were shaped and enhanced by the work of their hands.” [104, p. 10]

This leads directly to another difference between art and craft. The craftsman is more concerned, on average, with the utility of an object. There is a more practical side to crafts, and in fact one might add the word *useful* to the objects in our definition to distinguish craft from art. “In the crafts, the practical is magical.” [87, p. 69] The craftsman celebrates the practical, and if an object is not useful, she might argue that it is not beautiful as well, and in some cases, beauty is not a consideration.

The ordinary craftsman, I think, does not take the criterion of beauty very seriously. Busy satisfying the demands of a variety of jobs and customers, he contents himself that the pipes he installs carry water, that the bookcase he builds is sturdy and fits in the space he measured for it, that the meal is served expeditiously. I have deliberately, of course, chosen examples from crafts in which the idea of beauty seldom enters anyone’s calculations... [5, p. 866]

The artist, by contrast, is more concerned with beauty and self-expression, rather than making an object to be used. And Becker [5] distinguishes the *artist-craftsman*, to whom beauty is a major consideration, from the craftsman. Those making stained glass windows, for instance, care as

much for beauty as for keeping out the wind and rain. Using the criterion of utility, our plastic wall-hanging, although made from manufactured material by a traditional craft method, is art. But, considering how many handmade pots sit as decoration, and are never actually used to hold food, this distinction is not always useful either.

The term art is also used to praise objects which would otherwise be considered craft. Craft objects which are particularly skillfully made or beautiful will be called art by those talking about them. This is one aspect of the social value placed on the object and the maker. Craftsmen are paid less for their work, and are considered by Western societies to be lower on the social scale in some respects than artists. This scale has overlaps: an unknown artist might make less than an established craftsman. But she stands a better chance of her work selling for large amounts in the future. This leads to one humorous way to tell the difference: “[a]s far as I can tell there are only two real distinctions to make between arts and crafts. You are allowed to touch and handle crafts before you buy them. Also crafts always cost less than art.” [87, p. 75]

The preceding has shown that no distinctions made between art and craft are serviceable in all times and places. Any differences rely on the intent of the practitioner, the uses to which the object will be put, or the culture or period in which it is made. The differences between craft and art are far more subtle than that between craft and the products of industry. This is particularly true for the domain under consideration in this work. Pop-ups are made from paper, traditionally a fine arts material. They occur in books, and bookmaking is considered a craft. They can be made in a spirit of artistic creation, but are assembled (by hand) in large quantities. Their designers are called *paper engineers* but are often trained as artists. Whether pop-ups are art or craft has no real bearing on this work. For, in fact, “Craft are is replacing art; crafts are art, and perhaps no other art exists.” [87, p. 71]

This work will use the term *craft* to describe the process of pop-up design and construction. There are two primary reasons for this. First, the term helps to distinguish this activity from the curriculum subject of art in schools, although it can be produced there. Second, in the current context there is more concern with the technical workmanship of each item than with the

internal state and purpose of the maker; there is no concern with questions of self-expression vs. usefulness.

2.2 The Value of Craft

One view of craft previously mentioned is that it is of no value in today's society. In part, this is because modern manufacturing has removed much of craft's necessity in everyday life. A new laundry basket, made of plastic, performs the same task as a handmade basket at a fraction of the cost. That handmade basket is now a decorative object, valued for its uniqueness rather than its function. This is compounded by society's propensity to value the skill used in the production of theory, mental constructs, and words on paper more highly than the skill used to produce physical objects. Finally, crafts are often practiced by women and cultural minorities, causing additional devaluation [31].

The world of art (and society in general) often looks down upon the world of craft, as mentioned in Section 2.1.2. Art commonly costs more than craft. The craftsman, simply by calling herself an artist, can gain social acceptance and increase the value of her work. Interestingly, the craftsman can in fact be more skilled than the artist, but make less from the practice of the craft: "crafts are looked down upon because they are associated with manual labor and, thus, with poverty." [87, p. 74]

At the same time, it seems peculiar to be required to defend the value of making objects. After all, tool-use and the making of artifacts are in large part what makes us human. Even in an age when it is not necessary for most of us (in particular knowledge-workers, who are an ever-increasing segment of the workforce) to practice a craft, crafts as hobbies, as well as careers, retain their popularity. Many people practice some sort of craft, and those who do not consider themselves craftsmen can still cook gourmet food, a craft no matter how transient the results, or make their own house repairs even when frugality does not require it.

It is obvious that craft fills a basic human need. Man is a tool-user and builder; craft is pleasurable precisely because it is naturally a part of being human. "You cut and cut and all of

a sudden you see something grow...You feel good inside. You work, it gets brilliant, you see it move. I don't know, it fills you with some kind of emotion—such a sense of satisfaction.” [53, p. 6] The pleasure that most people derive from the practice of crafts and the human history of using tools are possibly the most important values of craft.

It is useful to focus on children's education in order to examine the types of advantages that craft education and practice provide. This work concerns the practice of a craft by children (for the most part, the same benefits exist in craft for adults as well as for children.) It is particularly helpful to examine the opinions of teachers in this regard. Teachers spend time observing children in the act of making objects, and their purpose in having children practice craft is more focused than that of the parents who may be more interested in their children spending time in a manner that is pleasant and safe rather than promoting some particular educational value. In the case of teachers, concrete data exist about their view on the usefulness of crafts to a child's education.

In their study of craft education in England and Japan, Mason, Norihisa and Naoe [70] described how teachers view the value of craft. A sampling of the results are summarized in Table 2.1. This is an interesting summation of the many benefits of craft, some of which are worth a closer examination.

It is important to note that the teachers surveyed were art teachers, and therefore they placed great value on expressiveness. This can be seen in the high rankings for expression and visual skills, knowledge of tools and materials, and aesthetics, all of which are of particular interest to the art teacher. Not surprisingly, items that dealt with self confidence and a sense of achievement received high ratings.

Other reasons that were rated highly do not seem immediately obvious, in particular, the appreciation of cultural heritage and inheritance. Craft often occurs within a tradition and is important as a part of family, regional and national identity. The ceramics of China (the country that gave one form of ceramics its name), the textiles of the Inca, the netsuke of Japan all help define the cultural identity of a place. This gives value to the craft, and to the craftsman. For stone carvers in Italy, the family tradition of stone working means that the craft becomes more

Reason for Valuing Craft	England	Japan
Gives a sense of pride and achievement	98	-
Gives first hand knowledge of tools and materials	95	97
Develops imaginative and expressive skills	96	85
Builds self confidence	95	-
Gives a positive attitude and a sense of achievement	-	95
Helps pupils to appreciate excellence and aesthetic value in crafts	-	92
Develops understanding of relationships between crafts and life	-	92
Develops understanding of the made world	90	-
Fosters visual sensitivity for adult life in the home	89	-
Fosters problem solving skills for adult life in the home	87	-
Fosters problem solving skills for adult life in the workplace	85	-
Fosters visual sensitivity for adult life in the workplace	83	-
Develops understanding of cultural heritage	-	83
Develops understanding of historical, technical and cultural inheritance	78	-
Fosters practical skills for adult life in the home	70	-
Fosters practical skills for adult life in the workplace	69	-
Provides for leisure time pursuits	62	68
Prepares pupils for adult life in the home	-	58
Helps to determine future career choices	57	27
Prepares pupils for adult life in the workplace	-	33

Table 2.1: Data selected and rearranged by decreasing percentage value from a table in [70, p. 405]. The numbers given are a percentage of positive answers for each value. Because of cultural differences, some reasons are different or are not provided for a country.

than simple stonework; it is a matter of identity and pride. As one carver explains:

Everybody when they see on the street the stoneman, they say hello to him, they take off their hat. It was a trade that involved not the mechanical work but involved the art. Everybody knew what kind of working man was that. Some of the old men was so proud of their work. They was so precise. And everybody call him master because he was so good, so meticulous. [53, p. 22]

Tradition also implies a structure of tools, forms, and methods. Working within a tradition, as occurs in most crafts, can be limiting. The tradition imposes a variety of constraints, and requires the craftsman to work within and around these constraints. Thus, the tradition of the craft encourages the fostering of problem-solving and visual skills that have value for children later in life, and were highly rated in the poll described above. The concept of working within constraints

will be elaborated upon in later chapters, as it is an important part of paper engineering, and problem-solving skills will be important in connection with the craft of pop-up making, and its role in various educational settings.

Although the categories in this study appear discrete, there is a significant area of overlap that may not be accurately reflected in the results. For example, although the value of craft in everyday life, particularly in the workplace, does not have a high placement in these results (particularly in Japan), other high ranking categories, such as the understanding of tools and materials and problem solving, would obviously be very useful in everyday life. Even if the workplace is not involved in craft directly, these are worthwhile abilities to acquire. In fact, Eggleston [27] found that making objects in school was actually quite important to success later in life, and that craft graduates were largely employed (not always in their original craft), often in management positions, and often in multi-track careers, that is, in a non-craft career as well as production of craft items separately.

Another study [119] of teachers in both primary and secondary schools in Britain included additional questions about personal qualities that might be fostered by craft. These included such qualities as willingness to experiment, motivation, responsibility, conscientiousness, and honesty. Teachers did not include these values unless asked, but when they were included respondents indicated they were important, although to a lesser extent than practical skills. This also varied by student age:

Teachers have expressed the view that pupils involved in making activities will develop far more than just practical capabilities, although these are seen to be of greatest importance...The research also reveals that the reasons for making activities do differ according to the age of the pupils. Teachers involved with younger pupils more consciously used making...because it enables them to stress the development of personal qualities and attitudes and cognitive abilities. At secondary level making is implicit to the subject and teachers' first concern is subject competence. [119, p. 229]

And finally, not mentioned by the teachers in these studies but obvious to parents with refrigerators covered with children's art, are the objects themselves that can be displayed, given as

gifts, and treasured for a lifetime. Objects inspire children as no immaterial results can, and can serve as social currency when used to interact with others [29].

Thus the practice of craft in schools (and by extension in the home) can be seen to have practical value beyond simple enjoyment. This value comes in many varieties, from employability, to cognitive skills, to creativity and work habits. There are also, of course, related specific skills that can be learned by working in crafts: the mathematics of measuring materials, reading of directions, and so forth, and the production of objects that have value in the eyes of children, as well as their peers and relatives. As with all human activities, the practice and learning of craft is complex, and effects on both the craftsman and society are manifold.

2.3 Learning and Practicing a Craft

In order to study the practice and learning of a craft, and the effect that a change in technology, such as computational design, might have on that craft, it is helpful to break the craft practice into smaller parts that can be more easily assessed. These divisions can be used to build a framework of craft, and in particular craft learning, to allow generalization of the use of computers to learn craft and assessment of the learning of craft. The word *competency* has been chosen to describe each part of craft learning, in order to stress that it embraces a continuum of development, and will change over time.

Many people equate craft with *skill*. It seems logical that the concept of skill should be a part of learning a craft, and that skill is developed by craft practice. But there are certain parts of craft that also involve learning facts apart from skill. For instance, one might understand what a glaze is in connection with pottery, without having any skill or experience in that craft. This cannot be defined as skill, and must be something else: *knowledge*. “In the pure folk definition, a craft consists of a body of knowledge and skill that can be used to produce useful objects.[5]” In addition, there are more subtle areas of craft learning and practice that appear to be different from knowledge or skill. The word *appreciation* is used to encompass these qualities that include the aesthetics, judgments, and traditions of a particular craft and that allow a practitioner to judge

the practice of herself and others. Knowledge, skill, and appreciation are the three competencies used in this framework of craft learning³.

A look at the National Standards for Arts Education [61] provides an example of how these competencies relate to an established assessment protocol. As can be seen in Section 2.1.2, arts and crafts are not naturally distinct; crafts are most commonly practiced in art classes in school, so this seems to be a good place to see what those who teach craft think is important for children in learning crafts. In examining standards for the visual arts there are six content standards defined and they can be seen to directly relate to the three competencies of knowledge, skill, and appreciation:

- (1) Understanding and applying media, techniques, and processes (Knowledge, Skill)
- (2) Using knowledge of structures and functions (Knowledge, Skill)
- (3) Choosing and evaluating a range of subject matter, symbols, and ideas (Knowledge, Appreciation)
- (4) Understanding the visual arts in relation to history and cultures (Knowledge)
- (5) Reflecting upon and assessing the characteristics and merits of their work and the work of others (Appreciation)
- (6) Making connections between visual arts and other disciplines (Knowledge, Appreciation)

The Content Standards can be described in terms of the competencies, and as such these competencies provide a sufficient and, as will be shown, useful framework for the study of craft learning.

A special note here concerns the design and planning of craft projects. This area is often separated from the actual production of objects. In this framework, each of the competencies has

³ The selection of these competencies was largely influenced by my own experiences in learning sewing, weaving, drawing and painting, and various other crafts. It has become apparent over the years that knowledge, in particular the vocabulary of the craft, and the skill of actually producing objects with the craft, were separate parts of the learning process. Appreciation was added later, when I realized that it existed as a separate entity and that knowledge and skill were not sufficient in themselves to cover the practice of a craft.

a relevance to the planning and design of the craft object as well as its construction, especially skill and knowledge. The design of an object is a skill in itself, and involves the knowledge of how such design should be done, as well as the aesthetics of the craft (appreciation). In a similar manner, planning is a skill, informed by the knowledge gained by the practitioner.

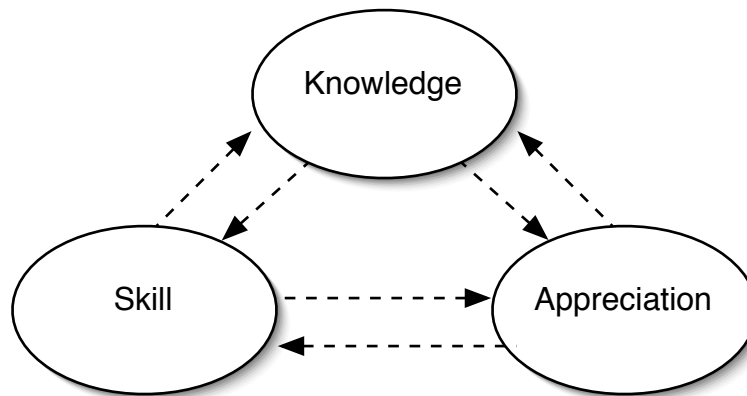


Figure 2.1: A framework of craft learning.

These competencies are not isolated from one another. In order to learn a craft, these are often approached simultaneously. One example is learning in a classroom setting where knowledge about tools or materials may be presented as the learners work to build skill, and where a variety of craft objects may be shown and discussed to build an appreciation of the craft. They also interact with one another, for instance learning a skill will often lead to the appreciation of the practice of that skill in others, and that appreciation might influence the way the craftsman builds her knowledge of the craft.

In validating and clarifying this framework, examples were taken from three craft traditions: Italian stone carving as described by Hunt[53], Southeastern American pottery making told to Hewitt and Sweezy [49] [111], and backstrap loom weaving among the Maya of the Chiapas recorded by Greenfield [40]. These examples are craft traditions, passed on in cultural, regional and family groups where people learn these crafts as a career. Such crafts are well documented by oral historians and anthropologists, and as such provide stories in the words of the craftsmen

themselves. Most of the artisans described learned their craft as children and are therefore better examples, as this work deals primarily with children, than those who learned the craft when older. These craft examples span a range of geographical locations, materials, and cultures, and are also mixed in terms of gender, as weaving is practiced by women, stone carving by men, and pottery by both genders. Since these are general areas of craft learning and practice, they should apply to all learners, whether within a tradition or not.

In the following sections each competency of the framework is discussed in more detail, its selection is explained along with some examples in the sample crafts showing ways it is acquired, its interactions with the other competencies, and ways that it can be assessed.

2.3.1 Knowledge

Knowledge is the competency that is arguably most amenable to study and testing, and probably most familiar to us. It is not by chance that most of the Content Standards listed above relate to knowledge of the craft. Knowledge includes those parts of a craft that can be orally transmitted, passed on in written form, or learned by observation of a craftsman, for example by growing up in a family that practices the craft. Knowledge can be said to be one part of any craft that can be learned without actually practicing the craft. (However, note that some of appreciation has this quality as well. See Section 2.3.3 for more discussion of the relationship of knowledge and appreciation.) Knowledge includes such things as vocabulary, such as tool and process names, and other terms in which the craftsmen talk about their work. Another important piece of craft knowledge is understanding what is possible and not possible given the craft form and includes constraints on aesthetic boundaries as set by the craft community. In addition, craft knowledge can include such things as the history of the craft and what other people have done with it, knowledge of the use and care of tools and the properties of materials, as well as the sort of knowledge of a craft that a good appraiser might possess, such as the value of the resulting object. All of this knowledge can be acquired without actually making a craft object. Knowledge is probably the easiest part of craft to assess, as oral or written tests, or talking with a craftsman

can elicit her level of understanding of the craft.

Something that is frequently mentioned by craftsmen recounting their experiences is that knowledge is often the first step in learning a craft. For example, for stone carvers this can come simply by listening:

I used to hear my father talking about the craft every evening of his life. He would talk about it for hours to my mother, and she was interested in it, too, because all her people were in the trade, and she knew nearly as much as he did. I remember well when I went to work first, how much I already knew about it. I was familiar with all the tools and the terms the men used about stone. [53, p. 21]

or by observing (in this case, watching the master work):

I had to stay right there beside him and look at him. If I was looking somewhere else or doing something else—pomb! I get a little smack on the back of my head. I had to stay there and watch; that was the only way I could learn. [53, p. 21]

Another example of learning through non-verbal instruction is seen with Chiapas weavers. Greenfield notes that young girls are always present when weaving is done, and that “...beginners spend 53 percent of the time observing rather than weaving.” [40, pp. 59–60]

It is obvious that one can know something about a craft without practicing it; the mother of the stone carver quoted above never actually carved. It is also obvious that no craftsman has all of the available information about a craft, its history or its practice in other regions or countries for instance. But even without complete knowledge of a craft, they can still have sufficient knowledge to practice the craft in their own tradition.

As previously stated, none of these competencies stand alone. Knowledge informs both skill and appreciation. In terms of skill, it is often a common practice to watch or listen, then attempt the process to learn the skill. Another example can be seen in the recollections of a potter: “My father had a place in the shop we could slide on under and watch him turn and sometimes he’d say, ‘You make it while I go to dinner.’” [111, p. 99] In the case of appreciation,

one requires some knowledge of the craft to be sensitive to the qualities of an object made within it. As one potter puts it:

The resemblance between the Asian and Catawba Valley pots is kind of intriguing...A thousand years ago fire and smoke and ash rushed through a kiln the same way as it does today. So I can tell by the color of the clay and the glaze on an old Chinese pot, where it was in the kiln and how it was fired. It's like what happens in this community today. Local people can look at my pots and say 'Oh, that one got hot, it must have been up front.' [49, p. 174]

In this case, general knowledge about pottery production can be expanded upon not only by the people in the same region, but applied across traditions in the appreciation of their pots. The knowledge of the physical changes produced by the kiln can be applied to pots made at different times and in different places. Knowledge serves as the foundation on which appreciation is built.

2.3.2 Skill

As previously discussed, to practice a craft knowledge is not enough; it also requires appropriate craft skills. In fact, most definitions of craft involve the word *skill*, and the original meaning of the Old English *cræft*, from which the word craft is derived, was skill or strength. All crafts have specific skills including tool selection and use (the ability to select the proper tool and use it correctly in action, beyond the knowledge about tools) and proper handling of appropriate materials.

Skills are acquired by actual practice of the craft. Knowledge about what skills are needed can be imparted by reading or by a mentor, but only actual practice will bring them into being. Admittedly, this is an arbitrary, culture and language-related division. The Mayan language does not make this distinction, for instance, and therefore the weavers of the Chiapas have a different concept of knowledge (*na'* in Tzotzil) that includes both skill and habit:

Na' includes knowledge of the soul or heart; "know" refers to knowledge of the mind. The central meaning of *na'* is knowledge of practice that is both habitual and characteristic of a given person...To say "I know how to weave"

in Tzotzil is to assert far more than skill development; it is to say that I am in the habit of weaving, and weaving is part of my identity [40, p. 52].

For the purposes of the framework being developed, skill is defined as those components of the craft that can only be learned by doing. This is what separates skill from knowledge and appreciation, both of which can be acquired by other means as well. Skill includes not only the more obvious parts of a craft—actually turning a pot on the wheel—but ones that are less obvious. For instance, design and planning of a craft project have a skill component in addition to knowledge about the feasibility and desirability of a particular design. A craftsman can be shown examples of good design and told what things to do in designing a product, but it is only by actually participating in the design process and seeing the results of her own planning that the skill of design, of seeing the result and what has to be done to get there develops:

You have to have the feel—the certain delicate tenderness. All these emotions contribute to a good carver. When you carve something, you have to feel it inside you. You gotta know it's got to be soft here, this has to be sharp, this has to be strong. And this you can't learn. Nobody can teach you that. [53, p. 131]

Even some of the small, and one would think inconsequential, skills of the craftsman become a large part of the practice. For instance, details like taking care of the tools, or cleaning up, are vital, and, while they can be learned (and therefore be part of the knowledge component), they become part of the craftsman's skill set only through practice.

In a woodworking shop, one of the distinctions between somebody who understands working with tools and somebody who does not is to realize that the process of sharpening or sweeping up are absolutely fundamental to the activity of making something. [11, p. 23]

Practice and experience are the defining qualities of skill, and it is only by experience, by actually making objects, that skill is developed. At some point, the learner goes from gaining knowledge to also gaining skill, often through a process of simplification of the skill. Each craft, culture and teacher has a different way of organizing and simplifying the learning of skill to allow

the beginner to experience the craft in a manner that helps to develop skill successfully. Some part of the skill to be learned is taken and presented to the learner, who proceeds to practice. This can be as simple as sweeping up the floor or carrying the finished pots to the shelves, or it can be one part of the process itself. For instance, in stone carving:

And well, you see, in the beginning they give you a piece of rock, and then they make you make a flat surface. That's the first thing you have to learn when you're starting carving. The block is all rough, so you have to make a flat surface—straight, nice, and smooth. Of course, when you know how to carve, you might do it in an hour or two, but when you're beginning, it might take three or four days, you know what I mean.

Another example of simplification of a craft in order to allow the beginner to build skill can be seen in weaving and involves *toy looms*, that are made by or for children from sticks and yarn, in the same style that adult looms are made, with one major design change. In an adult loom, the warp threads (threads that run the length of the material) hold the loom together. In a toy loom, there are extra ropes in addition to the warp threads. This allows the warp to be wound directly on the loom, with the extra ropes holding the loom together as this is done. The adult loom does not have these ropes and requires another device, the warping frame, to be used to wind the warp before it is placed on the loom. By eliminating the use of a warping frame, one step of the weaving process (and a major cognitive hurdle) is removed and the process simplified.

Because threads on a warping frame look so different from the way they will look on a loom, the weaver must mentally transform them to imagine how they should be arranged on the loom...In contrast, this sort of mental transformation is not necessary to set up a play loom...Whereas Zinacatec girls start on the toy loom from about age three, they generally do not set up a real loom before age seven...[40, pp. 47–49]

Skill reveals itself in the action of the craftsman as well as in the finished product. It often requires the eye of another experienced worker in the same craft in order to see skill in action. This is well described in a story one carver told of being tested to join the stone carver's union:

And the president of the union, he was working there, and he came down and gave me a piece of stone, and then he brought me this model, the head

of Christ, and he said, “Can you carve that?”...So I took a chisel and I started roughing it out and he’s watching me. And so after an hour, I’m working, he saw that I knew my business, that I knew how to carve, because you can tell right away, especially a man of his age, his experience, they can tell. [53, p. 33]

Another method of assessing skill is to observe the results of the craftsman’s labor. In this case, the assessment can be made by someone who has developed appreciation, judgment of the craft object (the subject of Section 2.3.3). Once again, having the experience and skill of the craft helps, but skill can also be judged from knowledge and experience of seeing other craft objects of the same type.

Skill helps to develop both knowledge and appreciation. Trying things, whether they work or not, informs the craftsman about what is possible in the craft, and what is not worth trying. It is obvious from the story of the carver testing for the union, that the practice of the skill gives one a sense of what is good in the craft. “All potters have an ‘eye’, a sensibility toward what they make, a dream they make real.” [49, p. 1]

2.3.3 Appreciation

Appreciation is the understanding and enjoyment of the craft results, the tradition and the aesthetics of the particular craft. One does not have to have the skills of the craft to appreciate the results—but appreciation is enhanced in their presence. One does have to have some knowledge of the craft to appreciate in any depth. Appreciation spans a continuum. Saying “Oh that’s pretty” is only the start of appreciation, and requires little or no knowledge or skill in the craft. For the experienced craftsman, there is the ability to look at a craft object and discern methods, tools, and materials used in its construction.

In his discussion of virtuosity as a standard of judgement, Becker [5] describes the relationship of appreciation and craft in general. “But no one can tell whether an object or performance displays virtuosity without learning and accepting the standards of the workers responsible for them.” [5, p. 888] One form of virtuosity is the recognition and development of a style, that

develops as part of skill:

...apprentices...were given the latitude to develop their own styles and techniques of carving, to catch what was best for them, but they also learned that there were “limits of acceptable expression”... what counted was not only inner competence but also the ability to relate that competence to the context that held them. [53, p. 60]

This relationship of competence and context is a key part of appreciation. Craftsmen develop a sense of what is valuable, often within the context of tradition, by watching others work, seeing the objects produced by others, and by practicing the craft themselves. In some cases, the aesthetics of the craft are affected by the business element of craft production⁴. For instance, in stone carving it is necessary not only to make the carving beautiful and in harmony with the tradition, but to produce enough carving to feed a family and the craftsman appreciates the speed with which the work is accomplished:

Thus Vincent began to discover the aesthetic principles that governed the way in which work was performed and evaluated in his grandfather’s shop. The good carver, he came to see, was one who produced quality work with speed, precision, and care; a craftsman who successfully balanced the need to “make more production” with the desire to do “the best first.” [53, p. 58]

The values of a tradition can change over time. The weavers of Chiapas commonly weave different patterns for sale outside the community than those for personal use, and also sell their poorer quality productions. There is a belief that the level of appreciation in those outside their culture is lower, and therefore simpler, rougher ware will pass muster. In addition, their weaving has changed due to greater contact with the outside world, and greater production for outsiders; the aesthetic has changed [40].

When compared to knowledge or skill, appreciation is more difficult to assess. A craftsman would be able to describe the work of others, place it within the context of her own work, and say

⁴ The business aspect of crafts is an important one, and well worth studying, however, it will not be pursued in detail. This is a matter of focus; the concern is with children learning crafts primarily, and the concentration is on other aspects of craft-work. It is not important for this work whether it is made for commercial purposes or purely personal ones.

something about the techniques and skill of the maker, and the value of the work. A craftsman would also be able to compare two works, and perhaps even to make some judgment of a work from another tradition. The ease and accuracy with which this can be done, and the discussion of the specifics of the construction of the assessment object(s) can be used as an assessment of the level of the craftsman's appreciation. Assessment of appreciation requires some level of craft knowledge and appreciation, and, in the best case, skill on the part of the assessor.

Skill and knowledge are necessary for the acquisition of appreciation. In a similar way, the appreciation of the work of others leads to the development of both knowledge and skill. For instance, viewing the work of others allows the experienced craftsman to envision new techniques, new designs, and build up the knowledge of what is possible and what is valuable and attempts to copy appreciated objects lead to the development of new skills or the improvement of old ones.

In the context of the workshop, surrounded by carvers of all levels of skill and ability, they continually watch one another, comparing individual styles and techniques, measuring themselves and evaluating the work of others, striving for the respect and recognition accorded to mastery. "Between ourselves we *knew*," said Roger Morigi, "we recognized the one who was doing very good...And you wanted that, to hear that, and you wanted to be one of them." [53, p. 6]

2.4 Adding the Computing Dimension

In Section 2.1.1, the argument was made that craft can be enhanced by technologies such as power tools and computers, and that if manual control is maintained over the process, it is still craft. This section will examine what can be gained and lost in craft through computer augmentation of the craft process, following the framework introduced in the preceding section to guide the discussion at a high level. This section will explore the possibilities of computer-aided craft-work, and in particular the use of the computer in designing the object to be made.

Adding computation to craft is not a new idea, of course. Computers are now commonly found in sewing and knitting machines, for instance, to allow the craftsman to design and execute complex patterns. Many craftsmen use computer aided drawing programs, the Web to access

pictures of craft objects designed by others, or email to keep in touch with other craftsmen. And there is a plethora of software aimed at specific crafts. At this point in fact, examples of computational craft are too numerous to include them all.

There are also a variety of ways in which computation can be added to craft. The materials that craft objects are made from can themselves be capable of carrying out computation [10, 128, 7]. The tools used to fabricate craft objects or their constituent pieces can be controlled by computers running under control of the craftsman [8]. Computers can also be used for the creation of a “virtual product” (an object that exists only on the computer screen), but as the definition of craft suggests, the product of a craft must be tangible, material and real; this is not augmentation of craft. Computers can be used by the craftsman to design craft objects and to plan for their creation, as in Hypergami [28], that allows children to design polyhedral shapes to produce paper sculpture, and it is this blending that is of particular interest in this work.

Even restricting a discussion to this single augmentation area leaves a vast landscape of topics for exploration, and implies that some bounding strategies are needed to proceed. Two methods will be employed to focus on the core questions around children, craft, and computers. First, the choice of a craft tradition appropriate to children’s abilities will help to assure that the effects of adding computation to the craft will be easier to determine. Second, by applying the framework developed in Section 2.3 to those observed effects, changes that occur in the areas of knowledge, skill, and appreciation can be more readily identified. These choices have also guided the design of the system described in Chapter 5 and the analysis of user studies profiled in Chapter 6.

In this discussion, the main focus is on children learning the craft. Computers can be and are used by experienced, adult craftsmen in their work. Computer-controlled embroidery is produced by many sewing machines today, and milling machines and other fabrication devices are in common use. But there are different considerations for the learner. For instance, efficiency is a major concern for the established craftsman, but too much efficiency can conceal much of what is going on in the process, and make learning more difficult. Much of this is a balancing-act.

It has been seen (in Section 2.3.2) that beginners are often given simple tasks (as with the stone carver), or provided with tools that bypass certain difficult operations (as with the play loom in weaving) in the traditional apprenticeship. This discussion addresses the use of the computer for a similar purpose.

2.4.1 Computer Enhancement of Craft Knowledge

Craft knowledge can be enhanced by applying computers to the design of craft objects in several ways. First, the user can be presented with information about the craft. To some extent, the Web can serve as one such tool⁵. It can introduce the beginner to information about the terms, tools, and techniques of a particular craft in the same way as a book. Computer software that provides help tools, documentation, or labels for its functionality can also introduce the learner to the vocabulary of the craft or provide information about the steps to follow to accomplish some task. By making it easier to design a functional craft item, and harder to design a non-functional one, the computer can build knowledge about how to design. That said, computer learning has the same limitations as learning about a craft by only using books; the learner needs to use those terms with another craftsman to truly learn and understand them. In addition, the helps and documentation may not in fact be used by the learner, even though present.

Notations are used in crafts to guide and record work in progress. For instance in weaving, there are standard notations used for loom set-up to produce particular weave patterns, in counted cross-stitch there are notations for creating a given design, and in architecture there are standard symbols used on blueprints. Sometimes there is no notation, or the craftsman is not aware of the existence of one, and develops it herself. An excellent example of this process can be found in Greenfield [40, p. 160-164], describing the invention of notations for embroidery by the weavers of Chiapas, who had no previous idea of such notations. The computer can present ideas for notations, and in fact can promote the creation of new notations for crafts [47]. Design

⁵ The term Web will be used in this study to mean the “world wide web”, one set of protocols used on the internet.

software requires some form of notation on the screen for the user, and these notations must be developed or adapted by the software designer. The computer can also facilitate the knowledge of notations by presenting both the notational form of the design, and the actual visual appearance of the artifact produced from that design. In weaving, for instance, the finished fabric is hard to visualize from the loom set-up. By showing both representations, the learner can see how they relate to one another, and learn about the notation system.

The computer can present possibilities for design that might not be obvious, or might otherwise be difficult or impossible. The ability to experiment without using valuable materials allows the craftsman to come to some knowledge about design that would be difficult, time-consuming, or impossible to otherwise obtain. Of course, it is possible that this can in fact limit choices and thus the knowledge gained, as the only designs created are those that the computer allows, a subset of those available to the craftsman. The software can hide other knowledge as well. For instance, if the computer uses certain rules to allow only functional designs, but those rules are hidden from the learner, it can be difficult to see what those rules are.

2.4.2 Computer Enhancement of Craft Skill

Computation can enhance skill acquisition, and also hinder it. In order to develop skill, a craftsman must gain experience in using her hands and tools to build. If the computer takes over too much of the work, skill cannot be acquired. If it takes over too little, there might be no advantage in using a computer for the task. It is possible that hands-on experience with the materials and tools will suffer, that only things that the computer supports will be attempted. There can be too much design and not enough fabrication; the learner will spend time gathering knowledge, but less time gaining skill. In addition, it can be possible through computer aid to design things that cannot be made by hand at all. For instance, a computer may be able to design a craft object that is so complex or tiny that it cannot be assembled, or that cannot be fabricated with available materials.

The computer can also promote the development of design skills. The ability to see what

the object will look like can aid the beginning craftsman in the skill of visualizing the object from the design notation. This is something that comes with practice, and there is more opportunity to practice if there are more designs made; the computer can allow more trial designs by making the design process faster. We see once again an advantage of showing not only a notation, but some idea of what the finished product looks like. More opportunity for seeing the finished object before committing time and material to its construction allows more occasions to observe the design process and its alternatives. Augmentation of the design of craft objects can have an effect not only on the skills of design, but on other skills of the craft involved in the actual fabrication of the object itself. For instance, if there is more complexity in the design, more skill must be brought into play to convert the design to reality.

The computer can aid in building skill by serving as a simpler way to design. The computer can function as a device to allow the learner to overcome early difficulties and to be presented with a simplified way to proceed with the craft, much like the toy looms of girls of Chiapas. If this is the case, one test of whether this succeeds is observing that the learner at some point does not need the tool.

2.4.3 Computer Enhancement of Craft Appreciation

Computer enhancement might be thought to be difficult to apply to craft appreciation, since appreciation is largely an aesthetic, a way of viewing the craft that requires the involvement in the craft and contact with its products, often over time. Of course, with enhanced knowledge and skill comes an attendant enhancement in appreciation. And so the discussion about the effects of computer enhancement on skill and knowledge also apply here.

One way that computers can help develop appreciation is by increasing the communication between craftsmen. In the traditional shop, craftsmen are able to compare work and interact. But most people, and especially most children, do not commonly learn a craft in a traditional shop. If they are lucky, they will take a class, where they can observe and trade ideas with teacher and other students. The decline of traditional trade associations and guilds has removed most crafts from

traditional shops and produced many non-traditional practitioners, who is able to only meet other craftsmen at craft fairs [3]. Computers can allow people to trade ideas, designs, and notations over long distances through email or on the Web.

In addition, appreciation can be enhanced through the ability to have contact with a wide variety of craft objects. Using the Web, museums, galleries, and craft shops have placed many examples of crafts for users to study. These examples can take the form not only of photos, but of videos showing the production of objects, and patterns or diagrams showing design. Of course, this is seldom as good as holding the object in one's hand. But it helps to spread ideas and allows users to make comparisons with their own work.

2.5 Summary

Since the rise of industrial production of everyday objects, attitudes about craft have been torn between an idealized view of the craftsman as representative of a lost, better world, and that of craft as useless and cheap. Craft can be defined as *the production of physical objects by manual means* and can be distinguished from manufactured objects by the principle of control. That is, there must be continuous control of the process in making the craft object. The relationship of craft to art is more complex, and it becomes obvious that any distinction is cultural and historical. Art is a form of craft; craft is a form of art.

It is commonly known, in particular by teachers, that craft is a valuable activity for children, and those values include cognitive effects, the development of specialized skills, knowledge of materials, the growth of personal qualities such as patience and responsibility, and the production of objects that have great personal and social value. It has been established that craft is worthwhile as a pursuit for children in many ways.

Since the learning of a craft is a complex human behavior, it is useful to organize it in a way that will allow generalizations to be made about its practice, particularly for the user tests that are part of this study. A framework for craft learning that embraces three competencies, knowledge, skill and appreciation allows for analysis and assessment. Knowledge is the collection

of facts about a given craft, and can be acquired without actually making craft objects, while skill requires actual participation in the craft. Appreciation covers the aesthetic and value judgments that the student learns to make about the craft. All are related, so that they influence one another. For instance, appreciation is frequently based upon knowledge of the craft, and appreciation aids design skills by allowing the craftsman to make value judgments about her designs. These competencies are necessary and sufficient to build a framework of craft learning.

In connection with that framework, and as an exercise in its use, the advantages and limitations of computational enhancement of the design process can be investigated. The advantages arise largely because of the ability of computation to allow more designs to be produced in a given time, the communication available with other craftsmen, the development of new notations and practice with old ones, and the process of simplifying the craft for a learner. The limitations are often caused by the possibility that skill will not be developed if fewer actual objects are created, a stifling of creativity caused by the production of only computer-aided designs, over-simplification of the craft or hiding necessary craft knowledge from the learner.

This discussion continues in Chapter 3, concentrating on the domain of paper engineering, focusing on movable books in general, and more specifically on pop-ups. The analysis of craft in general will be extended to paper engineering and will use the tradition (history) of pop-up making in order to establish the definition of the craft. A discussion of how pop-up making is commonly learned leverages the framework that has been developed. The concerns of the value of pop-up making for children are addressed with a presentation of its uses in education.

Chapter 3

The Craft of Pop-ups

Chapter 2 presented an overview of crafts: their definition, tradition, and value as a children's activity, as well as a framework for the study of craft learning. Moving from this general discussion of crafts, it is time to introduce the craft of making pop-up books and cards.

This chapter is primarily concerned with the pop-up book. While many children make isolated pop-ups, or pop-up cards, it is the pop-up book that introduces most children to the genre and that provides the inspiration for the pop-ups that children make. It therefore presents a reasonable starting point for this exploration. Children (and adults as well) love pop-up books. With approximately 300 new books published each year, popular titles being produced in printings of up to half a million books, and books for adults joining the usual children's titles, most people in the United States are exposed to pop-ups as part of their culture:

Today these books are finding wide popularity. They have transcended the borders of "children's books", being produced for adult markets as well as for younger readers. They have also attracted an enthusiastic following of collectors and of patrons for library special collections that have holdings of pop-up books.[114, p. 21]

The movement and transformation of the customary flat page to a three-dimensional object provides the excitement that these books hold for readers of every age:

Give a child (or an adult for that matter) a pop-up book and you will immediately hear oohs, aahs, and curious cries of "How does that work?" A child's natural curiosity and wonder are clearly evident as he or she interacts with

these books...Pop-up books are always a highlight for story time in the library, especially since many librarians choose not to circulate them because of wear and tear.[1, p. 25]

What is a pop-up? Technically, a pop-up is some subset of possible devices that occur in movable books. Movable books are those books with pages containing devices that can be moved separately from the page itself either manually by the reader, or automatically when the book is opened to the page. Movable books also include books that can themselves be transformed in unusual ways, for instance by being folded into a different shape.¹ Individual movable books may or may not include true pop-ups and many modern pop-up books also contain devices that are not strictly pop-ups. A true pop-up is self-opening, being lifted by the action of the book itself, and is truly three-dimensional. Both pop-up and non-pop-up movable devices are present in the pop-ups made by the children in the user tests, and will be discussed in the analysis of pop-up devices in Chapter 4. Pop-up devices were developed much later than other movable book devices. Therefore, it is useful to understand how pop-ups differ from other movable devices, and how they developed from them.

This chapter begins by describing what pop-ups are, and how they came to assume their present form, through the evolution of movable books. It next explores the making of pop-ups as a representative craft for computational enhancement by situating the craft within the framework of knowledge, skills and appreciation described in Chapter 2. It concludes with an exploration of the value of creating pop-ups as a children's activity and provides a sampling of teacher accounts as illustration.

¹ Movable books are also called *movables*, *toy books* or *action books* and can also be placed in the general category of *novelty books*. Those movable books with only flaps for the reader to lift are also called *flap books*. Movable books can be called pop-up books even when they contain movable devices that are not true pop-ups, since modern books often contain a mix of movable devices. This work will use the terms *movable books* for books containing no true pop-up devices and *pop-up books* for those containing any true pop-up devices, even if mixed with movable non-popup devices.

3.1 A Brief History of Movable Books

A valuable way to introduce and define the pop-up and to distinguish it from other movable book devices is to look at the history of movable books. In addition, to appreciate the structure, craft, and uses of pop-ups, it is useful to examine the history of the movable book and how its craft tradition grew and changed over time. This exploration of the history of the craft will also consider the present design and manufacture of pop-up books, as it is in many ways still a craft since all pop-up books, even though printed on automated presses, are largely designed and assembled by hand.

The discussion in this section is based largely on materials in three areas. First, Hunt [54] and Darton [22] provide excellent general overviews of the history of children's books. Second, the development of the movable book before the advent of pop-ups is described and beautifully illustrated by Haining [42]. Finally, three general works on movable books and particularly on pop-ups are provided by Hiner [51], Montanaro [79], and Rubin [94].

The history of the development of movable books is centered on two qualities: movement and three-dimensionality. The non-movable book page is static and 2-dimensional. Movement creates animation of illustrations, as well as the presentation of alternatives: results of a calculation or display of additional data or pictures. For instance, anatomy books can use an overlapping flap arrangement to show the layering of parts of the body and the structures that lie underneath the currently displayed picture, adding depth to the illustration. It was a natural step to extend this motion and depth to picture books for children who appreciate the surprise of a moving, complex page.

This history of movable books is organized by the types of movable design devices that have been used. These devices represent particular ways of fabricating the paper to produce a desired effect, for instance to put certain parts of a picture behind others or introduce some movement to the page. The order in which devices are presented here is roughly chronological. Once a particular design device was used, of course, it continued in use for some time and might be

reused in conjunction with other, newer devices. During most of this history the movable book was a product of Europe, particularly England and Germany, and later of the United States, and this chapter will concentrate on these countries.

Pop-up books are often thought of as being intermediate between children's books and toys. The precursors of the earliest children's movable books were adult movable books. However, many current pop-up books are created with adults as their intended audience, this previous trend from adult books to children's books is now reversing, and many movable books, including pop-up books, are now being produced once more for adults. But from about 1820, and until very recently, movable books were produced almost entirely for children.

The children's movable book shares both publishers and audience with other children's books, especially those conceived for children's entertainment, and the history of children's literature, publishing of books for children, and movable books is closely intertwined. For instance, movable books for children increased greatly in numbers and formats after about 1850, coinciding with the more general explosion of children's books that appeared around that time. (Hans Christian Andersen's fairy tales appeared in English for the first time in 1846 and *Alice in Wonderland* was published in 1855.) The first golden age of children's movable books started around the last decade of the 1800s (a time of the flowering of children's books of every type) and ended in 1914 with the start of World War I when not just movable books, but the production of all children's books, declined due to paper shortages and the focus of manufacturing capacity on the war effort.

There are several factors that must be considered when discussing the history of movable books. First, children's books in general, aside from books for reading instruction or religious use, are a relatively modern idea. In earlier years (before the late 18th century) it was assumed that children should be engaged only in useful pursuits and that did not include reading books for entertainment. The books available to children then were ABCs, often containing some religious texts, and primers, perhaps containing Aesop's Fables, the most entertaining literature available to them. There were hornbooks, wooden paddles with a single page glued to the paddle and a layer of thin, transparent horn protecting the page. These were the equivalent of the cloth or

board books that are given to children today. The page of the hornbook would have the alphabet and a few religious texts, usually including the Lord's Prayer, printed on it. The hornbook was replaced by the battledore. This was a simple piece of folded cardboard with similar contents, and was often illustrated. There were also a small number of primers and school-books, often readers, spelling books, and Latin grammars. Children in those days went from primers directly to adult reading:

...how did children learn to read? The experiences of Adam Martindale, a Lancashire yeoman born in 1623, were probably the same as generations of children before his time and after. His godmother gave him an ABC when he was nearly 6, 'a gift in itself exceeding small and contemptible, but in respect of the designe and event, worth more than its weight in gold'. With the help of older siblings, and 'a young man that came to court my sister', he quickly mastered it, 'and the primmer also after it. Then of mine owne accord I fell to reading the Bible and any other English booke.' [54, p. 3]

It seems amazing to us, with the variety of children's books presently available, that there were no children's books for entertainment. Any entertainment from stories came from oral storytelling. Yet children still learned to read, and to enjoy reading, and were expected to do so. Much of the reason for this was due to religion, and to the concept of childhood prevalent at the time. Children were expected to learn to read the Bible for themselves, with England and its colonies being at the time Protestant. So while a child needed to read to understand the Bible, reading for entertainment was considered a waste of time as was, in fact, most play. Work was considered the proper way for children to occupy their time as soon as they were able. A child's mind was considered a *tabula rasa*, a blank slate, on which anything might be written. Therefore, a child's experiences were very important in fixing his character. However, the doctrine of original sin was also held; a child naturally tended to vice rather than virtue. It was obvious that a child had to be carefully led to virtue, and that any pernicious influence could easily take hold of him. Therefore, he had to be protected from vain pursuits, such as reading fiction, that is untrue, a lie, and therefore by definition sinful:

Education...was less necessary than decency: and decency did not include

reading for pleasure...The objection to light reading as a recreation was that it led to idleness and to false beliefs: that it was harmful as well as a waste of time. [22, pp. 42–43]

Another factor that discouraged light reading material was the high children's mortality rate. Educating children in virtue to prepare them for an early death was considered of vital importance; there was little time to waste.

These views of childhood, the empty slate, a leaning toward vice and the necessity of instilling virtue for rapidly approaching death, were only slowly overcome. They influenced children's literature heavily until the mid 19th century, and are still with us today in imprecations against comic books, popular music, and video games.

Even after the rise of children's books for amusement, the production of movable books for children was slowed by the fact that many movable devices require durable materials, meaning good quality paper. This is particularly true for the devices, such as pull-tabs, that must work without binding and have hidden mechanisms that cannot be mended easily once the book is assembled. As any parent knows, even modern pop-up books can be fragile. In addition, the manufacture of movable books was limited by the state of book illustration in general. Methods of producing clear line and bright color, while keeping the price of the book within the means of a family, were only gradually developed. Finally, those means and the ability to buy children's books were influenced by economic factors and in particular by the rise of an economically stable middle class.

3.1.1 The First Mechanisms (pre-1700): Wheels and Flaps

Since few books were made for children before the late 18th century, the earliest movable books were obviously made for adults and, with the scarcity of fiction, were non-fiction books. It is interesting to note that movable books predate printing. Two mechanisms were used in manuscripts: volvelles (wheels) and flaps. Both volvelles and flaps found their way from manuscripts into printed books soon after the introduction of printing, by 1476 in the case of

volvelles [103]. As is often the case with manuscripts and early printed books, use and time have destroyed or damaged a large number of examples, and it is likely that we have lost many early movable books, as movable books are even more susceptible to such damage than other types of books. Pages often survive only as *fugitive sheets*, or sheets that have been separated from the original book.

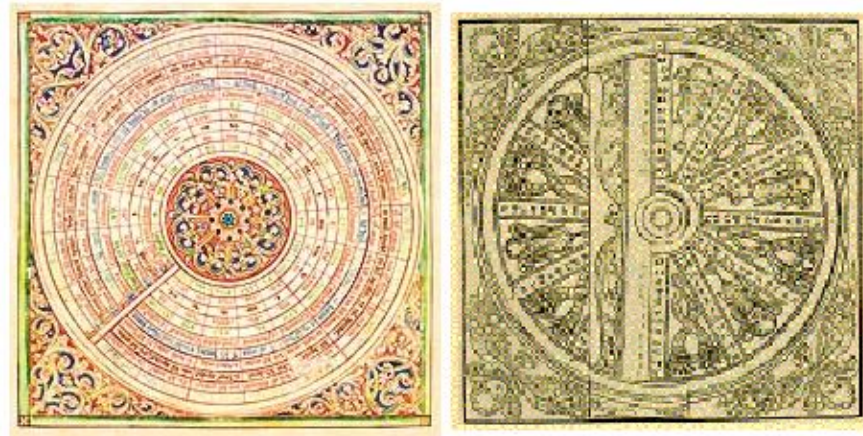


Figure 3.1: Various volvelles. On the left is a reproduction of a manuscript volvelle by Matthew Paris, used for calculating the dates of holidays. Photo courtesy Robert Sabuda [101]. On the right is a printed volvelle designed by Gabriel de Collange, in *Polygraphique et Vniverselle Escriture Cabalistique* by Johannes Trithemius, an edition of 1561. Photo courtesy Washington University of St. Louis Libraries [125].

The first movable mechanism used in manuscripts was the volvelle (from the French, meaning *to turn*) or wheel. Attached through its center to the page with a knotted linen string or a rivet, the volvelle could rotate independent of the page. There could be one or many wheels, each of which turned independently, and that could be lined up with each other and with marks on the page. The volvelle could also be a moving pointer instead of a full wheel.

Volvelles are particularly useful for doing calculations or presenting dense information in a compact form. For calendars or other tabular data, it is often easier to read a table by rotating a wheel than by following a row or column. Volvelles are used for computation by using nested wheels and quite complicated operations, such as astronomical calculations, can be performed

in this manner.² Another common use of volvelles was cryptography. On the right in Figure 3.1 is an example of a French volvelle used to read and write ciphers. Volvelles can provide rotating architectural diagrams that allow views from several angles [99]. Wheels were even used in fortune-telling books and the *Loofsbuch* by Paul Pambst (1546) used both wheels and dice for this purpose [103].

There are three notable names in the history of volvelles. The first was Matthew Paris (1236-1253), a Benedictine monk. He was the author of the first known movable manuscript, *Chronica Majorca*, that used a volvelle to calculate the dates of holidays. It was common at that time to have tables of holidays in circular form, but so far as we know Paris was the first to realize that it was easier to turn a paper circle on the book than to turn the heavy book itself. A reproduction of this volvelle is shown on the left in Figure 3.1 [94, 101]

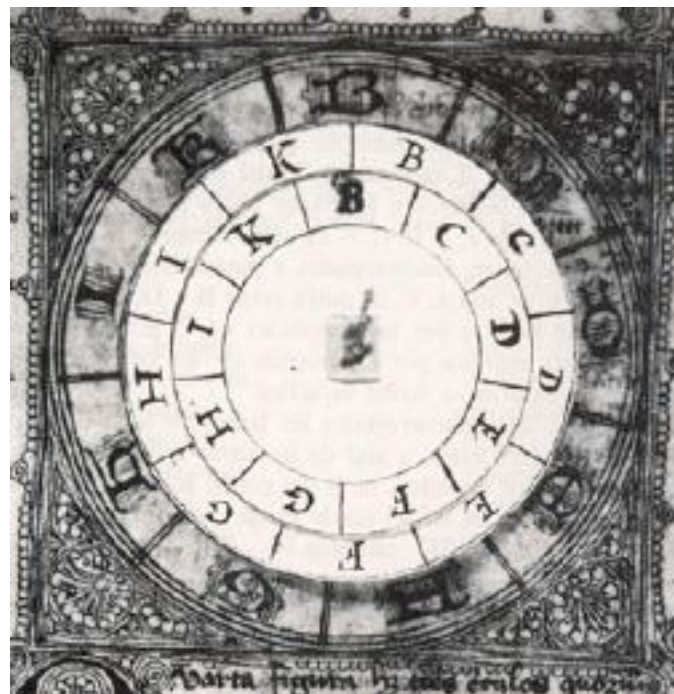


Figure 3.2: Lullian Circle. A figure from *Ars Brevis*, a work by Ramon Llull in manuscript form. This volvelle allows the reader to find all three-letter combinations of nine letters. Photo courtesy Centre de documentació Ramon Llull [16].

² The ultimate calculation volvelle is the circular slide rule. Although more accurate than a straight slide rule, as a long rule can be curved into a smaller space, it was never as popular as it did not fit into a shirt pocket.

The second important name in early volvelles was Ramon Llull, also known as Ramond Lully (c.1232-1315), a theologian and philosopher. His volvelles are sometimes referred to as Lullian circles and were used to illustrate his ideas about the *Ars Magna* (*Great Art*).

...a complex system, using semi-mechanical techniques combined with symbolic notation and combinatory diagrams, which was to be the basis of his apologetics in addition to being applicable to all fields of knowledge. [68, p. 1]

His desire was to encompass all knowledge in a single machine, with which one could prove or disprove any assertion (particularly in the area of theology.) In actual fact, his use of wheels was a system of combinatorics. For example, in one of his volvelles (Figure 3.2), two rotating wheels were positioned within a non-rotating circle. Each wheel, and the circle at the rim, was divided into nine areas, each labeled with a letter. The outer rim remained stationary, and all three-letter combinations could be produced by rotating the inner wheels that move independently.

When properly used, the triple layer of combinations of nine letters—which, as in the Cabala, signified the names of God—answered questions about all creation and even the future, as well as inquiries intended to settle religious disputes. [103, p. 1]

Finally, Petrus Apianus or Peter Apian (born Peter Bienowitz), a German humanist, produced *Cosmographica Liber* in 1524. This best-selling book was translated from the original Latin into several languages, was produced in 47 editions, and was reworked and reissued by at least one later author, Gemma Frisius. Covering cartography and geography with maps of the world, and in later editions incorporating a surveyor's handbook, it contained volvelles allowing astronomical calculations. Large, beautifully colored copies as well as small, easy to carry editions made it available to, and usable by, not only the rich, but the student and the sailor as well [118, 101]. Apian also wrote another book on astronomy, *Astronomicum Caesareum*, using volvelles as well, in which he was the first to note that the tails of comets pointed away from the sun. Figure 3.3 shows volvelles from both of these works.

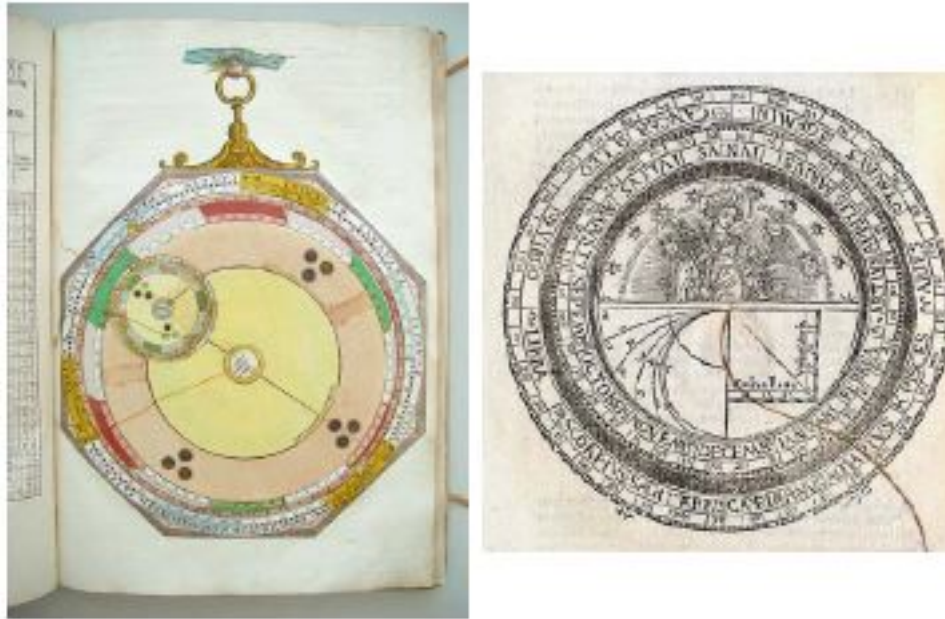


Figure 3.3: Volvelles in books by Peter Apian. On the left, a volvelle from *Astronomicum Caesareum* published in 1540. Image courtesy of Swiss Federal Institute of Technology Library [112]. On the right, a calendar volvelle from *Cosmographica Liber*, the 1545 edition. Image courtesy of the Museum of the History of Science, University of Oxford [82]

Flaps were probably introduced to manuscripts after volvelles, at least the surviving examples appear later. Flaps are made by adding an additional piece of paper to the book, either by gluing it over the sheet, or folding the sheet to provide extra layers and cutting away the upper layers to allow the reader to open the flap to expose the lower layers. The flap can be lifted to see underneath it, and then replaced. The flap was the first attempt to add three-dimensional illustration to books and was the beginning of attempts over the next four centuries or so to give book illustrations more depth. In addition, flaps allow for movement of sorts by providing a way for an illustration or text to be changed by lifting the flap.

The flap was used to greatest effect in anatomical books to allow layers of the illustration to be peeled away. An example can be seen in Figure 3.4. In many cases, the anatomical drawings were a “do it yourself” activity:



Figure 3.4: Examples of Flaps. On the left is an anatomical plate with movable flaps from *Ristretto Anatomico*, 1790, by Daniel Ricco, photo courtesy of the Library of Congress [67]. On the right, a later revision of *Beginning and Progress of Man* adapted for children and renamed *Metamorphosis, or, A transformation of pictures, with poetical explanations, for the amusement of young persons*, printed in 1814 in America, photo courtesy of the University of Delaware Libraries [120].

From 1538 onwards it is possible to trace a whole series of so-called anatomical fugitive sheets, depicting the parts of the body on a single sheet, or, often, as a pair of sheets, one male, one female. Sometime these were provided with the organs of the body arranged down the side of the sheet, so that they could be cut out and then stuck down (not always, alas, in the correct order) on a card beneath the figure. By lifting up the flap representing the trunk, one could then see how the internal organs of the body lay in relation to one another. They were often accompanied by a text describing the particular parts of the body. [83]

Some anatomical flap figures could be quite complex, such as:

...the famous Georg Bartisch *Augendienst* text on optometry printed in Dresden in 1583, in which the viewer can dissect an eyeball into five flaps, and then lift five more layers of a skull to view the optic nerves from above. [102, p. 12]

Other uses for flaps took advantage of their transformative, rather than their layering, prop-

erties. For instance in 1654, Benjamin Sand's *Beginning and Progress of Man* used a half-page flap to create a changeable picture. The illustrations taking up half of the page could be changed by covering or uncovering them with the flap [63]. The popularity of this book can be seen in the number of reprints including one adapted for children 160 years later and shown in Figure 3.4. Religious pamphlets used flaps to show the transformation of the Pope into a Devil, for the edification of Protestants. More prurient uses of a flap were quickly discovered and included such items as:

...a late 18th century watercolor of a lady, equipped with both another liftable skirt and considerable anatomical correctness. Liftable-skirt engravings were extremely popular in the late 16th century from the north to the south: one stereotypical Venetian courtesan found immense fame through the guise of ambiguously gendered undergarments and ludicrously tall shoes. [102, p. 12]

In addition to flaps and volvelles, some other forms that could be cut out and assembled from the pages of the book were developed in the Renaissance, such as games and astronomical instruments. Sundials were popular and were often meant to be cut out and pasted onto a wooden block.

Peter Apian included sheets for this purpose in several of his books, but like toys today, they often came “batteries not included.” While the sun powered the dial, it was missing components such as compasses to orient the dial for the correct time, and tiny pointers, or *gnomons* to catch the sun's shadow. Printed sundials and other paper instruments were also sold singly... [102, pp. 12–13]

But these were adult novelties and children's movable books had yet to be produced, largely because children's publishers did not yet exist. It was only in the 1700s that factors were right for the development of a separate children's literature.

3.1.2 The First Movable Books for Children (1700-1820): Harlequinades and Toilet Books

The idea of the children's book that entertains was born in the last half of the 18th century. Before that time, children read what adults read, with the exception of school texts or hornbooks for beginners. By 1820, there was a small body of what we would consider entertaining children's literature, influenced by the desire to guide children in the ways of rectitude—although that purpose was beginning to serve as a gloss to overcome the hesitancy of parents to allow their children pleasurable reading. Three primary changes led to the introduction of more playful children's books: the rise of the middle-class child, changes in adult views of childhood, and a flood of new stories arising in this period.

First, there were more children, and even more important, more children whose parents could afford to educate them. Families were large and life for the middle class child was much less apt to be cut short by disease. Jenner's first use of smallpox vaccination occurred in 1796, and medical advances were to continue through the 19th century. Better food was more generally available, leading to better nutritional health. With the rise of the British Empire, England had enough people who were well-off enough to give their children toys and books.³ Publishers were happy to fill this demand, and did well for themselves by doing so. They were helped by changes in the law that eliminated censorship and established copyright.

Second, there were changes in the way children were viewed in society that allowed parents to think that giving children more toys and books was a good idea. Puritanism, with its belief that life was simply preparation for death, was weakened by the general prosperity. The rise of Romanticism promoted the view that the child was closer to nature than the adult, and since the child was so newly come from heaven, closer to God. The view of the child as naturally evil began to be replaced with the view of the child as innocent; children were seen as possessing a natural

³ Poverty was horrendous at the time and throughout the Victorian period following, as any Dickens reader knows. But the fact that there were so many poor children, whose lives were nasty, brutish and bookless, does not preclude the rise of a middle class that was larger than ever before.

simplicity, and what would culminate in the Victorian sentimentality toward children began to develop. In addition, children were allowed to be children longer. School years were extended for middle-class children, and the child who might have been placed in apprenticeship at the age of seven instead went to a village school or academy, and possibly on to college. In addition, there began to be a realization that children had different needs based on age, for instance the perception that a teenager was neither an adult nor child, but something else. Not coincidentally, the early 18th century saw the rise of the child-care manual, in which appropriate ages for various activities were defined for the first time [54].

Finally, there were new stories that began to enter the market, both from the oral tradition and from adult books. In both Europe and America, a large body of potential children's literature had existed in oral form. When this was put into print, it produced a flood of stories. Mother Goose, a compendium of rhymes from "barrack room and alehouse songs, bawdy ballads and ribald love songs, political squibs, stage plays, street cries, ancient rituals, proverbs, riddles" [54, p. 63] became wildly popular in a variety of forms in the late 1700's. The fairy tale began to be published for children at about the same time. The tales of Charles Perrault, a French author, for instance, had been on the market since 1697, but in 1772 "were issued simply for children's delight, without the French alongside the English to serve as a token lesson book" [54, p. 71] and subsequently were reprinted in a multitude of editions. The most enduring of those stories were Cinderella, Little Red Riding Hood, and Sleeping Beauty, and are still loved by children, now in Disney productions. Other fairy stories followed, often to condemnation by the moralists, who saw them as dangerous for the young mind. But the young mind loved them, and doting parents bought them.

In addition, it must be remembered that novels for adults were a new development at that time as well, and that some of these novels were able to make the transition to a child's library. In particular, two publications intended for adults in the early part of the 18th century, *Robinson Crusoe* (1719) and *Gulliver's Travels* (1726), became staples of children's reading and were quickly adapted in an easier form for young children. "The novel-reading habit reached the

nursery almost before grown-ups had acquired it.”[42, p. 8]

For most youngsters in England, the medium for these adaptations, fairy tales, and children’s literature in general was the chapbook. Starting from about the mid-17th century, the chapbook was the mass market paperback of the time. Inexpensive, produced in large numbers, and appealing to children since they contained illustrations, chapbooks could be purchased from peddlers in any part of the country. They were so widely distributed that in the early 19th century, one publisher “was reputed to be able to sell two and a half million copies of *Of Rush’s Murder*.”[54, pp. 40–41] Made from cheap, durable cardboard, usually with 16 pages and often costing a mere halfpenny (about 50 cents in present United States currency), chapbooks recounted for adults the latest murder or hanging and were popular literature. Chapbook publishers realized the potential children’s market early and began printing ABC books alongside adult titles when the format first arose, and they soon became the vehicle for fairy tales, nursery rhymes and historical romances.

This market for children’s books made openings for publishers operating at the upper end of the price scale as well. John Newbery, the first publisher to produce children’s books exclusively, opened for business in about 1744. Newbery recognized the profit to be made from children’s books and developed ways of marketing that are still being used, such as aggressive advertising and including small toys with book purchases. His books were of far better quality in both printing and binding than the chapbooks, and appealed to children with their use of higher quality illustrations and brightly colored end-papers.

Even with the rise in popularity of children’s books, it took some time for movable books to become important in the children’s market. Movable devices are a form of illustration, and the state of illustration was still quite crude around 1800. The modern world takes high quality color printing in children’s books for granted, but the necessary technology was not invented until the last part of the 19th century. Woodblock printing, that lacked the ability to render fine detail, was the rule for most books for children during the 18th century, although copperplate was sometimes employed for more expensive volumes.⁴ Since they were expensive to produce,

⁴ Both woodblocks and copperplates were hand-engraved and therefore labor-intensive. Copper gave a finer line,

illustrations were often reused. For instance, if a publisher happened to have a woodblock of a dog, it might be inserted at any point in any book in which a dog was mentioned, or a wolf, or for random use of space even if no dog was written about at all. A giant move forward in illustration quality came when lithography was invented in 1798. Lithography could produce much finer lines and detail and was used increasingly throughout the 19th century, although not completely replacing wood blocks and copperplate until the 20th century. These advances in producing fine illustrations were still limited to a single ink color, usually black. All coloring was done by hand.

Around 1800:

The colour was put on by droves of children working together; so many put on the red patch, so many the blue, and the prints were passed on thus till the final gay thing was completed. Most of the colour-work thus done was not comparable in finish or delicacy with the very similar hand-colored aquatints of a few years later. But it was surprisingly good in the better-class volumes, and the method continued long in use; my father saw it being employed by his father—that is, about 1855-60. [22, p. 202]

Hand-coloring had one major advantage: books were sold both with and without color and uncolored books were considerably cheaper, allowing a wider range of families to purchase them.

This period from 1700 to 1820 saw little in the advance of actual paper engineering. Wheels and flaps were still the only devices used. The primary development during this time was the migration of movable books into the hands of children in the form of the *harlequinade*. *Beginning and Progress of Man* had used a half-page flap and the harlequinade was an extension of that form. Introduced in about 1765 by Robert Sayer in England, the book's paper was doubled, and cuts were made both horizontally and vertically across the page through the upper layer. This produced a picture that could be viewed with any of the four flaps down or up. The text told the reader which flap to lift to reveal the next portion of the text and the accompanying altered illustration. Figure 3.5 shows one of these original books. These ingenious books are also called *turn-ups* or, in the United States, *metamorphoses*. The name harlequinade comes from but the material was so much more expensive that, even given that the copper was reusable and less prone to wear, it could not be used for chapbooks. The woodblocks used for chapbooks were often done quickly by less skilled artists and used until well-worn as well.

the fact that the earliest examples featured a hero called Harlequin. (Harlequin was a common theater character of the time, and Sayer was a publisher of theatrical prints. Harlequinades were sometimes based on the plot of the latest play.) Early examples are extremely rare, as they were printed on poor-quality paper. While harlequinades were the first movable books published for children, many were aimed at adults as well. The making of harlequinades was a popular family activity, one of the few instances in history where movable bookmaking is mentioned as an activity in which children participated. The flaps are easy to make, so the paper engineering is easy. The trick is to make a picture in parts that create the desired effect for the story. Some of these handmade pages still exist [54].



Figure 3.5: An example of a harlequinade *Queen Mab or The Tricks of Harlequin*, #6 by Robert Sayer, and published in 1771. Photo courtesy Ellen G.K. Rubin [94].

Harlequinades are a good example of the use of flaps to produce motion:

Because the figure (usually Harlequin) lies over the break lifting the flaps creates an impression of a transformation being effected. The figure of Harlequin becomes animated, as in later cartoon illustration. The careful overlaying and underlaying of the figures in dramatic poses may suggest motion. [91, p. 9]

Harlequinades have never died out. They were still being produced in their original form

throughout the 1800's and survive today in the lift-the-flap books that are very popular with pre-school children. They have the advantages of being easily manipulated by little fingers, inexpensive to produce, and harder to damage than the more complex pop-up books. Harlequinades also survive in the *mix and match* books that allow children to pick parts of several characters and create a new picture by taking, for example, heads, bodies, and feet from the split images [107].



Figure 3.6: An example of a page from Grimaldi's toilet book, showing the operation of the flap. This is a later printing, from around 1840. Photo courtesy Philadelphia Rare Books and Manuscripts Company [88].

Movable devices also began finding their way into use in traditional book types. One popular non-movable early book form for children was the *emblem book*. In the emblem book, an animal or artifact was shown as a symbol for some moral quality. For instance, the bee might be pictured as an emblem of hard work, along with a suitable verse. The original book of this type was John Bunyan's *Divine Emblems, or Temporal Things Spiritualized* [22].

By adding flaps to an emblem book, the reader could change an illustration of the emblem into a picture or text of the virtue being illustrated. This created the first movable book to rise to "best seller" status, *The Toilet*, published by Grimaldi in the 1820's. Inspired by toilet items on a dressing table, this book extracted moral lessons from each item, with an accompanying illustration that, by lifting the flap containing it, changed the picture from the toilet item to an illustration of a virtue [42]. Figure 3.6 shows a page from a later reprint of the book, that used

text instead of the illustration of the virtue. (That the reprint was made 20 years after the original was published indicates the lasting popularity of the toilet book.)

3.1.3 Early 3-Dimensional Effects (1820-1850): Slots, Panoramas, and Peep-shows

Flaps were a beginning attempt to provide motion and depth in book illustration, and to merge toys and books for children by providing ways in which books could be manipulated to produce new effects. These were followed by several other early types of movable devices in children's books as well, that combined books with toys.

Paper doll books are one early example. These were developed around 1810. These books are still popular today but did not begin life as the “cut out a costume and place it on a doll” form currently found. Rather they consisted of either a series of scenes with the costume and a hole for the head, through which a head on the last page could be viewed, or a paper head that could be placed in a slot on a page that contained a costume and a scene. About 1830 these gave rise to the popular *slot books*. These took the form of paper figures that could be placed in a scene by putting them in slots cut in the page.



Figure 3.7: An example of a panorama book: a reproduction of Lothar Meggendorfer's 1887 *International Circus* [73]. For a closer view of one panel, see Figure 3.10.

While flaps, volvelles, and slots are devices that make a book movable or changeable, there are other kinds of movable books in which the form of the book itself can be changed. A few

examples developed during the early 19th century and still being produced will demonstrate the concept: panoramas, peep shows, and carousel books.



Figure 3.8: A modern example of a handmade carousel book *New York Dreams* by the artist Andrea Dezsö. Both the opening and the opened book are shown. Photo courtesy of the artist [25].

The *panorama* is a book that, rather than having the usual form of a cover and pages, can be unfolded into a long zig-zag form that can be many feet long. This actually an old form, re-invented for children. This form is ideal for telling stories that have long scenes that would not fit into a regular book, a battle-scene or a train for instance. The example in Figure 3.7 is a circus, and the panorama format allows the entire circus to be spread out at once. Panoramas sometimes employed slots and paper dolls that could be put in the slots. In this way an entire house of paper dolls could be moved about, or a set of cats dressed as people could be rearranged on the pages [45].

The form of the *carousel book* (sometimes called a *star book*) allows the book to be folded back on itself, creating a star-like shape. This is also a method for producing three-dimensional effects, since the heavy cardboard pages can have multiple shorter pages between them. These

books are sometimes made without the shorter pages, and fold into the form of a building for use with paper dolls.

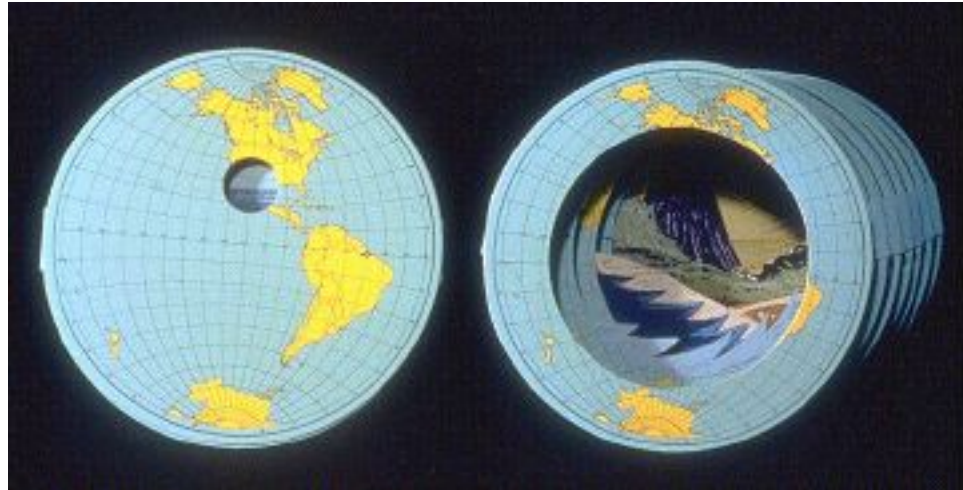


Figure 3.9: A modern example of a tunnel book, *Tunnel Map* by the artist Carol Barton showing both the outside of the book with the peep-hole, and the inside construction. This is an unusual circular form of the book type. Photo courtesy of Colophon Pages [19].

Still another type of 3-dimensional effect can be produced from an accordion-like method of attaching pages called a *peep-show*, also commonly known as a *tunnel book*. (Carousel books are sometimes called peep-shows as well, leading to confusion.) Each layer of the scene is attached to one of the folds, and a hole in the cover allows the scene to be viewed at the correct angle (see Figure 3.9). This book form grew out of the peep-shows that were a part of traveling carnivals:

These were often quite elaborate constructions which depicted scenes from famous stories or legends or topical events, which it was hoped would appeal to provincial or rural populations. The showmen sometimes made the cardboard scenes and figures themselves, changed the tableaux to those which they thought would attract the biggest crowds, and then charged inquisitive patrons a penny or so to stare in at the scene through the peep-hole. [42, p. 22]

In the book form of a peep-show, the viewer looks at the scene through a hole in the cover (see Figure 3.9). Peep-shows can also be used as part of a page within a book, and pulled out for the full effect. The illusion of depth in a peep-show can be quite dramatic.

3.1.4 The Golden Age of Movable Books (1850-1914): Tabs, Scenes, and Transformations

A look at the books for (or read by, at any rate) children between 1850 and World War I reveals the amazing burst of creativity of the period: *Moby Dick* (1851), *Hiawatha* (1855), *Tom Brown's Schooldays* (1857), *The Water Babies* (1863), *Alice's Adventures in Wonderland* and *Hans Brinker; or, The Silver Skates* (1865), *Little Women* (1868), *The Adventures of Tom Sawyer* (1876), *Uncle Remus* (1880), *Treasure Island* (1883), *Heidi* (1884), *King Solomon's Mines* (1885), *The Blue Fairy Book* (1889), *Pinocchio* (1891), *The Jungle Book* (1894), *The Wonderful Wizard of Oz* (1900), *The Tale of Peter Rabbit* (1902), *Peter Pan* (1904), *The Wind in the Willows* (1908), *The Secret Garden* (1911), and *Tarzan of the Apes* (1914) [54]. As publishers and authors found they could make a living from children's books, the status of children's book authors in society was elevated, and the trade exploded. Most important:

Fiction was now by a long way predominant over fact, magic was not rebuked but at large, nonsense was free. Children could go back to the enchantments of the Middle Ages without being told that they were really the work of the Devil; to Aesop and traveller's tales with the knowledge that such fables were not true but were thoroughly worthy of belief and love; to folk-lore with open rapture in the rogueries of the Booted Cat and the decapitation of ogres, without any warnings about superstition or ignorance or unreality; to fun, without being told not to be silly. [22, p. 290]

Attitudes were right for books that were pure fun, and movable books could supply that. Paper engineering had started to develop; children's movable books included paper doll books, books containing flaps (such as harlequinades), and books that were not in the standard format: panoramas for instance.

The next developments required for the advancement of movable books were enhanced printing techniques (including color printing) and good quality paper. Most movable books (if made in quantity) have to be printed well and carefully manufactured in order to allow more complex mechanisms to function correctly. Proper registration in printing is vital in order to allow two-sided printing, and die-cutting is valuable to keep hand-labor to a minimum. Color is

important for movable books as well, since with more life-like illustrations, animation and depth are shown at their best. For movable books, the paper must stand up to rough treatment. Some devices also require paper that is smooth enough to move easily when pieces connect or rub against each other, and stiff enough to stay straight when force is applied to create the motion. For more than the simplest movable devices, therefore, the manufacturing process is of great importance. These prerequisites were finally met in the Victorian era.

As in so many other areas, the industrial revolution drove changes in printing toward automation and powered machines:

...changes to books and book production took place at a rapid clip. Major innovations were introduced in every facet of the printing operation: typesetting, composition, inking, impression, and binding. By the end of the [19th] century, a web of integrated machines was producing books and other printed materials at rates that would have been unimaginable in the days of hand-composition and impression. [52, pp. 113–114]

This increase in the quantity of books produced was accompanied by a similar increase in the quality of the product. The development of lithography by Alois Senefelder in Germany in 1798 allowed better reproduction of images, and color lithography followed closely thereafter. Germany became the printing capital of Europe and much of the production of movable books shifted to Germany until World War I.

New advances in paper engineering began around 1855 [42], as publishers looked for new forms to capture children's attention, and the period between 1880 to 1915 is commonly called the Golden Age of Movable Books [94]. Because the technological advances had come in the form of printing techniques, color, and paper, the golden age was led primarily by publishers, although one artist stood out as an exception. The publishers were Dean & Sons, Raphael Tuck, and Ernest Nister; the artist was Lothar Meggendorfer of Germany, who was the first true paper engineer.

Dean & Sons of London was founded in the 18th century, began publishing movable books in the 1840's, and became one of the premiere producers of these books, publishing as many as 50 titles between 1860 and 1900, and having a special department in charge of this part of their

operation.

Also located in London was the publishing firm of Raphael Tuck (and later his sons). Tuck was born in Germany, but left for political reasons and moved to London where his books were designed although his printing was still done in Germany. His company produced movable books from about 1870 until 1952. Almost 100 movable books were published by Raphael Tuck & Sons during that time, about 30 of which were panoramas, of which they were the major producers [78].

The third publisher, Ernest Nister, was the son of a pastor. Being a businessman, he purchased a small Nuremberg printing shop in 1877:

At the time of his sudden death on 26 May 1909, he was able to leave to his son of the same name, a firm which employed some 600 people. This printing business was capable of producing work by all the major processes of the time...[63, p. 73]

His firm published anything printable including cards, calendars, books, and hundreds of movable books, for the English, American, and German markets. Although he ran a large business, he helped design some of the movable books he produced.

The exception to publisher driven advancement was Munich artist Lothar Meggendorfer (1847-1925). His work was ingenious, comedic, and, above all, different from that produced by the large publishers. While the movable artists employed by publishers made standard Victorian scenes of children playing or illustrated the usual fairy tales, Meggendorfer created funny characters like the Dancing Master (Figure 3.12), an angler who catches a fish too big to pull in, or an ugly woman looking into a mirror. Meggendorfer is still revered in paper engineering circles, and the annual prize of the Movable Book Society is named the Meggendorfer prize in his honor.

The first important new movable book device to be created during this period was the *scenic*, sometimes called a *lift-up*. Figures and scenes are arranged in overlapping layers and can be pulled out to separate them in space to produce a three-dimensional effect, a peep-show book without the peep-hole and surround (see Figure 3.10.) All of the major publishers had their own



Figure 3.10: An example of two scenic books with different methods of opening the scene. On the left, *The International Circus* by Lothar Meggendorfer [73]. The entire book is a panorama (see Figure 3.7), and each panel is a scenic, opened by the reader. On the right is a Dean & Sons scenic from *Aladdin and his Wonderful Lamp*, in which the scene is opened by pulling a ribbon. Photo courtesy of Robert Sabuda [100].

versions of these scenic books, often distinguished only by the method of pulling the layers apart. Dean & Sons incorporated a ribbon to pull the layers, while in Tuck's scenics they were pulled apart by hand. Nister's were the most technically interesting, as they were attached to the facing page by a tab, and opened automatically as the page was opened, anticipating true pop-ups.

While scenic books anticipated the depth of pop-ups, there were also advances in producing motion as well. One of these was the *transformation*, the second significant new device in movable books first produced in 1860 by Dean & Sons. Transformations are illustrations that change from one picture into another. To produce this effect, two pictures are fitted together so that rotation or sliding of the picture sections can cover one and reveal the other. This can be done in several ways. In one, the first picture is cut on the diagonal through the center and the two pieces slide away into the corners to reveal the second picture underneath. Another features a dissolving picture in which the two pictures overlap each other in either vertical or horizontal



Figure 3.11: An example of a transformation; the summer scene turns to winter. Photo courtesy Adriaan Heino [45].

sections. Yet another is a circular revolving picture that is essentially two interlocking volvelles. Tabs can be installed so that the reader can simply pull the tab to cause the motion. Figure 3.11 illustrates the dissolving version of a transformation.

The third major design development was the pull-tab. This has been mentioned in connection with scenic books and transformations, but they could also be used with a clever combination of hidden levers to cause parts of the illustration to move. Meggendorfer used several mechanisms, but was most famous for his pull-tabs. A diagonal tab could produce many simultaneous, or even delayed effects in the picture. Many of his creations contain 5 or 6 motions produced by a single tab. Figure 3.12 shows one such Meggendorfer picture and the mechanism behind it.

3.1.5 True Pop-ups Emerge (1914-1979)

The First World War was the end of this first golden age of movable books. Not only did the cooperation between Germany's fine printing technology and the British market end, but the use of labor (making movable books requires considerable hand-labor) for what could be seen as peacetime pursuits became less tenable. In a world consumed by war, books for children suffered in general. Publishing picked back up after the war, but movable books languished, perhaps as the result of labor scarcity and the slow recovery of the German printing industry.



Figure 3.12: The Dancing Master. An example of a pull-tab book by Lothar Meggendorfer, also showing the type of mechanisms used by the artist. The terpsichorean fiddler plays his instrument and dances, all with one pull-tab. Photo courtesy The Wonderful World of Pop-up and Animated Books [127].

It was not until the end of the 1920's that the next metamorphosis in movable books occurred: true pop-ups. Pop-up books are a particular type of movable books that provide enhanced depth and motion. They use types of movable book devices that open automatically and that create three-dimensional objects that can be viewed from multiple angles. Flaps, transformations, pull-tabs, and volvelles must be manually operated, while pop-ups are operated by the opening of the book's page. The scenic can come close in three-dimensionality, and some scenics do open automatically. But scenics only look three-dimensional from one angle since they are composed of multiple flat layers that give the effect of depth. Pop-ups can be constructed so as to fold up into a true three-dimensional form.

True pop-ups appeared in 1929 with their first publisher, S. Louis Giraud. Giraud was English and employed by the *Daily Express* newspaper as a book publisher. The newspaper made extra money and enlarged its readership by offering special publications of various books, some of which were children's books, and Giraud was placed in charge of these publications. He began producing pop-ups, or as he called them *Bookano* (perhaps a combination of *book*

and *meccano*) or *living models*, in annual issues timed for the Christmas market. He produced 17 of these annuals, the last of which was published in 1949 after his death. They were priced for the average reader, and became extremely popular. It is a tribute to their popularity, and to Giraud's management skills, that the series lasted through World War II, in spite of paper and labor shortages.

What was the reason for this popularity? It certainly was not the quality of the Bookano production. Unfortunately,

...production standards had to be kept pretty basic—coarse absorbent paper; crude photolitho printing and colour reproduction; cheap covers and bindings which (sadly) have rarely endured the ravages of time unscathed. Undoubtedly in their day the books were enormously popular with children and received much rough handling; as a result, those that have survived invariably look shabby. [23, p. 220]

Their literary and artistic qualities were not of the best, either,

...his own prose style as a children's writer, and that of his other contributors, can at best be described as vapid; at worst, glutinously sentimental or trite. The verse is rarely more than doggerel and the pictures...are adequate rather than inspired. It is really only the pop-ups that distinguish these books from the morass of cut-price juvenilia that appeared in the penny bazaars... [24, p. 251]

This popularity then came down to those pop-ups, that exhibited almost all of the pop-up devices currently in use. (See Figure 3.13 for two examples.) It was an amazing technical leap.

Whereas all the earlier movable books had been developed or refined from [scenics, pull-tabs, and transformations]...Giraud stumbled almost by accident upon a completely new way of devising three-dimensional effects—the first “true pop-ups” in fact...Unlike all previous movable books, the best of Giraud's popups stand four-square on the opened pages, truly three-dimensional, and so can be viewed from literally any angle. [23, page 220].

But it was not Giraud who invented the devices used in his pop-ups. A man about whom little is known named Theodore Brown brought him the idea, although Brown had little idea of what to do with it, other than advertising brochures or toys. Giraud, however, being a publisher,



Figure 3.13: Left: A replica of an early pop-up—one of Louis Giraud’s Bookano pop-ups. The clown spins on a bar as the book opens. Photo courtesy Ellen G.K. Rubin[94]. Right: Pop-up from Bookano No. 9. This photo gives some idea of the depth of Bookano pop-ups. Photo courtesy University of North Texas Libraries[121].

knew the market for movable books and understood the attraction that pop-ups could provide. Together they patented the designs in 1929. Mr. Brown evidently helped with the first two books, then promptly vanished. (One of Giraud’s assemblers said that he may have died at this time.) It was Giraud who wrote parts of the books, hired writers and illustrators, published the books, did the paper engineering, and set up the facilities for manufacture. Oddly enough, Giraud previously showed no interest in children’s books for other than business reasons or even in telling bedtime stories to his own children, and was never seen “with scissors and paste striving to achieve new effects”[24, p. 256]. He was no illustrator, and hired illustration from outside, but his talents as a paper engineer in a new field were undeniable.

Pop-ups were instantly popular with children, and were copied by many publishers, patent or no, becoming a staple in children’s books. Around 1932, one of these publishers, Blue Ribbon Books in the U.S., was responsible for calling these books *pop-ups*, the name by which they are now universally known.

Pop-ups produced between Giraud’s death in 1949 and 1979 were common but fairly forgettable. However one Czech artist, Vojtěch Kubašta (1914-1992) made pop-ups an art form and inspired many modern paper engineers. Kubašta, an architect who became a book illustrator, was a talented artist in many media and was well-known in his own country. Czechoslovakia at



Figure 3.14: A 1961 pop-up by Vojtěch Kubašta. The pop-up castle is a fold-out of the back cover of the book containing the story. Two separate knights on horseback, not shown, can be made to joust in the foreground. Photo courtesy Ann Montanaro and Rutgers University Libraries[79].

the time was producing some of the best children's books in the world, "creating native and folk images with bold colors and lines." [93, p. 27] Beginning in the early 1950s with advertising cards, Kubašta developed a unique style of pop-ups, and began to work with Artia, the state publishing company, to produce children's pop-up books. Exactly how many books he created is not known:

The sheer number of titles he designed continues to confound contemporary paper engineers. Today, a single pop-up book, from concept to publication, can require up to two years to completion...Kubašta illustrated and paper engineered over ninety books between 1955-1965, and collectors and scholars are still discovering titles that were not recorded. [93, p. 31]

One of his Artia pop-ups is shown in Figure 3.14, a castle rising from the back cover of a book about a medieval tournament.⁵

⁵ I have a special love of this pop-up. I first saw it in the library, was able to open, hold and examine it, and what initially struck me was how complex it was. However, on closer inspection, I realized that it was made completely

While initially unknown outside Eastern Europe, Kubašta's later works were exported all over the world, and he illustrated pop-up books for Disney (although his name never appeared on them) that were manufactured by Artia. Without leaving Czechoslovakia he influenced a new generation of paper engineers.

...Robert Sabuda, the well known contemporary illustrator and pop-up artist, remembered receiving his first Kubašta pop-up book when he was ten years old, "It was *Cinderella* and I couldn't believe that a pop-up could have such beautiful artwork. My whole notion of what a pop-up book could be changed forever that day." [93, p. 38]

It was not only children who noticed Kubašta's work. Waldo Hunt, the owner of Graphics International, a company that did printing and brokered book sales, also discovered these books, and wanted to import large quantities—a million books. Unfortunately, Artia could not export in such quantity, as the Czechoslovakian Five Year Plan did not allow for it. Hunt began producing his own pop-up books, and in 1974, after Hallmark bought Graphics International, he started a new company named Intervisual Communications (ICI). This was not a publishing, but rather a packaging company. Most pop-up books are now produced by packaging companies, and ICI has been one of the largest having, for instance, introduced 40 new titles in 1990 alone [115, 105]. Packagers are used in pop-up production to bring together illustrators, authors, paper engineers, printers and assemblers, and to sell books to multiple publishers internationally. The process of creating a modern movable book is more complicated than most publishers wish to take on themselves.

Most publishing houses do not have the expertise (nor the time) to design and execute a movable book from start to finish. It's bad enough that they have to spend so much time copy editing and color proofing their flat picture books. But correcting die moulds and overseeing assembly, too? Forget it! [95, p. 1]

from v-folds and tents (see Chapter 5), with a few connecting structures, and well within the capabilities of the program produced for this study. The paper engineering in fact, is quite simple, but quite appropriate to the subject and perfectly done—it is the artistry of the thing that makes it look complex and dazzles the eye. Viewing this pop-up convinced me that the pop-up devices selected for inclusion in the program could be used to make very complex pop-ups.

Packagers have helped support the growth in complexity and popularity of modern pop-up books, as their special expertise allows the development of books that publishers are not equipped to handle, and they can aid the beginning paper engineer with the details that are hard to learn for oneself.⁶

3.1.6 The Modern Pop-up Book (1979-present)

Some have termed the years since 1979 the second golden age of movable books, because of the variety, complexity, and number of these books produced each year. There are several trends that distinguish modern pop-ups from those produced before about 1979. First, modern pop-ups contain a larger quantity of devices, and often mix in types of devices including those that predate pop-ups, such as volvelles, flaps, and transformations. In addition, there is an increased complexity of devices. Because of this, the term “pop-ups” is often used to mean all movable devices, not just those that are technically and narrowly considered pop-ups. Children think of all movable devices as pop-ups, and use a combination of them in their work, just as modern adult paper engineers do. Finally, the rise of the modern paper engineer and artist that started with Meggendorfer and Kubařta has led to true “stars” of the pop-up world.

The book that might be considered the first of the modern pop-ups was published in 1979. *The Haunted House* [85] was a collaboration between illustrator Jan Pieńkowski and paper engineer Tor Lokvig, and combined several devices on each page, including flaps, pop-ups, volvelles, and other devices. It was an immediate success, and won the Kate Greenaway Medal for illustration⁷ in that year. A view of one page of this book can be seen in Figure 6.6.⁸

⁶ Experienced and famous paper engineers/illustrators often deal with the publisher directly. The advantages of using a packaging company are that it has the experience to deal with the publisher and the details of production, and that it sells the entire printing at once, thereby giving the paper engineer her royalties in one large check. One disadvantage is that the check is smaller; like middlemen everywhere, the packaging companies take a cut of the book price [124, 95].

⁷ The Kate Greenaway Medal is the annual British award for children’s illustration, and the equivalent of the Caldecott medal given in the United States.

⁸ I included this book in user testing and therefore viewed it with children ten times (two times with each child). I was still seeing new things in the illustrations or noticing connections between pictures, such as characters that show up repeatedly, at the end of testing.



Figure 3.15: An example of a recent pop-up book page (*Dinosaur Babies* [62], that is an excellent example of both multiple and varied mechanisms on a single page. In addition to the large tyrannosaurus rex popup, the smaller duckbill dinosaur turns its head as the page is opened. A pull-tab on the left side controls the movement of a small dinosaur in the background. A second tab operates a transformation that reveals a hidden dinosaur. Several flaps show hidden pop-up dinosaurs on the right side.

The 1980's saw the rise of Ron Van der Meer, a trained artist who produced several groundbreaking works, including *The Art Pack*[32], a book aimed at adults interested in art history and theory, illustrating such concepts as perspective (with pop-ups) and color (with a wheel). This work includes not only pop-ups (one of Vermeer's studio for instance) but a pack of postcards of famous artworks, and an audio-tape.

In 1996, Robert Sabuda, probably the best-known modern pop-up artist, published his first work, *The Christmas Alphabet* [97]. Mark Hiner, another paper engineer, says of him, "I still don't understand how he managed to include mechanisms that printers have always told me were impossible to die-cut!" [51] Sabuda has continued to amaze with versions of *The Wizard of Oz*

[4] and *Alice in Wonderland* [13] among a growing body of work. Figure 6.8 shows a page from Sabuda's *Alice*.

The evolution of the pop-up book has returned it to the adult sphere where movable books originated. Books such as *The Pop-up Book of Phobias* [39] by Matthew Reinhart, another artist of note, *The Pop-up Book of Sex* [72], and *Graceland: An Interactive Pop-Up Tour* [81] are examples of this trend [126].⁹

In a world dominated by mass-production, it is important to note that even popular pop-up books are made by hand. The process begins with a hand-made design, often a collaboration between the paper engineer and illustrator. Usually the paper engineer works with paper, glue and scissors to produce the first designs. The paper engineer produces a *working white* sample of the design with all the pieces, in uncolored form, that is sent to the printer for pricing, since the pricing is largely determined by the number and size of pieces to be cut, and such details as the number of glue points, that is, the number of places where pieces will have to be glued in assembly. A final copy containing all the art-work and die-cutting instructions is produced by both illustrator and paper engineer for the printer; this step is often done on a computer. The paper engineer must produce not only the pieces to be die-cut, but directions on assembly [43]. The printers and assemblers often work near one another to minimize shipping time and costs, therefore locations to do the assembly are chosen that have the facilities to maintain very complex printing processes (since pop-up books are made from heavy card-stock and the printing and die-cutting are technically advanced), and a population of hand assemblers. The final die-cut pieces are put together by the assemblers, who work in an assembly-line fashion, each doing one folding or gluing task. This is often a village activity, and can employ more than 100 people. Columbia and Bolivia were important centers at one time, but most pop-up printing and assembly is now done in Singapore, China, and Malaysia. For a book like Maurice Sendack's *Mommy?* with a print run of 500,000 copies, and employing a writer, an illustrator, and a paper engineer, this process is

⁹ Adults as much as children are attracted to pop-ups, I have noticed. There are many pop-up books in my office, and grown-ups are constantly looking at them. Moreover, many pop-ups are currently published specifically for adults, and even children's pop-ups are marketed primarily at Christmas, to attract the children's relatives.

elaborate [126]. However, as Robert Sabuda says, in some sense pop-up books are still handmade:

Children always seem to get the impression that I actually make every single one of my books by hand. Obviously I don't...but I am always happy to tell them that someone else does. All pop-ups are indeed made by hand, so someone really does fold each piece, add a spot of glue, and carefully put it into the page. Maybe that's why I love making pop-up books. Each one goes from my hand creating it, to the pop-up assembler building it, to a young person's hand enjoying it. [96, p. 11]

As a complement to mass-produced pop-up books, there are also producers of *art books* who make the entire book by hand, sometimes in single volumes, sometimes with limited editions of a few hundred books. These can be movable books (often such forms as panoramas) or include movable devices. Figures 3.8 and 3.9 are examples of two such books. Such personal expressions are better examples of movable books as craft, if much less common.¹⁰

Paper engineering, then, can be considered a craft, both in its professional forms, and by those who practice it for artistic expression, including children. As a craft, it shares with other crafts previously discussed a tradition of knowledge, skill, and appreciation.

3.2 Pop-up Making as a Representative Craft

Chapter 2 presented a framework of craft learning and practice and examples from sample crafts were explored. This section examines paper engineering in terms of that framework. To do this, it is necessary to examine both how the paper engineer learns her craft and how she practices it. As there exist accounts of professional paper engineers, it is useful to look at these first in order to see the patterns that emerge.

Many paper engineers start as artists or illustrators and turn to movable illustrations or bookmaking in general when they find that static, flat pictures are not what they are interested in doing. This can happen at almost any age, but most pop-up makers start as adults. Carol Barton, a book artist and pop-up making teacher who began her career as a painter says that she

¹⁰ And terribly expensive to buy, with books costing in the hundreds and even thousands of U.S. dollars.

was fascinated with “the mechanics and sculptural qualities of the pop-ups.”[2]. Bruce Foster has been a paper engineer for several professional books but:

...missed out on pop-up books during his childhood. He went to the University of Tennessee, attended art school and worked for decades as a graphic designer before seeing his first one in the 1990's...Foster, who has always been fascinated by the three-dimensional, was instantly intrigued: “From the first time I saw it, I really wanted to do it. I thought it would be a great way to combine my three-dimensional skills with the skills I already had.” [126]

Mary Beth Cryan, who makes pop-up greeting cards, is also a fine arts graduate and was drawn into the craft first through a review of geometry taken for graduate school and then when she found a book on paper engineering while looking for one on origami [64]. One of the few pop-up artists that did not come to the craft as an adult was Robert Sabuda.

“I made my first pop-up book when I was 9, ” he said. “It was ‘The Wizard of Oz.’ I spent weeks on it. I couldn’t get the cyclone to spin around. My room was a mess of paper scraps, pipe cleaners, glue and drawings. I did the illustrations with a pencil.” [44]

Sabuda used manila folders his mother brought him from work. (Paper engineering requires stiff paper.) He went to art school, and spent years learning about book illustration and publishing before beginning to produce professional pop-ups, but his interest started at a early age. The cyclone in his *Wonderful Wizard of Oz* published in 2000 does spin.

Sabuda, like most paper engineers, is self-taught.¹¹ Descriptions of the self-teaching process involve two main ways of mastering the craft. The first method is simply practice. Although simple pop-up devices can be learned easily, it takes a great deal of trial and error to learn to make pop-ups that are more complex and that satisfy the engineer’s design and vision of the page. The second method of learning the craft is to collect and learn from professional pop-ups. These accounts tell us that almost every paper engineer has used other’s pop-ups as a learning tool, often

¹¹ All published accounts of paper engineers I have found indicate they were self-taught.

through the use of reverse engineering.¹² Foster “taught himself by taking pop-up books apart. ‘I destroyed a lot of them trying to figure out how they were done.’ ” [126] Anton Radevsky, a Bulgarian paper engineer, collected Kubašta, and “I used to destroy them to see how they worked.” [33, p. 8] Mary Beth Cryan was the only person who made reference to learning from a ‘how-to’ book.

Although most paper engineers begin making pop-ups when they are adults, this is not because children are unable to make their own. Carol Barton, who teaches classes in pop-up making, emphasizes the ease with which children can pick up the craft:

I can actually teach someone how to make a simple box or triangle pop-up in about three or four minutes, and I haven’t had a failure yet. I can teach a class of 4th graders how to make four or five different kinds of pop-ups in a 50-minute session, and the kids have no problem coming up with drawings that turn those pop-ups into all manner of 3-D flowers, furniture, food, and talking animals. They invent stories, too, and string the pop-ups together into narrative books. Adults are a little slower with the visuals, so in an adult class I usually concentrate just on the mechanics. Because many adults are intimidated by long-forgotten geometry formulas, I teach adult classes without any math. And in a two-day workshop, we cover about 85% of the basic pop-up structures used in commercial books. [2]

Where most children acquire the craft of making pop-ups has not been studied. Some children gain their knowledge of pop-ups through the sort of crafts instruction that Barton describes. Of the sample of users in this study (five children), three had previously made pop-ups, but none had taken classes or used “how-to” books (see Chapter 6 for more information on the prior experience of the users) and it is probable that written instructional material plays little or no part in children’s pop-up making despite the number of instructional books and kits available for children (see Appendix B). Instead, this ability may come from a combination of self-teaching and knowledge passed from person to person rather than from any organized knowledge base. As an example of a child’s self-teaching, Robert Sabuda serves as an example of someone who used the trial and

¹² Considering the cost of many pop-up books, this can be an expensive way to learn. However, some pop-ups for small children are simple, yet well-engineered, and can often be found in bargain bins and thrift stores—although in a tattered condition in the latter—if the reader desires to follow this method of instruction.

error method as an extremely tenacious child. It is likely that most parents would not be pleased if their children took the reverse engineering approach seriously.

One account of the adoption of the pop-up form by children in a guided activity is given by Power [89] who studied pop-ups as a means to make observations about conventions in a first-grade writing class. In the writing class, time was spent writing whatever the students wanted and a sharing session, in which the students read their writing aloud and took questions from the rest of the class, followed. Illustrations were often included with the stories and it was there that pop-ups were introduced by one student. Pop-ups were then picked up by others, reaching a peak of popularity before dying out, most likely because the teacher made no attempt to help the children acquire the craft. The original student who introduced pop-ups to her writing was Megan:

Megan's mother said that she first became interested in pop-ups when she was overseas at age four, and had been attempting to make them when she worked with paper and pens ever since...More than half the class attempted to include pop-ups with their stories in the week following Megan's sharing. [89, p. 61]

Power is not clear about the forms that the pop-ups took, although she does state that:

Use of the pop-ups required two important skills; the ability to manipulate paper, tape, scissors and glue, and the ability to integrate a pop-up with the words and pictures on a page. Attempts at pop-ups during this experimental phase included balls and characters flying off the page, as well as cut-outs of characters and objects glued to the page...as the use of the convention continued, the pop-up became more defined. Pop-ups were used to show motion...Not all the children continued to do pop-ups. But those who did wrote and shared movement through the pop-ups...Even though [the teacher] had pop-up books displayed throughout the room which show a wide variety of uses for pop-ups (i.e. showing dimension), the class defined pop-ups as symbolizing motion. [89, p. 61-62]

Power uses these observations to discuss issues of literary convention and social behavior, a subject outside the area of this dissertation, but certainly the ease with which children picked up the craft on their own speaks to the lack of difficulty of this craft for children and their attraction to it.

These observations also provide two other interesting details. First, the children took ownership of the pop-up form by defining how it was to be used: as an indicator of motion. Second, the pop-ups changed over time to match this agreed-upon definition.

Change in the practice of craft over time occurs during the learning period as a matter of course, and not just in the case of the children in the writing class. Learning develops both skill and knowledge that influence the way a craftsman practices the craft, leading to more skill and knowledge. It is necessary to look not only at the way craft is learned, but the way that it is practiced in order to talk about the competencies in paper engineering.

Two examples illustrate some of the techniques paper engineers apply to their craft. Vojtěch Kubašta was an artist who was trained as an architect and this most certainly influenced how he approached his pop-ups. For instance:

He once entertained in his studio a famous author who came to see how his pop-ups were made. According to the visitor, Kubašta seemed to have everything worked out in his head and knew how the pop-up would finally turn out even before he began the design process. The visitor did not realize that “each and every one of [Kubašta’s] books demanded an extensive knowledge of descriptive geometry.” Kubašta admitted, however, to hating math but loving geometry because it “made perfect sense.”...Kubašta said his books were created in stages: 1) inspiration for the artistic solution of an idea; 2) pencil sketches; 3) calculations for the pop-up; 4) mock up of the actual size book. [93, pp. 30–31]

Robert Sabuda, on the other hand, with a background and training as an artist, uses a method of trial and error with multiple prototypes. As he describes his process:

Before any work begins I must decide what I want the pop-up to be. Should it be a static, three-dimensional object, like a castle, or should it be more about movement, like birds flying?...Instead of using a pencil to draw on the paper, I use scissors to cut the paper. I work with broad, general shapes when I’m designing a pop-up. I know that the simple, white rectangle I’m cutting in the beginning will become a very colorful, detailed structure later on. The most important thing at this early stage is that the pieces I cut and attach to the page work properly when opened and closed...Eventually I will make up to eight or ten white mock-ups of the same pop-up, each one more detailed and refined than the last...and I never have to use a protractor! [96, pp. 9–10]

The difference in these approaches is obvious and it is likely that every paper engineer has a unique approach since pop-up makers are generally self-taught. Kubašta consciously employed mathematics in designing his pop-ups. He also had the pop-up planned before making a mock-up, while Sabuda employs successively more refined prototypes and eschews mathematics. As a result of the dissimilarity in design methods, the design tools employed, pencil vs. scissors, are also different. Kubašta used the pencil to design, so that the final mock-up was a verification of what he had already planned. Sabuda, on the other hand, uses successive mock-ups, each a bit closer to the final product.

Although they employ different design techniques, the pop-ups produced by Kubašta and Sabuda use a similar set of elements and that is not surprising. Pop-up devices are made up of simpler elements, of which there are a limited number (although capable of endless combination and variation.) Sabuda's combinations of elements are much more difficult to understand and it is harder to see what basic elements he has used, possibly because of his prototyping approach. But both paper engineers knew how elements can be combined, and both knew before they began what effect they wished to achieve. In both cases, the pop-up is designed to fit the situation being portrayed, the desired motion and depth are considered and the design is based on those qualities. It is some of these commonalities in technique that should be identified when examining children's pop-up progress. Children can also work in many styles, and the analysis of their work should reflect this. The assessment of the children who participated in the user tests is guided by the following sections, in which the competencies of Chapter 2 are applied to paper engineering.

It should be obvious that there are differences between children who make pop-ups and professional pop-up makers. The following sections on skill, knowledge and appreciation deal with the competencies that one expects of children. A professional pop-up designer must know what can be manufactured, must be able to produce instructions for the assemblers, and must be able to provide printer-ready art with die-cutting marks and instructions. This requires a knowledge of publishing and printing that is not necessary for a child making a single copy of a hand-made card or book. In this, children are more like the artist-craftsmen who make single or limited

edition books for the art market.

Once again, it is worth stressing that even the most complex pop-up devices are modular, being built up from a small, basic set of elements and their variations combined together into a more elaborate structure. This modularity is important in discussing competencies, but the details of element construction will be left to Chapter 4.

As discussed in Chapter 2, the competencies are interrelated. As examples, knowledge of what is possible allows practice to develop skill and appreciation of the work of others increases knowledge by showing the craftsman possibilities that she has not yet considered. This should be kept in mind in the following discussion of the competencies as they apply to paper engineering.

3.2.1 The Pop-up Maker's Knowledge Set

Assuming that a child can build up a systematic base of knowledge about pop-ups, what would this base include? The how-to books available provide a useful look at what could be learned and elements, the basic building blocks of pop-ups, provide a convenient starting point.

The three children in user testing who had previously made pop-ups each knew one element. While it is not necessary to know many elements (many professional pop-ups commonly use variations on three or four¹³), in general, the more elements that one can recognize and construct the better, as this leads to more interesting pop-ups and a greater range of possible motions.

Besides the basic form of an element, there commonly exist one or more variations. Elements are made of cuts, folds, and applied pieces, and it is important to know how the direction, length and shape of these affects the element. Folds come in two varieties, mountain folds and valley folds (pointing toward and away from the viewer respectively). This is important, as fold direction affects the element both visually and functionally. For instance, some elements can be placed on either a mountain or valley fold, and will look quite different when this is done. Applied pieces can be attached over folds, or over the seams where other applied pieces sit; once

¹³ See Section 4.1.2 for an analysis of several representative pop-up books' use of elements.

again, the direction of the fold or the seam orientation is important to the function and look of the element. In addition, elements may be made symmetric or asymmetric, and rules exist for the constraints of both. In general, cuts may be made in any shape although folds, as a matter of course, are straight. Paper may be removed from an element so long as the element is not seriously weakened, and additional paper may be added so long as the addition does not collide with other elements. Although making variations on the elements is partly a matter of skill, these general rules about possible variations can be learned as part of the knowledge base.

At a more conceptual level, a child should develop some intuition and perhaps some quantitative knowledge about how elements function [8]. The motion produced by each type of element is also an important factor when used in selecting the element for a particular use in a design.

Once single elements are learned, there are certain facts about element combinations that become important. Most elements sit on folds and each element that is added creates more folds in the pop-up structure. Elements must be connected to a fold in order to move when the page is opened, and ultimately every series of associated folds must be connected to the center fold of the page itself. These requirements for fold connectedness commonly occur when designing pop-ups.

In addition to how folds can be connected, some knowledge of which elements can be combined is also important. For instance, some elements can sit on the folds created by gluing pieces together, and some cannot. In general, the motion created by a combination of elements can be hard to predict, but in designing a pop-up it is best to have some idea of what motion is likely, in order to reduce trial and error.

Another general area of craft knowledge concerns tools and materials. Children are, by and large, acquainted with the qualities of paper since they use it frequently both at home and at school. However, they may be presented with paper that they are less familiar with when doing paper engineering. Pop-ups usually work best, and sometimes require, heavier paper than notebook paper. Construction paper, despite its name, does not work well for pop-ups, as it

does not crease smoothly when folded. Pull-tabs may require doubling of the paper, and must be smooth and strong to work well. Understanding which papers work well is knowledge that children need to acquire. A similar problem exists when selecting glue. For example, familiar water-based glues often wrinkle paper, and glue-sticks are not strong enough for pop-up making. Such fasteners as tape and staples are not usually used in pop-up making, as they tend to bind.

There are only a few tools required for pop-up making, but knowing which is the correct tool is important. It is possible to use scissors on many elements, but a craft knife is needed for others¹⁴. Knowing about the use and care of craft knives becomes important and is made more difficult as children seldom have the opportunity to own or use them. A self-healing mat is important to facilitate good cutting, and not dull the knife blades. A metal ruler (not plastic) can be used to guide the blade. Since pop-ups are made with heavy paper, a tool is required to make good folds. This tool has a round, small, smooth end and is used to press along the fold and compress the paper fibers so that the paper folds correctly and easily. This tool can be a burnishing tool, an embossing stylus, or simply a pen that is out of ink. Again, this sort of tool for making creases is not something that children ordinarily encounter. Of even greater importance is the knowledge of how to use these tools safely.

Every craft has a vocabulary, and paper engineering is no exception. Unfortunately, the vocabulary of pop-ups is less standardized than many. The names of elements, for instance, vary widely and even the term *element* is not standard. It is common to find the terms: form, mechanism, structure, device, and even technique used to identify an element. This may be another effect of the prevalence of self-teaching in the craft. However, it is useful for children to learn or make up terms for the elements they make, the tools and materials they work with, and the techniques they use so that they can talk about their work.

Finally, the knowledge of what is possible given the elements available, and what is not possible grows over time. This can come with experience in designing one's own pop-ups, or by

¹⁴ Children love using the knife, and will use it even when scissors are more appropriate and faster. One would hope that this changes with time, but the time of the user tests was inadequate for the glamor of the knife to wear off.

examining the pop-ups of others (through the growth of appreciation). It can also come through the experience of trial and error in making pop-ups (through the growth of skill). At some point, a young paper engineer should develop the knowledge that a particular element will or will not produce the effect desired, and have some idea of how to work around the problem if it will not.

3.2.2 The Pop-up Maker's Skill Set

The skills that a young paper engineer might be expected to develop come in two areas. First are the skills of actually constructing a pop-up. Cutting, folding and gluing skills are foremost in this area. Pieces are most easily (if the child is old enough) cut with a craft knife and it takes practice to be able to cut smoothly with a craft knife without producing “slivers” of paper that stick out and may impede motion.

Folds are most easily made in the paper if the paper is scored properly. Use of a stylus or empty pen takes practice in order to produce enough even, straight scoring to get a good fold, but not enough to tear the paper. The skill of folding also encompasses the skill of folding the paper in the correct direction, towards the viewer (mountain folds) or away from the viewer (valley folds.) This can be confusing, especially when several folds are combined in an element.

Gluing applied pieces onto the page requires using the proper amount of glue. Too much glue can cause pieces to stick together and prevent proper opening while too little will produce a page that comes apart. In addition, some gluing operations are best done by applying glue and then closing the page to allow the piece to come to its proper resting place.

Finally, putting several devices together compounds these problems. Multiple folds, applied pieces, and cuts on a page are best done in a regular order (from the largest, lowest elements to the smallest and topmost elements) and while this can be internalized as knowledge, it really can only be mastered as a skill. Small elements, and those that are not parallel to the fold they sit on are most difficult, and may require a pencil point or tip of a stylus to “poke” them into place.

The second skill area is in design and planning. There are two main qualities to consider in designing a pop-up: depth and motion. Understanding which elements can be put together is

something that needs to be tried to be learned. Different combinations produce different shapes and motion, and trial and error is the only way to really learn it. Likewise, it is difficult without practice designing pop-ups to know which elements are appropriate for which illustration. Certain elements make very good mouths, for instance, and others do not. Planning encompasses such skills as the ability to fit the design into the available page without pieces sticking out from the closed page and using available materials wisely (cutting paper in a way to avoid waste, for instance). And perhaps the hardest skill to acquire is the ability to visualize the final product that will result from the multiple pieces, cuts and folds. It takes a great deal of practice to make everything work together.

Skill is dependent on knowledge and appreciation. Knowledge of which elements are available is necessary in order to assign the best element to create a particular motion, and in order to visualize the results one must know what each element does. Appreciation allows the paper engineer to view pop-ups made by others and imagine new variations or applications of elements that she can already make.

3.2.3 Appreciation of Pop-ups

Children can learn to appreciate pop-ups by viewing the pop-ups of others, in particular professionally produced books, and by comparing their own efforts to these. The first step in this process is for them to be able to recognize which element is being used in a given pop-up that they look at. Being able to say “This is a v-fold” can be a major achievement when the pop-up involved is a complex one. This complexity can come from the presence of multiple elements that disguise or embellish each other, or from variations in the form of known elements. For instance, pieces can be added or parts of the element can be cut away to produce a different effect.

When several elements are combined in a single pop-up, appreciation may entail understanding how a given motion results. This goes beyond recognizing the individual elements to grasping the entire structure produced by the motions or form of the parts.

Another aspect of appreciation is the ability to recognize the appropriateness of the ele-

ments used. The child should be able to suggest some alternate element that might work as well or to recognize new elements and how they might be used in her own work.

Finally, a child can learn about pop-up styles and learn to recognize or compare pop-ups from different paper engineers, or to compare a professional pop-up with her own work.

Children of all ages who discover, empirically, the joy of making their own pop-up books will approach the 'Children's Pop-Up Books' section of a book shop with a maturity and confidence, for they will be able to say 'I know how that pop-up was made because I've invented one like it!' [58, p. *xix*]

This can also contribute to knowledge, since seeing variations of known elements or even new ones can will increase her understanding of their function and use. Her design skills will be similarly enhanced as she applies this knowledge to her own work.

3.3 The Value of Paper Engineering for Children

Section 2.2 highlighted ways in which craft has value as an activity for children, primarily based on studies involving teachers who use crafts in the classroom. This section examines the craft of pop-up making and its particular values for children as well as some of the uses to which it has been put in the classroom.

Children typically experience pop-ups and other movable books in two ways: the use of professionally made movable books and by making pop-up cards and books for themselves. These are related, as professional books can serve as models for the pop-ups children make. Activities in the classroom can use both of these but this section focuses on the craft of making pop-ups and its value both as a craft and as a tool to teach subject content. The use of professional pop-ups is touched on only as it relates to the actual activity of children making their own pop-ups.

Paper engineering can be taught both on its own as a craft, or as a tool for teaching other subjects although sometimes these two uses intersect. Section 3.3.1 focuses on pop-up making as a craft, while Section 3.3.2 considers the use of pop-up making when introducing curricular subject matter.

3.3.1 The Value of Pop-ups as Craft

In discussing the value derived from having children make pop-ups, it is clear that the previously discussed qualities of craft (Section 2.2) apply here as well. Crafts teach personal values, such as hard work and patience. There are also lessons to be learned about the use of materials and tools, the ability to make aesthetic judgments, and the acquisition of problem-solving skills. All of the general values of craft that have been previously discussed can be applied to paper engineering. For example, a willingness to experiment is important in a craft that relies as this one often does on trial and error. Patience is developed in a craft that requires time for glue to dry before the result can be opened and closed. Imagination, expressive skills, and visual sensitivity are certainly in evidence when work in two dimensions is combined into three dimensional products that include both words and pictures¹⁵.

There are several basic reasons that paper engineering is a particularly good vehicle for children's craft-work. First, children are familiar with pop-ups, attracted to pop-up books, and enjoy pop-ups. However, pop-up books are often expensive and are easily damaged, so most children do not own many of them, giving them special possession status. There is real value, therefore, in teaching children to make their own pop-ups, and it is surprisingly easy to persuade them to do so. There is a built-in motivational factor, a familiarity that might not occur with other crafts, and the sense that a child is creating something special.

Second, the craft uses paper as its raw material. Paper is an excellent material for children to use. They are familiar with its properties, as they use it at home and at school from a young age. It is inexpensive and moderately durable, and has the advantage of coming in many textures, sizes, thicknesses, and colors. It is easy to transport and store the resulting craft objects if they fold flat, as pop-ups do. This seems like a minor point, but in working with children's art it is a quality to be appreciated as it "enables pop-ups from a class of thirty-five children to be stored in

¹⁵ It is not the intent of the author to argue for the teaching of pop-up making in order to produce more paper engineers. As Robert Sabuda points out, "There may be 36 paper engineers on the planet. It is a small field." [44] It is more important that paper engineering offers many of the values of craft in a form that is easy for schools and parents to encourage.

no more space than that required for the same number of exercise books.”[58, p. *vii*] In addition, the tools needed to work with paper are few in number, simple to use, inexpensive, and often already available (scissors and glue, for example) in the home and classroom.

Third, although almost all children have seen and read pop-ups, few have ever made them. Occasionally a teacher will show children how to make a *beak* (a simple triangular pop-up made with a single cut across the paper, and two folds as seen in Figure 5.11) and that is the extent of the exercise. Children can make much more complicated pop-ups, as a look at the web [98], or a perusal of Johnson’s work [58] will show. It is a craft that is under-utilized in education, possibly because the craft is unfamiliar to teachers. Textbooks for the aspiring art teacher or studies of children’s artistic development seldom mention pop-up making. For example, one textbook on art education, Hurwitz and Day [55], spends only two pages on bookmaking, with no mention of paper engineering. Because children rarely get to make pop-ups there is an element of excitement that comes when they create something that they usually consider a product to be purchased. One eleven year-old expressed this surprise:

I used to think that pop-ups were very difficult to make but now that I’ve made them I think they are not so difficult and that anyone can make them. I think they’re the best thing we’ve done at school this year. [58, p. 107]

Fourth, pop-ups are modular, being constructed from a combination of simpler elements. This makes them ideal for teaching design, as the design space is constrained to a few simple forms while simultaneously being capable of seemingly infinite variation on those forms. Interesting designs can emerge from knowledge of only one element allowing the beginning paper engineer to see results quickly. The teacher can introduce new forms gradually as the student needs them. And, in addition, basic principles of design can be taught without requiring too much complexity of construction.

Fifth, pop-ups have a mathematical basis, with constraints that must be met to allow them to pop up and fold down again. These constraints will be explored in more detail in Chapters 4 and 5, and involve such principles as parallel lines, equal distances between sets of lines, and

equal angles. There is a geometrical component to making a pop-up that is seldom encountered in making a flat drawing. Since pop-ups are both 2- and 3-dimensional, they require a level of topological visualization unnecessary in flat art.

Finally, pop-ups are often a part of books, with all that implies—reading, writing, and creating a love of books that can last a lifetime. It is a small step from making a simple pop-up card to joining that card with others to create a book. Children spend a great deal of their time in school, and one hopes at home, in contact with books. So there should be something special about making their own:

When children plan and design a book of their own, integrate handwriting, lettering, illustration, layout, and binding as a vehicle for the communication of ideas, a superior kind of mental activity comes into play. [59, p. 13–14]

Since pop-up making is so well-suited as a children's craft, and combines verbal, mathematical, and artistic effort in one package, it seems natural to use it as a vehicle for curricular centered activities.

3.3.2 Pop-ups in the Classroom

This section examines some specific methods for using pop-ups in the classroom by looking at a sampling of the literature by and for teachers in specific subject areas. This discussion is not focused on instructional books about making pop-ups, although such material is included in some of the examples that will be covered. It focuses rather on reports by teachers of projects they have used, curricula they have developed through making pop-ups, and books and articles that aim to help teachers to integrate movable bookmaking into their classrooms. This section is not intended to be an exhaustive look at the literature on educational uses of paper engineering, and covers only a few important, inclusive, and interesting works in the subject areas of literacy, mathematics, and art.¹⁶ These will demonstrate the pedagogical usefulness of paper engineering.

¹⁶ The reader desiring a list of other publications dealing with pop-ups in education, including how-to books for teachers, reviews of pop-up books for use in the classroom and the library, and minor or esoteric sidelines such as pop-up polyhedra should consult Appendix B.

Making pop-ups can serve as a vehicle for practicing a variety of skills, such as measuring, group interaction, writing, and problem solving, or the finished product can serve as a manipulative or illustration of a principle being studied. Since pop-up books exist in the realms of writing and art, and incorporate principles of mathematics and design, their classroom uses are often cross-curricular and hard to classify by subject. In addition, authors often include details on the craft activity as well as the subject material. There is value in both for the student, so this analysis will examine both aspects. One purpose of this analysis is to look at the sample literature from the vantage point of the framework of Chapter 2 to establish how both the craft and subject matter are learned and integrated.

Movable books and pop-up making in particular have been most often employed in the teaching of reading and writing. Pop-up books as literature have sometimes been maligned by educators and reviewers and consigned to the category of *novelty books*. They have suffered such reviews as this (penned in 1979, the year considered by many to be the start of a second golden age of movable books):

It is now difficult to go into a bookshop without being assailed by books whose pages flap and slide and rotate and creak, a tribute to designer's ingenuity, printer's sophistication, publisher's business acumen—and book-buyer's gullibility...apart from the subliminal message to children that things shaped as books can be fun, they have nothing whatever to do with the magic of the word. [80, p. 6]

Of course “things shaped as books can be fun” is not a bad message to send to children. Children who are lucky enough to have parents who read to them and who discover books at a young age might not need this message, but other children do. Another reviewer notes:

As delighted as I was, I couldn't help but wonder how soon these books would cease to surprise and amuse. A good book enriches the reader with each new reading. A book is not a book when it is a toy. [60]

Both of these reviews illustrate that one reason pop-up books are criticized is that they often have minimal or even no text. However, some teachers have found a way to turn this seeming drawback into a boon in the teaching of literacy.

One of the most complete descriptions of a literacy unit built around both making and reading pop-up books is described in Shannon and Samuels [106]. The authors' concern is with building literacy, which they define as children having the ability to express themselves. They use pop-up book reading and production for this purpose, finding them "useful tools with which children can develop and practice their literacy and begin to understand its nature—the production of meaning." [106, pp. 213] They describe a four-step process. The first step consists of the teacher reading pop-up books to the children and asking questions to elicit ideas from the children about how the pop-ups work, and how the story is constructed. As they say:

The goal of step one is to familiarize children with the structures of pop-up books to the point where they can articulate hypothetical but real reasons for author's use of text and illustrator's reasons for movable pictures... It is important that most children in a group can articulate explicitly some of the uses of movable illustrations and hypothesize about the construction of these movable forms... [106, pp. 214–215]

Second, small groups of children convert a non-movable story book into a pop-up book using pop-ups they create along with the original book's text. This introduces the children to the mechanisms without involving them in story construction. Third, the children write or rewrite the text for pop-up books. This allows them to concentrate on the textual aspects of making a book. This is one place where the paucity of text and the non-verbal complexity of professional pop-ups become important, as there is often more story in the books than is made explicit in the text and the pop-ups serve as springboards for the imagination. Finally, working in groups again, the children make an original pop-up book, writing the story, designing the illustrations and making the movable parts. Unfortunately, the authors do not indicate the age groups with which they have worked, provide examples of the children's work, or discuss the results observed. To assist teachers who may want to use their methods, they provide directions for making some simple pop-up elements, descriptions of the teacher's role at each step of the process, and indications of when the children are ready for each new step.

Shannon and Samuels stress the subject matter over any details of the craft of paper engi-

neering in their account. They take their own advice and emphasize “the process rather than the outcome” [106, p. 215]. However, it is clear that the craft and subject matter are well-integrated in their approach, and that the craft is very important to it, “providing stimuli for oral, artistic and written expression.” [106, p. 218] Although they do not discuss details of the children’s pop-ups, applying the framework makes it possible to understand what is happening at each step of the process. The authors’ first step focuses on appreciation by exposing the children to pop-up books and asking them to analyze and think about how the pop-ups are made and how they relate to the story being told. This provides a base for the acquisition of knowledge (that is hypothetical at step one) and skill during steps two (making the pop-ups for a story) and four (creating a complete book). The acquisition of these competencies is simplified by first having the children observe pop-ups without having to make them, and second by removing the process of story-making from the task of making a book. As has been noted, simplification by removal of some of the complexity of the task is one way of aiding the beginner.

Rather than focusing on pop-ups alone, Johnson [59] concentrates on children making panorama books (called *concertina books* by the author) and variations on them that he calls *origami books*, along with limited types of pop-ups. His main concern is the integration of visual (illustration) and linguistic modes of communication though book design. His is a holistic approach, in both curriculum and assessment, stressing the whole: design, writing, and art. Johnson presents a variety of work by children, examples of the works in progress, dialogues with individual children, and ways of encouraging both group and individual design methods. He does not present an organized step-by-step process as Shannon and Samuels do, but rather presents a large assortment of techniques for working with both paper and children that he tailors to individual students. This may, however, make it more difficult for teachers to pick up and use his methods. Pop-ups take a secondary role to the panorama movables here, but they appear to be a very useful tool for the encouragement of young writers.

The use of panorama books and their variants is an interesting activity for children for several reasons. First, it is a book form more easily made by children than regular bound books

and this represents another method of simplification for learning. This simplification allows the development of the competencies of knowledge and skill in bookmaking, by integrating words and pictures in a book form that is easily constructed by children. Second, as he constructs it, with one large piece of paper folded to produce four pages with separate backs and fronts, each book is always of a standard length and structure. His argument is that children will work to fill the book and will naturally develop a narrative rather than writing only a sentence or two. Third, the book form can also be varied in interesting ways by changes to the folding and cutting, and the addition of pop-ups. These variations on a simple form may be more instructive and easier for children to pick up than exploring multiple ways of making pop-ups. Johnson, by encouraging group work and using a holistic approach, also allows for the growth of appreciation of the book form. He stresses skill in areas such as using cutting tools (the tops and sides of panoramas may be cut to vary the shape). The subject areas explored here are the creation of a movable book form, and the integration of illustration and writing for self-expression, making the subject and the craft tightly integrated.

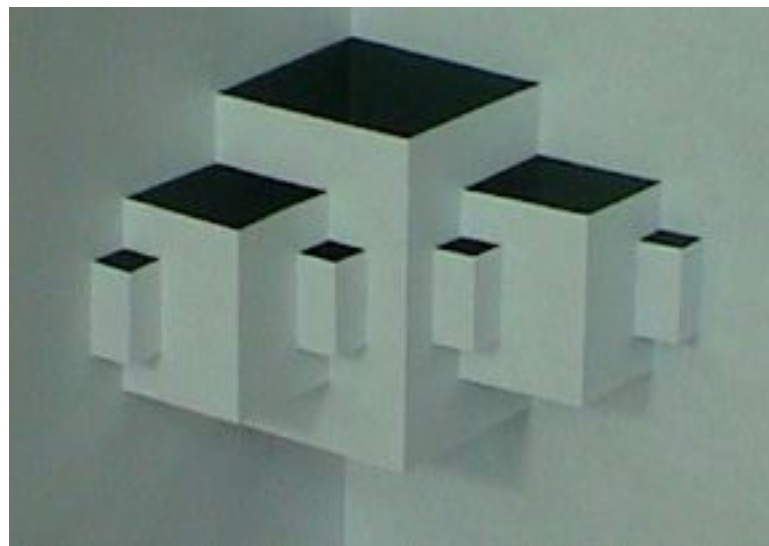


Figure 3.16: A fractal pop-up of the type used by Simmt and Davis [108] as a manipulative to study fractals and other mathematical concepts. The boxes are self-similar, and could theoretically be repeated forever, if the paper allowed it. This pop-up was made with Popup Workshop.

An extremely different approach in a different subject, mathematics, is provided by Simmt and Davis [108]. They work with simple pop-up cards produced using a single sheet of paper by means of cuts and folds. The major inspiration behind these cards is Uribe's *Fractal Cuts* [122] that explores pop-up elements that may be repeated in a fractal pattern. Their approach is oriented toward classroom use, and could be used in middle school as well as in high school. They describe their use of several cards of this type¹⁷ in the study of fractals, limits, series, and growth patterns. Each pattern is built from self-similar elements and represents a manipulative of a fractal design and is limited only by the size of element that can be cut from the paper. Simmt and Davis describe several exercises that can be used with cards of this type. For instance, students can learn about growth patterns by studying the number of boxes or number of cuts, explore the concept of a limit by measuring the area occupied by the boxes as their numbers increase, or investigate the length of the line segments running across the card. This paper does not present actual classroom studies, but there are many ideas here for incorporating these simple pop-ups into a mathematics class.

Simmt and Davis are concerned almost entirely with the subject matter, and the pop-ups they use are clearly present as manipulatives only, but they offer an interesting study in how the craft of pop-up making can be used to explore these manipulatives. In terms of the subject matter, they contend that the pop-up cards are helpful for several reasons. They “tend to capture people’s interest and attention” [108, p. 102], involve a wide range of mathematical possibilities, and are usable over a wide range of ages and abilities. They provide an easy to make manipulative for investigations of fractals that can be hard to visualize otherwise. The authors express the opinion that making the cards by repetitive folding and cutting before opening the card, itself has value, in that:

The increased resistance encountered with each repetition of the process, coupled with such other changes as the decreasing dimensions of the shapes... provides learners with hints about the nature of the object...When students

¹⁷ All of the cards described could be made with Popup Workshop. See Figure 3.16 for an example of the sort of pop-up used in this paper.

open up their cards...their most common reaction is one of pleasant surprise: the cells are sometimes unexpectedly arranged...the relatively large number of cells generated often seems to be out of line with the few cuts and folds made; and the completed image is generally far more complicated and attractive than students would predict...The aesthetic dimension of the activity cannot be overstated. [108, p. 104]

From this statement, it can be seen that it is also possible to separate out some of the actual craft learning that occurs. The student's reaction to the often unexpected relationship between the cuts and the resulting pop-up and the aesthetic dimension is clearly due to a change in appreciation. In addition, although only one type of element is used, the activity nonetheless introduces some craft knowledge about element construction and positioning and exercises the skill required to effectively lay out and cut the pop-ups. The authors also encourage students to develop their own variations on the card, thus allowing more opportunity for the development of these competencies.

Another use of pop-ups in mathematics classes is illustrated in *Be a Paper Engineer* [110], one of the series called *Numeracy Through Problem Solving*. The basic approach is the teaching of mathematics through design, and therefore it is more oriented toward the craft of paper engineering and less oriented toward pure mathematics than the work of Simmt and Davis. Aimed at young people ages 13-16, it not only presents a range of projects, but lays out the mathematics behind the projects and provides assessment methods for the teacher. The course is divided into four stages. In the first stage, students make several examples of pop-up cards and paper boxes that illustrate various techniques and elements. They also practice classifying the assortment of items they have made by technique and look at professionally made paper products. The second stage consists of explorations of the previous techniques in more depth through a series of worksheets. In the third stage, students design and make a prototype of a "product" that they would like to develop, a paper box or pop-up card, and make a cut-out version of the product on a single sheet. Stage four is production. Using the cut-out from stage three, the students write directions for assembling the product and package it as a kit that can be duplicated and sold.

These four stages present numerous opportunities for learning the subject matter of mathematics and design. Drawing to scale and in perspective, classifying the techniques, creating flow charts, brainstorming, algebraic descriptions of geometry, and some trigonometry are used in the process of making the final product. This subject matter knowledge is integrated well with the craft. Knowledge of notation is introduced in stage one with the first examples that the students make, and by making a variety of objects using different techniques and elements that knowledge is extended to several types of individual elements. Skill is enhanced by having the students build a range of objects and practice folding, cutting and gluing. The use of standard examples in stage one allows the separation of the learning of skill and knowledge around making the object from the activity of design, simplifying the process. In the second stage, elements are combined, and the students use several elements to produce designs of their own, building both skill and knowledge. Perhaps the most interesting difference between this course and any of the other literature in this section is the emphasis on mathematical constraints. The teacher is encouraged to help students discover the constraints on various elements and designs. This is an important part of pop-up design that is usually neglected in classroom literature, although it is given its proper importance in how-to books on the subject, and is an important mathematical tool. During stages one and two, the course emphasizes bringing in examples of paper products and finding some similarities between them, providing the opportunity to compare various products and build appreciation. The final project in stages three and four allows the students to put what they have learned to use in building the kit for others to make, working with all three competencies.

Taking a different tack, Johnson's *Pop-Up Paper Engineering: Cross-Curricular Activities in Design Engineering Technology, English and Art* [58] also uses paper engineering to teach design, but its emphasis is more on writing and artistic creativity than on the mathematics involved. A large collection of movable book elements is covered in detail. For instance, pull-tab mechanisms are included although these are seldom part of paper engineering learning for children due to the difficulty inherent in making them. While writing skills are discussed and used in assessment, the primary emphasis is on making the pop-ups themselves. Numerous examples of the students'

work are described along with assessment criteria, and a structured curriculum is mapped out.

Johnson's approach touches all the competencies. The knowledge of various pop-up elements is introduced systematically, each is practiced to teach skill, and the use of group work encourages appreciation. It is useful to take one of the elements he introduces and examine his approach in detail. For this purpose, his first element, the basic box is appropriate as it is the same element used by Simmt and Davis for their mathematical manipulatives.

The section on the basic box is divided into two parts. In the first section, the basics of making the box are described. Constraints are mentioned, but not always made explicit. For instance, the lengths of the cuts necessary to keep the box from extending beyond the page when closed is detailed, but the necessity of the folds being parallel to allow the box to fold flat is not. The second section presents activities using the basic box. First, the children practice making some basic boxes to develop the necessary knowledge and skill. Next, since the box may be oriented vertically or horizontally, the children talk about the differences, and what pictures might go with each orientation. Artwork is then added to the boxes and a story is created around that picture and added to the page to produce the finished pop-up. Additional activities can involve adding doors and windows in the box or varying the cutting patterns. The section ends with evaluation methods (that include self-evaluation for the teacher, as well as evaluation of the student's progress) and a list of key points for the teacher to remember, in this case revolving around the appropriateness of the artwork to the pop-up form.

The sections for each pop-up element differ in their specific curricular activities but the formats are similar. In particular, the evaluation methods, although they vary in detail depending on the activity, are always divided into four sections (conceptualization, manipulation, imaging, and visualizing), and are interesting to examine within the craft framework. Conceptualization is the assessment of the children's knowledge and the teacher's presentation of it. Manipulation is the assessment of the skill competency, in particular the student's use of tools. Imaging involves storytelling and writing, and therefore does not directly relate to the craft. Visualizing assesses the relationship of the pop-up and the story, and the artwork itself and relates to the children's

appreciation of the craft.

Johnson here, as in his book on panoramas, tightly integrates the craft and the subject matter, to the point where it is impossible to separate them.

At a time when every subject has to justify itself in the curriculum, there can be no other area of technology and design which addresses itself to so many adaptable skills and cross-curricular areas as pop-up work... The opportunities for technological inventiveness are endless. Integrated with the visually aesthetic and scientific dimension of pop-up work is the rich kingdom of the literary imagination...The greatest danger of this book is that the techniques it demonstrates will be 'lifted' out of the context of an interrelated programme of study and given to children as one-off novelties. [58, pp. *vii-viii*]

3.4 Summary

The craft of pop-up making, also referred to as paper engineering, arose before the advent of printing, and continued with the advent of printed books, with its goals to provide better access to data, motion, and depth. The first elements to be used for this purpose were volvelles (wheels) and flaps. Although originally produced for adults, movable books made the transition to children's literature as that genre became prevalent in the mid-nineteenth century. Movable books reached their first golden age in the latter part of the 19th century, with the introduction of such elements as pull-tabs and scenics. True pop-ups, as opposed to other forms of movable books, exhibit true three-dimensional forms that rise from the page automatically when it is opened. Pop-ups are a later development and were not produced until 1929, but they quickly became popular with children. Today they are a common part of children's culture and have entered a second golden age. Current pop-up books are produced for adults as well as children and are more complex and striking than ever before, often using many types of movable elements in addition to pop-ups. Mass-produced pop-up books are, in spite of the high technology involved in their printing, designed and assembled largely by hand. By contrast, they are also made by artists and children as a personal craft.

Since it is practiced as a craft, paper engineering can be studied as a representative craft and the framework established in Chapter 2 can be applied to it. By focusing on the modularity of pop-ups, the knowledge of the various elements, their combinations and possible variations, the skill of making them, and the ability to appreciate the way the elements are used in the pop-ups of others can be seen to lie at the heart of the craft.

Engaging in paper engineering also exhibits the established values of craft, in that it provides personal and cognitive benefits for children practicing it. As a children's activity paper engineering benefits from using a well-known material (paper) and simple tools to create a product with which children are familiar and that combines mathematical content, both 2- and 3-dimensional artwork and written text. These attributes have been recognized by educators who apply pop-up making to classroom programs in literacy, mathematics, and design. In spite of this, paper engineering is under-utilized by teachers, who seldom know about these possible uses of the craft.

The discussion of pop-up construction begun here continues in Chapter 4 with a more detailed look at what pop-up elements are, how they are classified, how they are combined, and how they work. Methods for integrating computation into the making of pop-ups will be examined through a review of the literature surrounding the mathematics and simulation of pop-ups, and software systems previously developed to aid in their design. This knowledge of pop-up composition and previous research, combined with the discussion of the requirements for computer enhancement of craft learning described in Section 2.4, supports the development of general requirements for a system to aid children in learning paper engineering.

Chapter 4

Pop-ups and Computation

Paper engineering was introduced in Chapter 3 as a representative craft with history, practice, and value as an activity for children. During the discussion of pop-ups as a craft, mention was often made of their modularity, in that pop-ups are composed of simpler elements.¹ This modularity influences the way that the craft is practiced and learned. For instance, in developing the knowledge necessary to be a paper engineer, it is important to learn which elements are available, the motions they produce, and ways in which they can be combined.

Since modularity is so important to the craft of paper engineering, this chapter examines the pop-up elements that form its building blocks. Two of the ways that computation can aid the learning of a craft that were presented in Chapter 2 are particularly applicable here. First, the computer can simplify the design process. In the case of the pop-up elements, not only are a limited number of elements used in pop-ups, but each element requires certain geometric constraints be followed in its construction. These geometric constraints are amenable to computational enforcement. Second, the learner can benefit from seeing both the notation or pattern for a design and the finished construction, in this case the 2-dimensional paper to be cut, folded and glued alongside the 3-dimensional pop-up in motion. The computer can present these simultaneously.

In order to develop the high-level requirements for a system that aids users in learning pop-up design, it is appropriate to first examine the elements that form the foundation of pop-

¹ In that discussion, the term *device* is used to indicate everything from a single moving part, such as a flap, to an entire page of moving paper mechanisms. The word *element* is used for the more basic structures that make up pop-ups specifically.

ups in more detail. In addition, previous research into software for pop-up design will provide some guidance.

This chapter begins with a description of movable book devices and terminology, and more specifically, pop-up element types and construction. A literature review of research in the area of pop-up animation, mathematics and modeling follows. Finally, a brief summary of the principles and philosophy for pop-up design software for children is presented, along with a discussion of how these follow from the literature, from the discussions in previous chapters, and from the pop-up elements themselves.

4.1 The Composition of Movable and Pop-up Books

This section introduces a taxonomy of pop-up elements and how they are related to other movable book devices, the terminology needed to discuss them, the construction, motion, and use of those elements, and how they can be combined. The most useful sources for this information come from instructional books about paper engineering. A list of these books can be found in Appendix B. In particular, the current section relies largely on four references. Carter and Diaz, *The Elements of Pop-up* [14] is a large collection of pop-up elements in actual, functioning form. Jackson and Forrester's *The Pop-up Book* [56] is an excellent source for variations and combinations of elements and includes a design section and striking photos. The best description of most elements, and certainly the most complete and useful explanation of constraints in pop-up elements is found in Birmingham's *Pop-up! A Manual* [6], although it is primarily aimed at older children and teens. Finally, it is useful to be able to consult a pop-up book made for the use of young children, Valenta's *Pop-o-Mania* [123]. This book uses a highly restricted set of elements, and yet demonstrates the large variety of pop-ups that can be constructed from them.

A few words should be added here about terminology. The terminology in pop-up making is not standardized, and the case of elements illustrates this perfectly. Various books use different terms for what here will be called an element: device, form, mechanism, structure, element, construction and technique. In the same way, the names for individual elements, portions of

elements and construction techniques also vary greatly. The names for elements used here were chosen for their simplicity (“step” rather than “180° parallel double slit” for instance) or their commonness (“v-fold” is used commonly, although not universally, for one element). In part, this is to allow the software to use child-friendly names, but consistency in naming also simplifies the discussion of element types.

4.1.1 Movable Devices

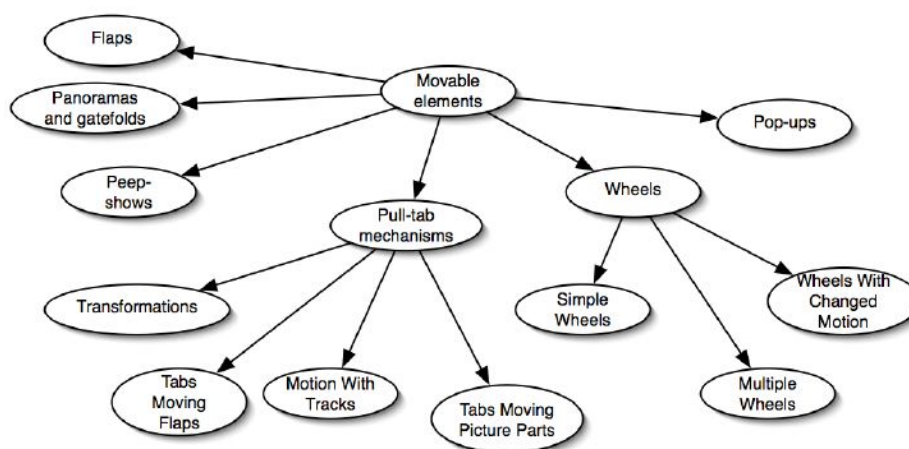


Figure 4.1: A Partial Taxonomy of Movable Devices: This illustrates the relationship between some of the more commonly used devices. Note that pull-tabs can animate multiple types of devices.

Figure 4.1 presents a partial taxonomy of devices used in movable books, most of which were introduced in Section 3.1. It can be seen that pop-ups are a distinct type of movable device. When talking about movable books the discussion focuses on the device and devices are composed of elements (even if a device is but one element.)

In the above taxonomy, both wheels and tabs can be used to produce motion in several ways, and are therefore divided into several types. There can be one or many wheels in a mechanism, and the wheel’s motion can further be transformed by a lever into other types of motion. Similarly, pull-tabs can move the parts of transformations to change one picture to another or animate flaps or parts of a picture (as seen in Figure 3.12) or even pull or push a piece along a track.

Besides being pulled manually, pull-tabs can also be attached to other parts of the page², or the opposite side of the gutter (the center fold of the page) to allow the tab to be pulled automatically when the book is opened.

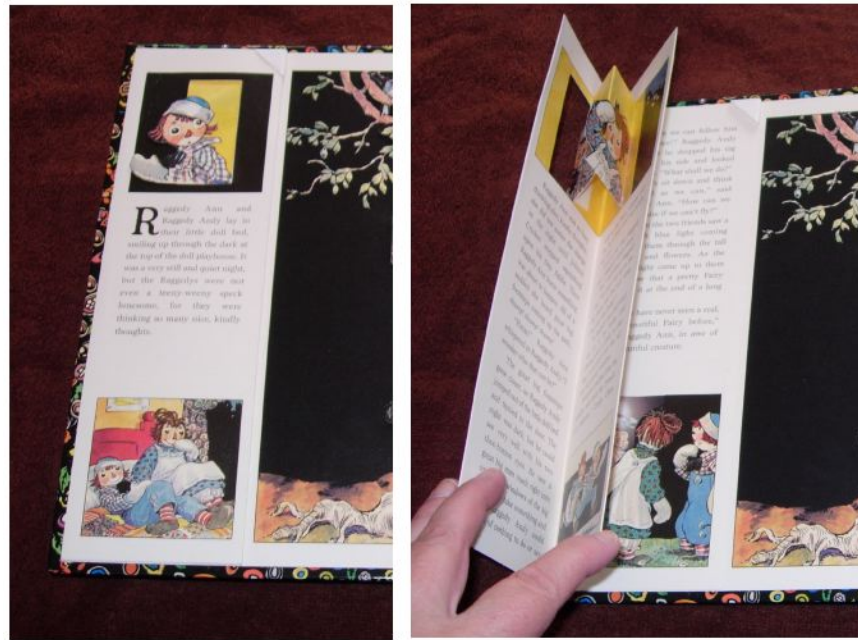


Figure 4.2: A Gatefold Producing Side-Pages: A page from *Raggedy Ann and Andy and the Camel with the Wrinkled Knees* [41]. The gatefold is folded into a panorama and the folds are glued on the back side to produce the effect of an additional book on the left side of the page.

Carousels are a form of book and not simple devices, and have therefore been left out of this taxonomy, but peep-shows have been included, as they can be present in small size on a single page. Panoramas can also exist on a single page, most commonly in the form of *gatefolds*. Gatefolds are made by folding over one end of the page that has been made wider than the book itself (the *Playboy* centerfold is a perfect example of a gatefold.) Gatefolds can also be multiply-folded to produce a panorama effect, or glued together on the back side to produce the effect of another book attached to the edge of the page. An example of this device can be seen in Figure 4.2. This has become quite common in contemporary pop-up books, as the extra pages produced

² The term *page* is used in this dissertation to refer to the combinations of left and right leaves of a book or card when it is opened.

by the gatefold can accommodate more text or, as seen in this example, additional small pop-ups. It also allows the book to close into a flatter form. Most pop-ups are thicker near the gutter, and the gatefold adds thickness to the outer edges of the left or right sides of the page.

4.1.2 Pop-up Elements

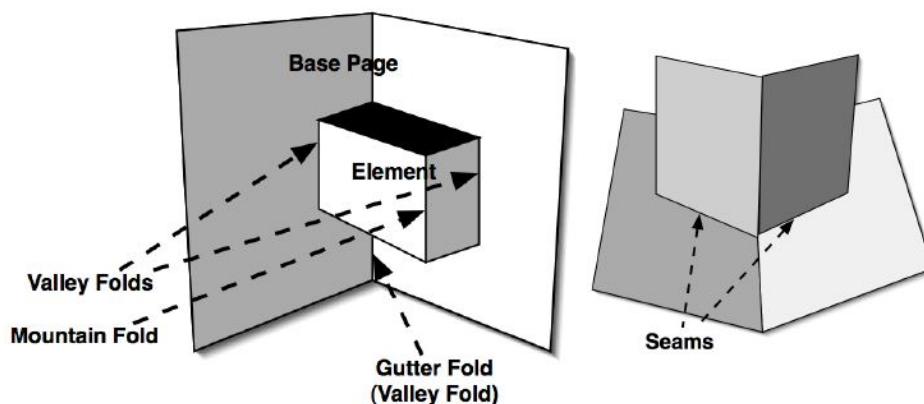


Figure 4.3: Parts of Pop-up Elements on the Base Page: Shown on the left is an element without extra pieces (a 90° element). The element on the right demonstrates seams on an element with an extra piece attached to the page (a 180° element).

The features of elements arise from the three operations that can be performed on paper to produce pop-ups: folding, cutting, and gluing. A feature common to all pop-up elements is the fold. For the purposes of introducing pop-up elements, assume that the element is sitting alone on the *base page* (that is, the open page of the book)³. Folds are of two types, valley folds and mountain folds. A *valley fold* is a fold in which the fold line is farther from the viewer than the paper on either side. The opposite fold is a *mountain fold*. The center fold or seam of the book or card is called the *gutter*, and is most commonly a valley fold. Cutting creates a *cut*, and gluing a piece onto the page creates a *seam*.

Figure 4.3 illustrates folds and seams. The element on the left is called a *step*, and is composed of two cuts and three folds. The step will be used for many examples in this chapter, as

³ Combinations of elements will be discussed in Section 4.1.3, and, as it will be seen, are not very different from isolated elements, except for some additional terminology.

it is a simple element both to make and to visualize. The element on the right, used to illustrate the seam, is composed of an extra piece glued onto the base page and is called a *v-fold*.

For an element to fold and unfold properly two conditions must be met. First, its geometric constraints must be satisfied. Second, it must not collide with any other element.

To illustrate how geometric constraints affect an element, consider the two example step elements shown in in Figure 4.4. As previously mentioned, a step consists of two cuts, indicated by the solid lines, and three folds (plus the gutter over which the step is placed) indicated by the dashed lines. While the shape of the cuts is unconstrained, so long as the cuts intersect the folds and do not intersect each other, the folds are constrained such that all of the folds, including the fold in the underlying page, must be parallel and the distances between them must allow for the formation of a parallelogram cross-section.⁴ That is, $\overline{AB} \parallel \overline{CD} \parallel \overline{EF} \parallel \overline{GH}$, and the distance from $\overline{AB}$ to $\overline{CD}$ = the distance from $\overline{EF}$ to $\overline{GH}$. While the step has a fairly simple set of constraints, others, like the v-fold are more complex. Detailed information about the geometric constraints of five common elements (those shown in Figure 4.6) is presented in Section 5.4.3.

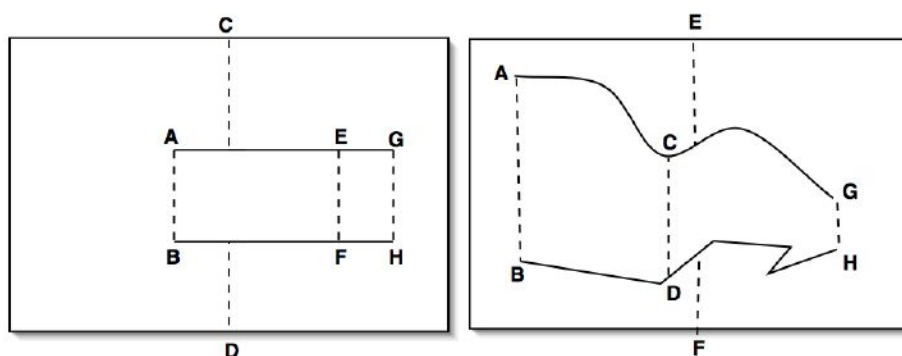


Figure 4.4: Two examples of the step element that follow the constraints on this element. Regardless of the shape of the cuts, the folds are parallel, and the distances allow both elements to fold.

Variations can be made to elements so long as the constraints are not violated. Cuts can be of any shape and material can be added or removed from elements. For instance, a door or

⁴ Most pop-up elements rely on the collapsibility of the parallelogram (the cross-section of the element) or, in 3-dimensional terms, the collapsibility of a four-sided prism or pyramid.

window could be cut into a step that represents a house, or a v-fold could be trimmed into an animal's nose.

Figure 4.5 shows a partial taxonomy of pop-up elements. Those elements that are part of Popup Workshop are shown shaded. There are other elements in the pop-up domain, but some are combinations or variations of these elements and others are seldom used. The elements included here serve to illustrate the general categories of pop-up elements.

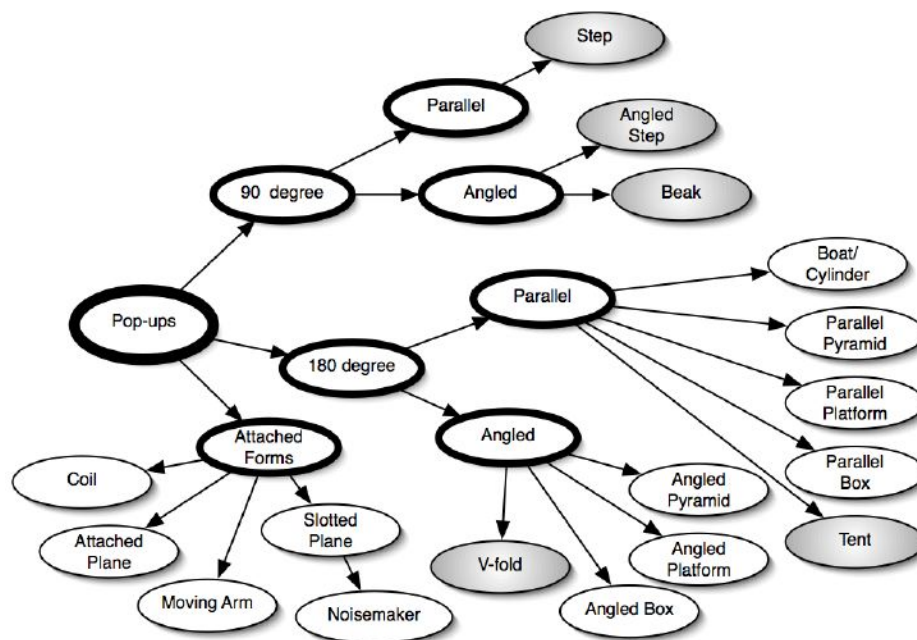


Figure 4.5: A Partial Taxonomy of Pop-up Elements: This illustrates the relationship between some of the more commonly used basic elements. Shaded elements are available in Popup Workshop.

Most pop-up elements can be divided into 90° and 180° elements. As their name suggests, 90° elements are best viewed when the page is halfway open at 90° , and folding the page flat results in these elements rejoining the page from which they are cut. Another distinguishing feature of 90° elements is that they are made without additional pieces. That is, they are composed only of cuts and folds made to the base page. 180° elements, while they can have cuts and folds, will also have extra pieces glued onto the page and are best viewed when the page is fully opened. Since the pages of a pop-up book are usually opened fully when viewing the pages, professional

pop-ups are made almost entirely from 180° elements.

Each of those categories is further divided into angled and parallel elements. A parallel element's folds or seams are parallel to the fold or seam on which it is placed (the *parent fold*), while in an angled element, the folds and seams are at some angle to the parent fold. Many elements exist in both angled and parallel forms.

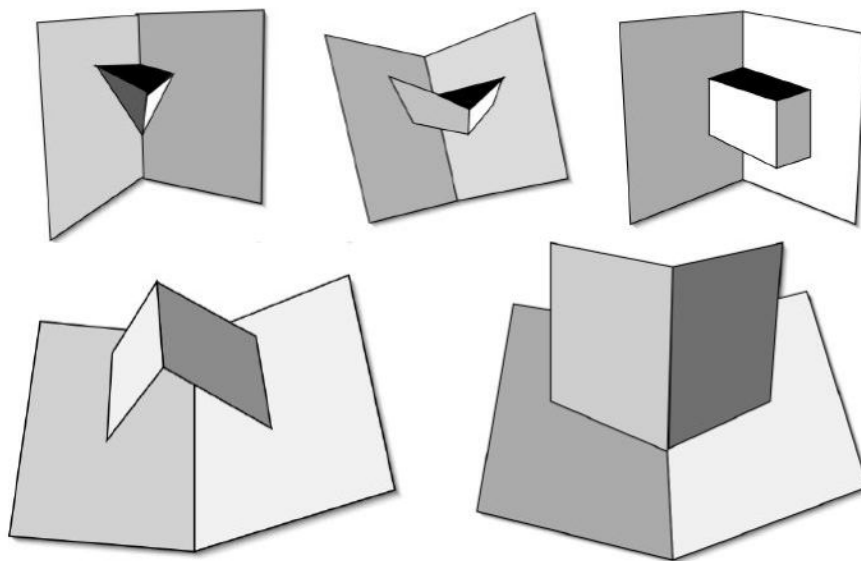


Figure 4.6: Five Commonly Encountered Pop-up Elements: Top from left to right, three 90° elements: beak, angled step, step. Bottom from left to right, two 180° elements: tent, v-fold. These are the elements used in Popup Workshop.

In this taxonomy the three 90° elements are closely related (Figure 4.6). The *beak* consists of a single cut across the parent fold. Three folds are made from a single point lying on the parent fold (or an extension of the parent fold) to the cut, forming a pyramid. Since the pyramid's base is a parallelogram, the pyramid can be flattened, and will therefore open and close. The *angled step* is essentially a beak with the point removed by another cut. (The folds, if extended, would still all meet to form the pyramid.) The *step*, on the other hand, is the case where all of the folds, including the parent fold are parallel. This produces a four-sided prism that is also flat-foldable. Although the step is produced with parallel folds and the angled step with a hidden intersection point of all the folds, they are similar in appearance.

The geometric constraints on the step have been discussed. Those of the beak are similar but as it is an angled element, the constraints are on the angles between the intersecting folds rather than on the distances between parallel folds. See Section 5.4.3.2 for more detail.

With respect to 180° elements, two of the simplest and most common are the *tent* and the *v-fold* (Figure 4.6). The tent is a relative of the step and relies on the production of a prism with a parallelogram cross-section. However, two of the sides of the prism are produced by an added piece of paper. The tent and the step provide a good example of the difference between 180° and 90° elements. If the page is opened to 180° , the tent stands up from the page (if the sides are long enough) while the step lies flat. The tent, like the step, is a parallel element, since the sides that are glued to the page must be parallel to the parent fold. The v-fold, on the other hand, is an angled element since the sides glued to the page are not parallel to the parent fold. The v-fold is in fact the 180° equivalent of the beak, with the same pyramidal cross-section and similar geometric constraints, even though the added piece involved makes its constraints more complex.

There are two ways to produce collapsable pop-up elements. One is for all folds to meet at a point on the parent fold. This is seen in the beak, the angled step, and the v-fold. The other method is for all folds to be parallel as in the tent and the step. A proof of the necessity that one of these conditions must exist is presented in Lee, Tor and Soo [66]. The existence of these two conditions provides the basis for the differentiation between angled and parallel elements. In all cases, the geometric constraints on angled elements include the intersection of the folds. In all cases, the geometric constraints on parallel elements require parallel folds. Several elements exist in both angled and parallel forms, and three of the most illustrative are boxes, pyramids and platforms (Figure 4.7).

Boxes are frequently used in professional pop-ups, often to represent houses or other structures. The boxes illustrated here are open on the top, but a top can be added to pop up or down into place, or even produce a peaked roof effect. The parallel form of the box has extra folds along the sides that intersect the parent fold in order to allow the box to fold. The angled

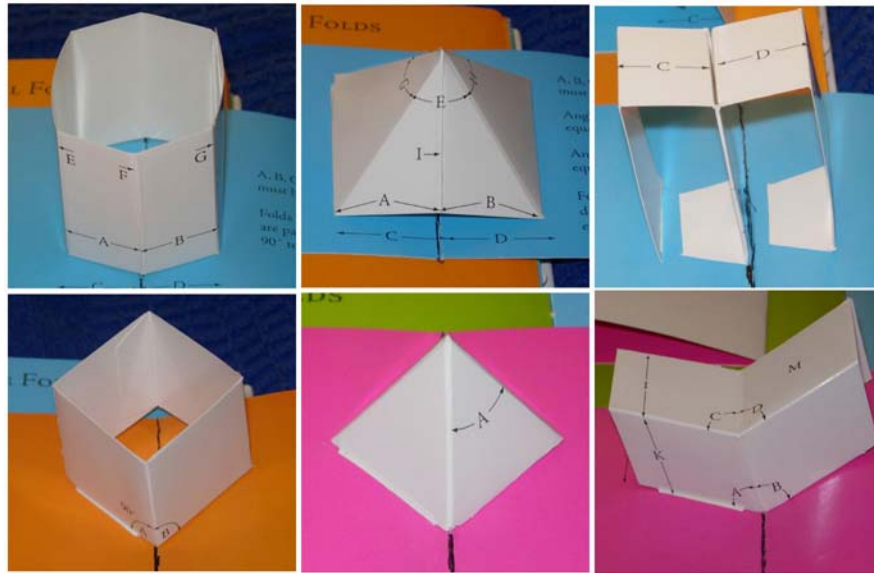


Figure 4.7: Box, Pyramid, and Platform Elements: Each element is shown in parallel (top) and angled form (bottom). Photos of elements included in Carter and Diaz, *The Elements of Pop-up* [14]

box, on the other hand, acts much like a v-fold as one side on either side of the parent fold is attached to the page, while the other sides are not attached and lift up from the page as the page is closed.

While *pyramids* are seldom used in professional pop-ups they are included here as an example of unusual shapes that are possible using the same principles as boxes. Once again, the parallel form of the element folds in the center, and the angled form lifts up to allow the page to close.

The *platform* is an interesting element. It is commonly used to hold up a flat, table-like sheet of paper, and the platform and the attached sheet bend in the center to allow closure. This supported sheet or plane can be part of the design, a lily-pad or table for instance, and is often used to hide elements that are needed to produce motion but are best kept invisible. The most important difference between the platform and the box is that the platform allows the center of the element to collapse to allow the folding of the attached paper surface. There are several variations of the parallel platform, that can be made more or less stable depending on the paper

engineer's desires. The parallel platform pictured in Figure 4.7, for instance, can sway from left to right when pushed, while the angled platform shown is much more rigid. The angled platform is, at its heart, two v-folds connected in the center while the parallel platform is based on uprights placed parallel to the parent fold.



Figure 4.8: Boat and Coil Elements: On the left, a boat element, a 180° parallel element that bends the paper. Photo of element included in Carter and Diaz, *The Elements of Pop-up* [14]. On the right is a coil, illustrated in Valenta, *Pop-o-Mania* [123]. The coil is here classified as an attached form, as it has no folds.

It is also possible to have elements that rely on the bending of the paper. One of these elements is the *boat*, shown in 4.8. The boat is pulled from two sides, and the attachment points are parallel to the parent fold, making the boat a parallel element. If the pull is large enough, a cylinder can be formed. As with the box, a top can be attached if a closed form is desired.

One group of elements that is not so easily placed into 90° or 180° categories is the attached forms. These are flat pieces of paper placed onto an element to either extend it or to provide some desired motion. They can be attached to any form of element: 90° , 180° , angled or parallel. Attached forms provide great latitude in creativity for the paper engineer. Attached forms can be divided into several categories.

One type, the coil (Figure 4.8), is extremely simple to make but can produce a striking effect. It is simply a spiral cut from paper, with one end glued to each half of the page, between



Figure 4.9: Attached Planes: Two methods of attaching extra planes to an element. On the left, an arm holds the attached plane away from the element, a parallel box in this case. Photo of element included in Carter and Diaz, *The Elements of Pop-up* [14]. On the right, the planes are directly attached to the side of step elements, from Valenta, *Pop-o-Mania* [123].

elements, or between an element and the page. The coil spreads as the page is opened, and the spring-like form curves and bends.

Attached planes are flat pieces that are attached to elements in order to extend them. There are two main ways in which this is accomplished as illustrated in Figure 4.9. First, an arm can be used to hold the plane away from an element and parallel to it. This can be done with either a modified tent or a doubled set of arms for additional stability as shown in the figure. Second, pieces can be glued to the side of an existing element. So long as the attached plane does not interfere with the motion of other elements, any plane of an element can be extended and the element will fold correctly. In the figure, the sides of two steps are extended with attached planes to model a house and a tree.

A special case of the attached plane is the *moving arm*. There are several methods of constructing a moving arm, but the most common is to add a beak to another element and connect the arm to the beak. This is one place where a 90° element is used in professional pop-ups. Figure 4.10 shows the attachment and motion of one such moving arm.

Finally, attached forms can be slotted into other elements. Slots are made in the piece to be attached and part or parts of the elements are pushed through them. Conversely, the elements



Figure 4.10: Moving Arm Element: The motion of the lamb is surprisingly large, and the motion is driven by a beak to which the lamb is attached. From Steer, *Snappy Little Farmyard* [109]

can be slotted and the attached form pushed through. Figure 4.11 shows a slotted attached form and a special case of the attached form called the *noisemaker* that rubs small teeth across an element to produce a sawing noise as the page is opened and closed.

While the taxonomy of Figure 4.5 includes virtually all pop-up elements, it gives no indication of how common each element is in practice. Table 4.1 summarizes the number of occurrences of all of the elements found in three example pop-up books. These books are ones that were shown to the children during user testing in order to observe whether children learned to identify the elements used in professionally produced pop-ups (see Section 6.2.2). These particular books were chosen because they varied in the complexity of their construction and in the age level of their intended audiences. *Snappy Little Farmyard* [109] is a simple picture book aimed at pre-school or younger elementary school aged children. *Haunted House* [85] (previously discussed in Section 3.1.6) started the trend of including many pop-up elements on each page and is intended for older elementary school aged children. Finally, *Raggedy Ann and Andy and the*



Figure 4.11: Slotted and noisemaker elements: On the left is a slotted plane with three v-folds positioned through the slots to produce a floating castle effect, from *Raggedy Ann and Andy and the Camel with the Wrinkled Knees* [41]. On the right is a noisemaker. The plane, slotted through a tent, rubs on the tab and creates noise, from *Haunted House* [85]

Camel with the Wrinkled Knees [41] is intended for young people or adults and presents sophisticated variations on a variety of pop-up elements. Example pages from each of these books are shown in Chapter 6.

In counting elements in these books, variations were included along with the simple form. For instance, a v-fold can be bent into a beak shape or the center of the added piece can be cut out to make an arch, but both would be counted as v-folds. When moving arms were attached to beaks, the beak and arm were counted separately. Wheels were counted once for each page on which they were displayed so a wheel serving two pages counted as two wheels.

Attached planes, v-folds, and tents were the most commonly used elements and accounted for 65% of the total used. Examples of attached forms vary widely, being used in a multitude of ways and attached by different means. The only 90° elements found in these books were beaks, used both alone and as supports for moving arms.⁵ The books intended for an older audience contained not only more elements, with the number of element roughly doubling with each book, but also displayed more variety in the elements chosen. The large number of attached planes in

⁵ All of the moving arms were supported by beaks.

Element Type	Element	Farmyard	Haunted House	Raggedy Ann	Total
90°	beak	5	8	4	17
180°	v-fold	8	5	15	28
	tent	15	11	36	62
	parallel box	0	0	1	1
	angled box	0	1	0	1
	angled platform	0	0	1	1
Attached piece	moving arm	4	5	8	17
	coil	0	2	0	2
	slotted piece	0	3	5	8
	noisemaker	0	1	0	1
	attached plane	2	9	47	58
Movable device	gatefold/panorama	0	0	12	12
	transformation	0	1	1	2
	pull-tab	0	7	1	8
	wheel	0	2	0	2
	flap	0	8	0	8
	Total	34	63	131	228

Table 4.1: Elements used in three commercial pop-up books of increasing complexity and age level. The intended age of the reader increases from left to right.

Raggedy Ann is particularly striking and may be partly a factor of the paper engineer's (Kees Moerbeek) style. Of these books, *Haunted House* accounted for the majority of the non-pop-up movable elements. Gatefolds were only seen in *Raggedy Ann* where two are found on each page.

4.1.3 Combining Pop-up Elements

So far, the discussion has centered on individual elements attached to the base page. Construction techniques for combining elements are much the same although they can introduce difficulties when trying to visualize or calculate the resulting motion. Combining multiple levels of elements also presents challenges when considering computer aided design of pop-ups, as the points to which an element is anchored change in ways that depend on changes to the elements beneath it.

Combining elements can introduce dependencies since the removal or change of one element can affect those elements placed on it. Because of these dependencies, it is important to

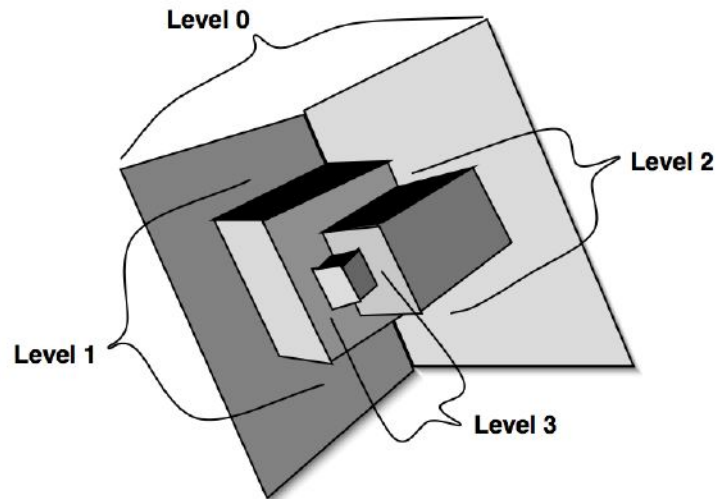


Figure 4.12: Three step elements combined into one pop-up. The base page is at level 0 and each added element is at a level one greater than the highest level to which it is attached.

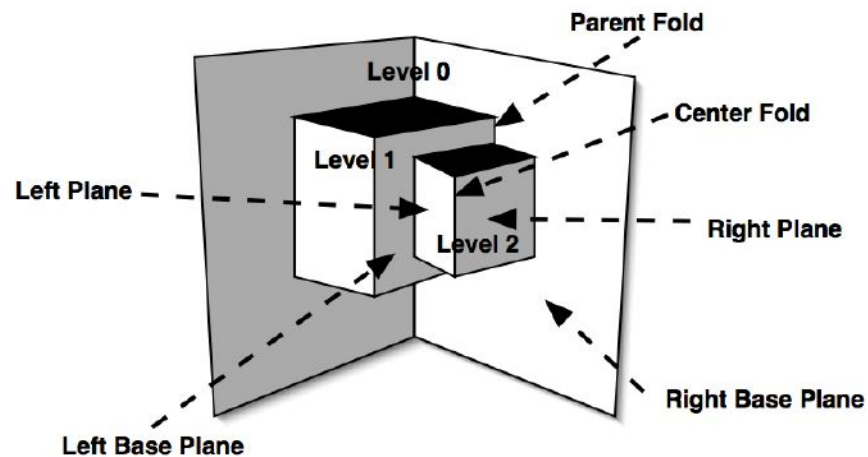


Figure 4.13: Terms describing a pop-up element at Level 2. Note that every element of level 1 or greater has these parts and that Level 0 lacks base planes and a parent fold. Note also that the parent fold for elements of level 1 is the gutter of the base page.

know the level of each element whenever elements are to be placed on one another. As an example, Figure 4.12 shows the result of combining three step elements. In this example the base page is designated level 0 and the level of each added step is always one more than the highest numbered level to which it is attached. Additional terminology also becomes necessary when de-

scribing combinations of elements. Figure 4.13 illustrates these terms for a step at level 2. This step has both a left and right plane. The fold over which the step sits is its parent fold (if the element is at level 1 its parent fold will be the gutter). Additionally, there are right and left base planes, to which the right and left planes of the step are attached.

Constraints on individual elements also apply to combinations of elements. So long as the constraints in relation to the parent folds are met for an element and all the elements below it, the pop-up will fold. One additional constraint for higher-level elements is that they must be small enough to sit on the planes of the elements below them. Therefore, elements become smaller at higher levels.

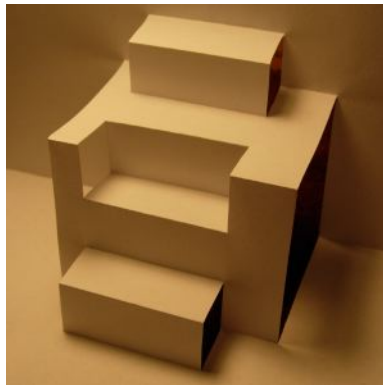


Figure 4.14: An Inverted Element: Placing the same element over valley and mountain folds changes the appearance of an element. Three steps have been placed on another step. The center step, placed over a mountain fold, looks different than the steps over the valley folds.

All elements can be placed over either mountain or valley folds, and 180° elements can also be placed over seams (the edge where a tab is glued). 90° elements cannot be placed over seams, as they rely on a cut being made across the parent fold and in the case of the seam, not a simple fold, this is not possible. Whether a 90° element is placed over a mountain or valley fold directly affects its shape. The normal form of a 90° element can be considered to be one placed over the gutter or any other valley fold. In contrast, a 90° element placed over a mountain fold has all of its own folds reversed in direction from that normal form. 90° elements which have folds reversed from their normal form will be termed *inverted elements*. To illustrate, in Figure

4.14, steps have been placed over each of the folds of a step at level 1 with the center step being an inverted step. Inverted 180° elements are seldom encountered, as they must be placed on the back of the page or other elements in order to have their folds reversed.⁶

4.2 Previous Research on Computationally Enhanced Pop-up Design

While the literature dedicated to the study of using computers to design pop-ups is quite small, common threads of inquiry nonetheless emerge and will help to focus the discussion in this section. Four core topics appear repeatedly: the mathematics underlying the operation of pop-ups, the animation of virtual pop-ups, design tools for creating pop-ups, and techniques for bringing virtual pop-ups to physical realization.

The work reviewed here comes from the only research areas known to be considering computational tools for the creation of pop-ups. First, the work from Nanyang Technological University (NTU) in Singapore focuses primarily on the mathematics of pop-up creation and the design of tools for professional paper engineers that would facilitate the production of mass-produced pop-up books. Second, the literature from the origamic architecture community⁷ concentrates on the development of computer based design tools to allow adult hobbyists to create one-off pop-up cards in the origamic architecture style. Finally, Andrew Glassner's work describes a software tool to help adult hobbyists create multiple copies of pop-up cards that could be given for special occasions.

There is other related research not included here. For example, general research on the modeling of paper and the extensive literature of computational origami are not included. Although these areas of inquiry relate to paper-crafts, they do not involve the production of pop-ups. The production of virtual books, such as the digitization and display of movable books for digital library purposes (see Cubaud, Dupire and Topol [21] for one such study), has been eschewed, as the focus here is on creating physical objects.

⁶ The v-fold may be considered to have an inverted form. For a description of the inverted v-fold, see Section 5.4.3.4.

⁷ See Section 4.2.2 for a description of origamic architecture and examples of pop-ups produced in that style.

4.2.1 Mathematics of Pop-ups

Two papers from NTU focus on the mathematical properties of both 90° and 180° pop-ups elements. The authors' ultimate goal is stated to be the production of a CAD system for creating professional pop-ups. As they point out, only a small number of skilled people are paper engineers. In addition, pop-ups require a great deal of time to design, and the publishing process requires a large number of steps:

...pop-up book manufacturers are looking to computerization, which can capture some of the tedious and time consuming parts of the process and perform them automatically and efficiently. Ultimately the goal is a computer-aided design system with integrated manufacturing facilities. [66, p. 21]

Much of their emphasis, therefore, is on efficiency. Their concerns are not those of this work, focused as it is on keeping the craft aspects of the design and building of pop-ups alive and particularly on helping children learn the craft. However, the authors are clearly focused on paper engineering as it is practiced, and their work is required reading in this area.

Lee, Tor and Soo [66] focus on 180° elements—tents and v-folds—both of which they call v-folds. In fact, a v-fold is an angled form of a tent or more precisely, the angled tent is a variation of the v-fold as shown in Figure 4.15. Angled tents were not included in the taxonomy of Section 4.1.2 for that reason.

The authors present an informal proof that either all four folds or seams of these elements must be parallel (the tent), or all must meet at a single point (the v-fold/angled tent) in order to produce a foldable element.⁸ In addition, they explore the requirement that all attached pieces must be long enough that the page can completely open. They also develop equations for the intermediate locations of the planes of the pop-up as it opens and closes in order to animate the pop-up (see Section 4.2.3).

⁸ It also can be shown that this restriction extends to the 90° elements (step, angled step and beak), although the authors do not do so. Their method of proof relies on the properties of planes bounded by pairwise intersection lines, and the geometry in question is identical in the case of a step and a tent, for instance.

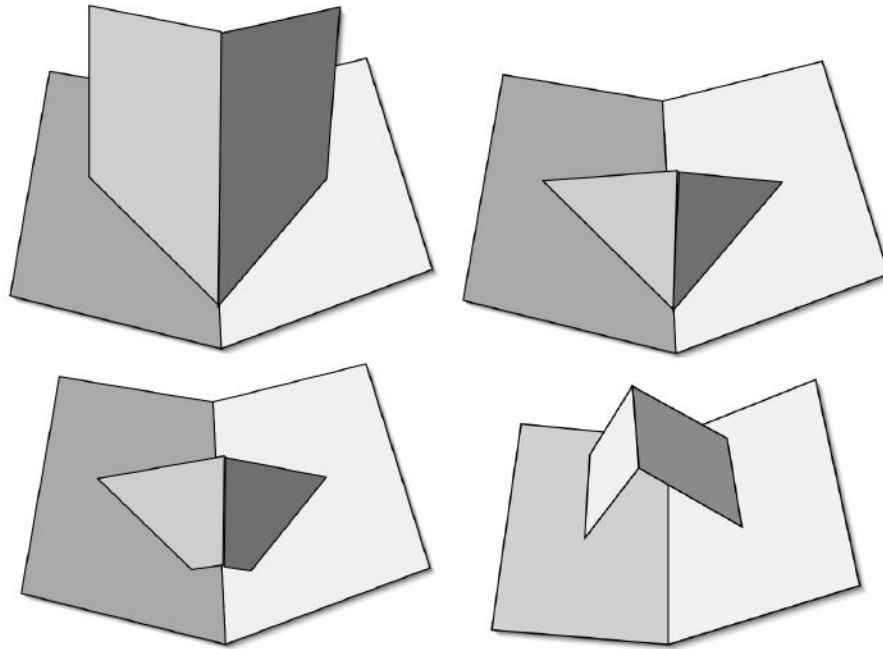


Figure 4.15: The Relationship Between V-fold, Angled Tent, and Parallel Tent: A v-fold (upper left) can be shortened (upper right), and the point trimmed to produce an angled tent (lower left). The angled tent is therefore a modified v-fold. The parallel tent (lower right) is the other possible form of a tent.

90° elements are the subject of a second paper by Tor, Mak and Lee [117]. Here they are concerned with the numbers of valley folds and mountain folds necessary for the elements to be flat-foldable, examining both angled and parallel forms. They present a set of relationships between the numbers of mountain and valley folds and establish that in order to be foldable, a 90° element must satisfy these relationships. However, the reverse is not true: an element can satisfy their relationships on fold numbers and still not be flat foldable, as other constraints may not be satisfied (the angles or distances of the folds from each other, for instance). This paper is much less useful to the designer of pop-up software, as the geometric constraints derived are a subset of those required to produce a foldable pop-up.

Most of the papers by Glassner investigate pop-up mathematics as a tool for animating the pop-up while it is being designed (see Section 4.2.3). However he does derive the major constraint on a beak [36]: that the angles between one outer fold and the parent fold and the other outer

fold and the center fold must remain equal. This constraint is ubiquitous in the pop-up literature but this appears to be the sole proof published.

Groups working in the field of origamic architecture are primarily interested in the relationship of the 2-dimensional pattern to the 3-dimensional folded card in order to store the card in only one form and convert easily from one to another, and in the relationships of the moving points in order to animate the card. These relationships will be discussed in more detail in Section 4.2.3.

The papers from NTU are certainly important work in the area of the mathematics of pop-ups. They present informal proofs of constraints of both 90° and 180° elements as well as a discussion of methods of animation. In contrast, work by groups in origamic architecture and by Andrew Glassner explores the mathematics of pop-up elements primarily as a prerequisite for producing a software tool for pop-up design. That is, they are concerned with the points of elements in three dimensions as the pop-up is opened and closed, but not in the general mathematics of pop-up foldability, with the single exception of Glassner who presents a proof of the constraints on asymmetric beaks.

4.2.2 Computer Based Pop-up Design Tools

The only available software for the design of pop-ups is produced for the construction of origamic architecture. Origamic architecture (OA) encompasses a subset of pop-up elements, and has been developed by Masahiro Chatani [17] in a series of books of origamic architecture designs. Technically, origamic architecture cards are produced by cutting and folding one sheet of paper. It differs from traditional pop-up making in that there are no pieces added by gluing and therefore most origamic architecture consists entirely of 90° elements. Three examples of origamic architecture designs are shown in Figure 4.16. Buildings are a popular subject of origamic architecture cards, but lovely abstract designs can be produced as well.

Origamic architecture designs are simple in concept, but that simplicity can be deceptive. As Mitani says:



Figure 4.16: Examples of Origamic Architecture: Three designs by Masahiro Chatani. Clockwise from left are Rokuzan Museum, Todaiji Temple-Daibutsu-Den, and Wedding Cake. Picture courtesy Masahiro Chatani [17].

Because of the limitations that the paper can be cut but not added to, designing OAs requires a great deal of experience. Traditionally they have been designed by a process of trial and error. [75, p. 93]

Computer enhancement of the design of origamic architecture is aimed at the adult hobbyist of this style and the production of single cards.

Mitani, Suzuki and Uno [76] provided the first description of software to aid the origamic architecture designer. The software described was called 3D Card Maker [77] and was later distributed by Tama Software as Pop-Up Card Designer⁹ [113]. This is the only currently available commercial software for pop-ups, albeit for a limited subset of elements. In fact, the only pop-up element available is the step.

⁹ Pop-Up Card Designer is available for Windows only at a current price of US\$18.

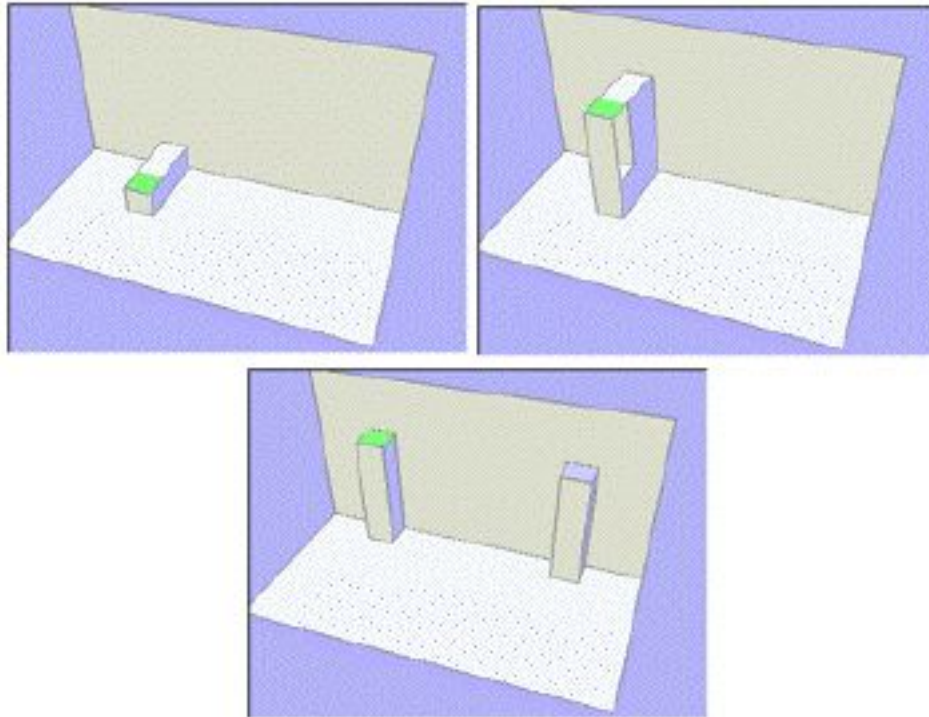


Figure 4.17: Making a Pop-up with Pop-Up Card Designer: The cursor (green square) is controlled with the arrow keys and space bar. A mirroring mode is available (below) for making balanced designs. Picture courtesy Tama Software [113].

The user interface for Pop-Up Card Designer is a simple one. As shown in Figure 4.17, the design is made on the 3D representation of the card. Keyboard keys are used to position the cursor and build the element. A mirroring function is provided as well, since origamic architecture designs are often symmetrical. The design can also include “windows” cut out of the vertical planes.

One limitation of Pop-Up Card Designer is that it only produces designs in which an edge is parallel to an axis. That is, all cuts are straight, and the design is built by stacking cubes.¹⁰ Diagonal lines must be approximated with staggered-height cubes, and a design like the Todaiji Temple-Daibutsu-Den in Figure 4.16 cannot be made with this software as it contains curved cuts. In a later paper, Mitani and Suzuki [75] describe a method to overcome this restriction. As with the

¹⁰ In the 2 dimensional form in which the design is stored, this equates to covering the design with squares.

Pop-Up Card Designer method, the process is simplified by origamic architecture requirements confining designs to a single sheet of paper without added pieces. This provides two primary simplifications in the software. First, there is a one-to-one mapping between points on the 2D sheet of paper and the 3D construction since all points exist on only one sheet. Second, every design can be defined on the paper sheet as a set of non-overlapping polygons.

To generalize from the original design using squares to the new design in which any combination of polygons can be used, Mitani and Suzuki propose a system in which the plane of the new polygon is overlaid on previous polygons. The previous ones are cut away, creating a non-overlapping set of polygons that completely cover the paper. Since this can lead to a design that satisfies the condition of having no overlapping polygons but will not be foldable, a “test for pop-up condition” is used to allow the user to verify the design. This is a simple connectivity test, as the pieces must connect in order to be lifted by the opening process. The authors have created prototype software that implements this method.

There are several remaining issues with this method. For instance, the authors have not implemented the creation of curved cuts. Also, the interface is not as simple as that in the existing software, although it is incompletely described. In addition, it is not clear when the “test for pop-up condition” is made, or what the software does when the test fails. If the test is made on design completion it seems that it might be painful for the user to finish a design, then find that it does not open. If the test is made at each change operation, it may be intrusive to the design process. Moreover, the authors indicate that a successful test does not guarantee that the pop-up will open and they do not indicate how often or under what conditions it would fail to predict pop-up behavior.

In Chen and Zhang [18] and Zhang and Chen [130], this method is extended. These papers draw heavily from Mitani and Suzuki but simplify the user interface and incorporate smooth contoured faces via curved cuts.

The most complete software for the design of pop-ups is described by Glassner in a two-part paper [36, 37], a technical report [34], and a patent [35]. These four sources describe

the same system, although each concentrates on different details. The software is not publicly available, although Glassner claims to have used it to design cards for personal use. The two-part IEEE article is required reading for anyone desiring to model pop-ups computationally, as Glassner is an experienced paper engineer who is familiar with the existing literature, range of elements, and problems involved in the computer generation of pop-up elements.

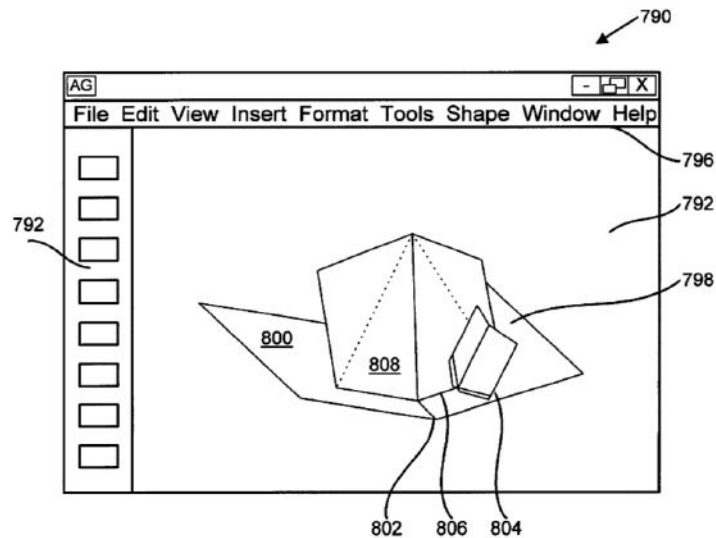


Figure 4.18: Pop-up Assistant Interface. Picture from the patent [35].

Glassner's focus is on the hobbyist who wants to make multiple copies of a single pop-up card, such as could be used for a party invitation for example, something that becomes time-consuming if the cards are made completely by hand. In addition, Glassner notes that some elements are difficult to make, and take a considerable amount of trial and error to produce—in particular he mentions v-folds where the designer desires a particular slant when opened, and his software is aimed at reducing the effort to make such elements.

Glassner describes a wide variety of pop-up elements that he has implemented, but excludes those that require bending (boats for example) as do the other authors in this section. He works with both 90° and 180° elements but only talks in depth about beaks and v-folds, using beaks as an example to develop the mathematics of his animation method (see Section 4.2.3).

Glassner has developed his *pop-up assistant* to enable the user to design cards using an array of elements, which include v-folds, beaks, tents, steps, moving arms, pull-tabs, and wheels. The interface is incompletely described, and as the software is not available, the reader is required to make inferences about how it might function. Figure 4.18 shows the interface as illustrated in the patent, which is the best illustration available. The pop-up assistant as described appears to manipulate the 3-D representation, with the elements added to the screen using drag-and-drop from a menu. The corners of elements appear to be equipped with handles to change their location, however Glassner also mentions that the user is able to specify the angle for a v-fold separately. The pop-up assistant checks the constraints for each element and modifies the card to preserve them:

The designer may create mechanisms, open and close the card, and interactively drag points around; the rest of the mechanism is automatically adjusted as necessary. [34, p. 4]

The pop-up assistant also incorporates some useful error detection for the designer. Glassner locates colliding elements as well as elements that protrude from the cover when the card is closed.

The team at NTU, although their long-term intent is to produce software for professional pop-up publishing, has no software system for design as yet. The pop-ups used in animation tests are hard-coded into a graphics package, which allows them to produce an animation of the pop-up and images of the result.

Although two systems have been described in the literature, only one actual system is available and this system allows only the production of designs in the origamic architecture style, a limited subset of elements not including those used in professional pop-up books. Both systems allow manipulation of the elements, including changes to elements already placed, although Pop-Up Card Designer uses a keyboard interface while Glassner's interface appears to be primarily mouse-driven. In both cases, changes are made to the 3-dimensional representation of the card being designed.

4.2.3 Viewing the Operation of Virtual Pop-ups

One important part of any design system for pop-ups is some method for viewing the operation of the virtual pop-up by animating¹¹ the 3-dimensional representation. That this is necessary, or at least highly desirable, follows from the importance of both the motion of the design (the aesthetics) and the need to verify that the opening proceeds smoothly with no pieces colliding (the functionality). All of the researchers in the field have addressed this problem.

There are two parts to the problem. The first, and most easily solved, is that the change in the positions of elements on one level causes a corresponding change in the positions of elements on the levels above it when the pop-up is opened and closed. It is necessary to consider how these changes are propagated through all of the levels of the pop-up. Second, and the more difficult, is to determine exactly how the points defining each element move in 3-space.

In Lee, Tor and Soo [66], formulas for calculating the positions of the elements when the pop-up is partially open are derived trigonometrically. The authors consider only 180° elements in the form of tents and v-folds. In the case of the tent this is the calculation of the distance between the two side folds for a given angle of opening, while in the case of the v-fold, the formulas produce the angle between the pop-up and the page on each side fold. They also discuss the necessity for calculating the positions of elements on each level in order to provide input to those calculations for the next level. This requires the element information to be contained in a list of N elements, where N is the total number of elements in the pop-up with the elements added to the list starting with the lowest level. If calculations for a given angle of opening proceed in list order, the opened points can be calculated in $O(N)$ time. Because the authors have no software for generating pop-up designs, examples of pop-ups are given pre-computed starting points and are displayed on the screen at various opening angles.

In origamic architecture the animation is easier, as there is a simple trigonometric relation-

¹¹ The word *animation* is the most accurate to describe this process. Wrench [128] provides a good description of the problems with simulation and suggests the term animation to describe “lightweight simulation [128, pp. 96–99]” of the kind presented here.

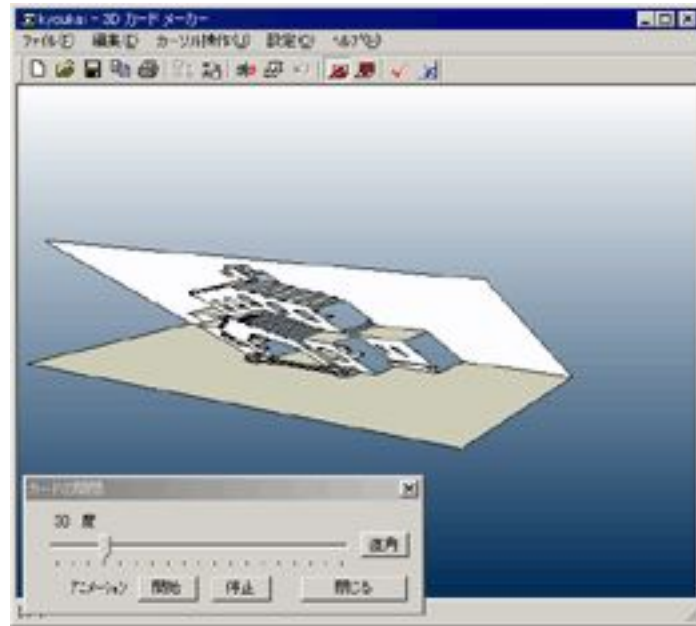


Figure 4.19: Animation of the Pop-up with Pop-Up Card Designer: A slider controls the opening angle. Picture courtesy Tama Software [113].

ship between a point on the pattern and its position in space as the paper is lifted, as described in Mitani and Suzuki [75]. If the point is stored with the values (x, y, z) when $\theta = 90^\circ$, the final point in 3-space (X, Y, Z) for any other angle θ is $X = x$, $Y = y - z\cos\theta$, and $Z = z\sin\theta$. This is the method most likely used in Pop-up Card Designer where, once created, the design can be animated to show the opening and closing (see Figure 4.19). There is no enforced order in which to calculate the 3-space version of the points, as there are no dependencies between them when stored in the (x, y, z) form.

In Glassner [36, 37], the locations of the moving points during opening and closing are found using equations derived for intersection points of three spheres. This calculation is illustrated for the beak and the v-fold. Glassner states that other elements (including parallel elements that he mentions but does not describe in detail) can use the same method, but he does not provide an example of how this can be done. He uses, as do Lee, Tor and Soo [66], a list to keep the elements in order so as to process the lower before the upper. However, the statements:

To process the risers [his element data structure], I start at the beginning of the list and look for a riser that can be positioned..I compute its points and mark it as positioned...When I reach the end of the list, if I positioned any riser on that pass, I go back to the start and go through the list again... If efficiency is an issue, you can preprocess the list and build a tree structure that you can later traverse in a single pass. [37, p. 75]

are somewhat puzzling, as a list with the elements added in order of construction should only need to be traversed once, as established by Lee, Tor, and Soo [66].

The subject of pop-up animation is an important one as witnessed by the fact that all the researchers involved have been concerned with the subject. Animation provides visual feedback to the user about the the pop-up, including the motion produced and the interaction, including collisions, among the elements. Paper engineering is a craft in which the final motion of the object is of paramount importance. Not surprisingly, among the three approaches, there are three solutions. The simple case is origamic architecture, in which the points can be calculated with a simple set of formulas in no particular order. For the more complex 180° elements NTU and Glassner employ a similar method, a linked list of elements, although the methods by which the points for each are calculated are derived differently. And in all cases, once the points defining the elements are calculated, they may be displayed by use of a graphics package.

4.2.4 Creating Physical Pop-ups from Virtual Representations

The two complete design systems examined have been those of Glassner and Pop-Up Card Designer. In these systems, the 3-dimensional representation of the pop-up is the one on which all additions and changes are made. Some method needs to exist to transform this representation into two dimensions so that construction of a physical pop-up can be undertaken. Neither system presents a 2-dimensional representation to the user during the design phase.

Figure 4.20 shows the original design page of a complex design and the pattern page produced from it in Pop-Up Card Designer. While the user can view either representation, she must switch between them. The pattern shows fold and cut marks in the usual form for origamic

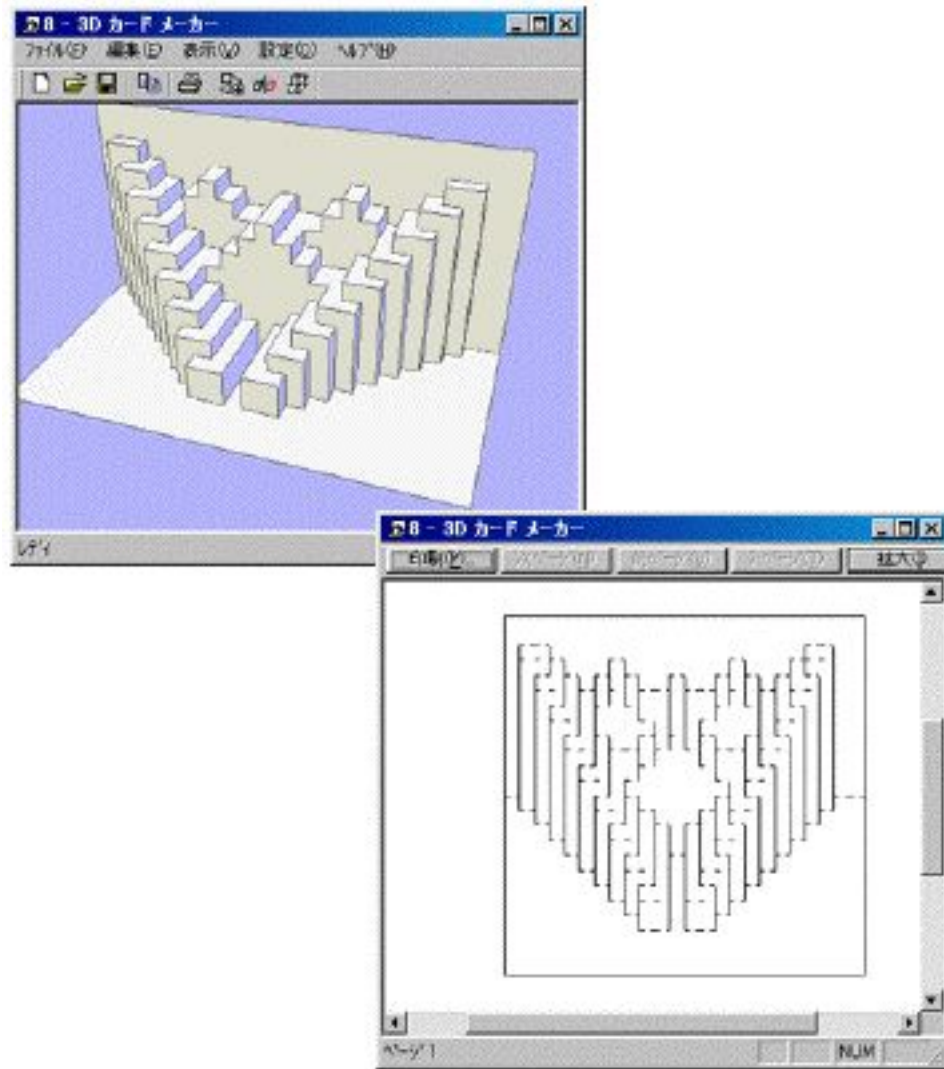


Figure 4.20: Printing a Final Pattern with Pop-Up Card Designer: After designing the pop-up, a pattern with cut and fold marks can be produced and printed. Picture courtesy Tama Software [113].

architecture patterns, with folds as dashed lines, and cuts as solid lines which are transferred to the printed sheet.

Glassner's system presumably acts in the same way, although no details are given. It seems likely that a window displaying the separate pieces to be printed is not displayed, since one is not shown. He does have one concern which does not arise in origamic architecture in that he must provide tabs for pieces that will be glued onto the pop-up, and guide lines to position the pieces.

Glassner also considers one additional detail that becomes important when printing many cards. He proposes a simple method to pack pieces on the page to reduce paper waste. Such algorithms are used for applications in clothing manufacture where patterns for cutting must be packed onto the smallest amount of cloth. (See Milenkovic, Daniels, and Li [74], for instance). Glassner places bounding rectangles around each piece and uses a greedy algorithm to position the rectangles onto the paper.

NTU has not yet reported developing a system which is capable of actually designing or producing physical pop-ups, rather their work has focused exclusively on the mathematics such a system would require.

Of the three research areas, the two which can produce physical pop-ups have chosen to present the pop-up in progress for editing in 3-dimensional form and either show the pattern separately for printing, or simply print the resulting pattern. Having the pattern (the notational representation) displayed with the 3-dimensional representation would seem to be particularly useful for the learner. However, even the practiced maker of pop-ups could benefit from seeing the 2- and 3-dimensional forms change together as the pop-up is designed or decorated.

4.3 Introduction to a System for Children's Use in Pop-up Crafts

The research discussed in the previous section focuses both on mathematical and theoretical work on computational enhancement of paper engineering, as well as actual systems. But for the purposes of this research, there are some things that have not been examined in this literature. First, children are never considered as users of these systems which are designed with adults, either hobbyists or professional paper engineers, in mind. Second, the systems described or envisioned are not seen as learning tools. The users would be employing these systems to design pop-ups on a continuing basis, not learning how to make pop-ups without the system.

There are, however, important similarities among these works that are useful to consider for the design of a system for children's pop-up construction learning. All of the researchers discuss the importance of presenting a 3-dimensional view of a pop-up in progress, and of animating

this view in order to show the motion produced. All have considered pop-up elements as the basis for their design system, although they differ on which elements they feel are most important. Finally, all propose to produce output that can be used to make the final pop-up in physical form.

A framework was previously established to investigate the acquisition of craft ability. This framework was used in Chapter 2 to explore the use of computers in providing tools for learning craft in general and in Chapter 3 for a similar exploration for learning paper engineering. This framework can also serve as a guide to the design of software for teaching the craft of pop-up making by helping to focus on ways that knowledge, skill and appreciation of pop-ups can be enhanced through the use of software.

Some general principles should be recalled here. First, the desired operation of the software is a great deal like that of the toy looms used by children of Mayan weavers. The software should help the learner bypass some of the more difficult tasks involved in the design of pop-ups, in particular the geometric constraints required for the page's opening and closing. Second, the software should be based on the actual practice of paper engineering. For instance, elements are at the heart of the pop-up design process and should be introduced explicitly. In addition, the notation should be as standard as possible. Finally, the software should be simple to use. It should not present barriers of its own, but be an easy guide to the craft of paper engineering.

4.3.1 Supporting the Growth of Knowledge

Section 2.4 mentions several ways in which computer software can aid in the acquisition of knowledge. The first was to enforce standards so that it is easier to design a working item, thus reducing frustration. This suggests that it would be helpful to design a pop-up system where the geometric constraints on elements are always enforced thereby making it more difficult to design a pop-up that will not open and close properly. Second, every craft has a notation, and the simultaneous presentation of both notation and final craft object can help one learn how the notation works and how to predict the form of the final object from the notation. For this reason, it makes sense to present both the notational representation (also called the pattern) and

the 3-dimensional representations of the virtual pop-up to children, not just the 3-dimensional representation alone. In addition, since a paper engineer commonly works on the pattern sheet of paper directly and not a 3-dimensional form, it also makes sense to have the user draw elements directly on the pattern in preparation for a time when she is no longer using the tool. Third, it is important to be able to experiment quickly with many designs. For this reason the user should be able to change and remove elements easily. Fourth, vocabulary learning can be aided through the use of standard vocabulary in the software and documentation. It has been noted that the names used for elements are not standardized across the domain. The taxonomies in this chapter (Figures 4.1 and 4.5) use names that are meaningful and child-friendly: *step* rather than *90° double slit* for example. It is also important that these names be used consistently in help tools, the interface, and the documentation. This promotes learning a standard vocabulary from the beginning and improves understanding. Finally, a useful set of elements should be included. However, these should be a basic set, leaving the user room in which to experiment with variations of these as well as other elements on her own.

4.3.2 Supporting the Growth of Skill

The desire to have an incomplete set of elements present, so as to force the user to modify and innovate, is also an example of an aid to skill development. By offering the most commonly used elements but not restricting the user solely to them, the user is encouraged to make changes to the elements and to add elements without the use of the software.

Section 2.4.2 cautioned that computational enhancement of a craft can take too much away from users in terms of actual fabrication practice. For this reason, the actual construction of the pop-up, including cutting, folding and gluing, should be accomplished by the user. To that end, it is also advisable to have the documentation cover some of the details on how to assemble final pop-ups, as children may be working without adult or experienced help. Flagging of errors, if it is included, could include collision detection as in Glassner's pop-up assistant. This is another way in which the computer can easily perform a task that would be otherwise impossible until the

time that physical construction occurs.

4.3.3 Supporting the Growth of Appreciation

The growth of appreciation is linked to the opportunity to see the designs of others and compare them to one's own. This part of craft learning is harder to support computationally than the other competencies, but several design decisions can be made to allow these opportunities.

Such facilitation is promoted by the ability to share designs among users of the software. For example, printed copies of the designs can not only be used to construct the pop-up, but can be shared among users. This ability to print multiple copies allows several children the opportunity to own a copy of a book that they have designed together. In another possible scenario, a simple pop-up produced in multiple copies for a group of children can be decorated and varied in numerous ways by each, with the addition of color, craft decorations such as sequins, or additional pieces of paper. A simple pop-up could also be made to tell a different story by each child. The ability to print multiple copies of a pop-up therefore becomes an aid to the acquisition of appreciation. Johnson [58] uses lessons such as these frequently, for example, his exercise on a step element (that he calls a *basic box*) as described in Section 3.3.2.

Another method of sharing designs is provided by writing files from the software that allow the user to save her work. This not only allows the user to return to the design later, but to share it with others who have the software and want to make their own changes to it. The user is therefore able to use the designs of others directly, or to revisit her previous designs to improve them. It is important that this format produces files that are small in size for easy transmission. It is also useful to have a format which can be parsed without the help of the software making a text-based format desirable.

Yet another way of sharing designs is by creating pictures of the pop-up pages. These can not only be sent to others who may not have the program, but can be imported into graphical tools to add textures, photos, or other decorations.

To further support the growth of appreciation, the documentation for the software can

be an important adjunct to the software itself as it can include places the user can go for more information, pictures of other pop-ups, and tips on how to alter and decorate pop-ups. This provides the learner with other sources, in particular on-line sources, for ideas and pictures of pop-ups by other artists.

4.3.4 Other Design Considerations

There are a few design considerations which may be gleaned from the research in this area but are hard to place in a particular competency.

When printing the final copy to construct the pop-up, Glassner makes a good case for putting as many pieces on one sheet as possible to decrease paper waste, and suggests a possible simple algorithm for doing so. However, Glassner is designing software for the use of the hobbyist making multiple copies of each pop-up, a case in which a great deal of wasted paper could result. For the young learner of the craft of paper engineering it seems likely that only one copy of a given design will be made at any time. Paper waste would be minimal. Even if multiple pieces are placed on one page, it might be best to have the option for printing one piece per page in order to allow printing of a given piece on differently colored paper, or to easily replace a piece damaged in the cutting process.

A mirroring function is provided in Pop-Up Card Designer. This is particularly useful in the origamic architecture style as such designs are often symmetric. In addition, this is a task that is easy for the computer to provide and difficult for the paper engineer to accurately produce and could be a useful addition to such a system.

4.4 Summary

In order to come to an understanding of the ways in which computation can be added to pop-up design, it is necessary to understand how paper engineers construct these objects with an eye toward mimicking those methods. Pop-ups and other movable forms are composed of elements that can be combined and modified to produce the desired results.

Pop-up elements are a subset of movable book elements, and can be divided into 90° elements that are best displayed when the page is half-opened, and 180° elements that are shown to best effect on a fully-opened page and most professional pop-ups are composed of 180° elements. Elements can further be divided into angled and parallel forms depending on their relationships with their parent fold (the underlying fold over which the element sits).

Elements can be transformed by the addition of attached planes. Each type of element has its own set of geometric constraints that must be met to allow it to fold properly when the page is opened and closed. These constraints continue to hold when elements are placed on top of one another and this poses a number of problems when attempting to animate such structures in software.

The literature on the computational enhancement of the animation and design of pop-ups focuses primarily on mathematical descriptions of pop-ups and work on simulating the opening and closing of pop-up elements. The main problem, determining the locations of the points of a pop-up at any degree of opening, has been approached mathematically both trigonometrically and by calculating the intersection of three spheres. It has been established that a list of elements can produce these locations in $O(N)$ time, where N is the number of elements.

Several pieces of design software have been produced, only one of which is available to the public. This program, Pop-Up Card Designer, is easy to use but is not designed as a learning tool for children and designs only a limited set of pop-ups in the style called origamic architecture (OA). Origamic architecture consists of single-sheet pop-ups that are produced by cutting and folding, but not gluing on additional pieces. Andrew Glassner has designed a more flexible system, but it is only minimally described and not available. All systems so far rely on the user making changes on the 3D representation of the pop-up, and none are aimed at children learning the craft.

Using the framework described in Chapter 2, the research results from Section 4.2, and the analysis of paper engineering as a craft as seen in Section 3.2, general rules for the design of pop-up design software for children can be established. First, it is desirable to have the editing done

on the 2D pattern, rather than on the 3D representation to facilitate learning about the notation of paper engineering, and to mimic the design methods of most paper engineers. The interface should be kept as simple as possible, and unneeded features should not be included. Part of the purpose of these choices is to force the user to develop skills of folding, cutting, gluing, altering the elements into new shapes, and decorating. Elements included should be common, versatile, and provide a range of types: 90° , 180° , angled and parallel. In addition, users should be able to share designs.

Now that the basic criteria used in the design of such a tool have been established, Chapter 5 provides the details of the design of Popup Workshop and the implementation of the program.

Chapter 5

The Popup Workshop System

In the previous chapter, the basic types of elements, the building blocks of pop-ups, were introduced since any attempt to provide design tools for paper engineering must be based on these elements. In addition, the methods used by other researchers in this area were examined. It has been shown that these methods are not aimed at children, nor are they proposed as a learning tool for this craft. In addition, it was seen that the only available software is designed only for the very limited subset of origamic architecture and not for pop-ups in general and that more general pop-up software is not available. Finally, some broad proposals were made as to how software for children learning the craft of pop-up making should function.

This chapter proceeds from that discussion and details the design and construction of the Popup Workshop system. Section 5.1 builds upon the general requirements for a pop-up design system for children developed in Section 4.3 to present the overall criteria for the design of Popup Workshop. An outline of the version history and the reasons behind the selection of Java as the programming language are reviewed in Section 5.2. Section 5.3 discusses the software from the viewpoint of the user: the windows, tools, and menu items. Section 5.4 is concerned with the internals of the software including the data structures, the geometric constraints that must be maintained for each element, and the algorithm used in opening and closing a page.

5.1 High-Level Design Considerations

Section 4.3 introduced several general principles that are embodied in Popup Workshop. First is the desire is to emulate the actions of a paper engineer as closely as possible. This means that the focus of the process should be on selecting elements to produce the desired design and motion, and then drawing each element's shape on the pattern rather than on a 3-dimensional representation, as a paper engineer cuts or draws her design on a flat piece of paper. But it also suggests that a 3-dimensional representation be made available that can be easily manipulated to see what the motion of the pop-up is like before the design is printed, glued and folded. Second, by enforcing geometric constraints on the elements, it is possible to insure that any design can always be folded flat. Third, the user should be able to change and delete elements easily in order to allow experimentation with many designs and their variations. Fourth, the operation of the software should be as simple as possible, offering ample help and with minimal or no explicit error conditions presented to frustrate the user. Fifth, the most commonly used elements should be available in the software while allowing them to be decorated, modified, or augmented when the pop-up is constructed. This helps the user build the knowledge and skill necessary to grow beyond the capabilities of the software. Sixth, easy to remember names for the elements should be used consistently in all parts of the software. And finally, standard file formats should be used in order to allow users to share designs or to bring them into other programs for decoration. In this section, some specific design decisions embodied in Popup Workshop are described that extend or complement these general principles.

The decision to include limited numbers of the most useful elements in Popup Workshop needs to be further explored. While there is the desire to add more elements, thus expanding the capabilities of the software, it also helps learning to have some things that cannot be done by the program, forcing the learner to do them. In the design of Popup Workshop, many elements and their variations were considered. However, it was decided to include only a few of the most widely used elements. This allows children the opportunity to modify those elements into new forms

for themselves while minimizing confusion from having to choose between similar elements when designing a pop-up. 90° elements are useful for origamic architecture and mathematics education and are more apt to be already known to children from any previous pop-up making experiences. 180° elements are used extensively in traditional pop-up books with which children are familiar. Popup Workshop thus contains both of these types of elements in order to allow children access to those elements that may have been encountered previously. In both of these categories angled and parallel elements are represented giving users the opportunity to create more varied and interesting pop-ups. To this end, five elements were chosen for Popup Workshop: the beak (angled 90°), the step (parallel 90°), the angled step (angled 90°), the tent (parallel 180°) and the v-fold (angled 180°). It is interesting to note that in Table 4.1, tents, v-folds, and beaks account for approximately half of all of the forms used in the books examined.

Some important elements were not included. Elements that utilized bent paper shapes were considered beyond the scope of this work, as they introduce complications in modeling. A major assumption in modeling the 3D shape was that distances of points on a plane of an element remain the same during the opening of a pop-up, something that does not occur with bent paper. Attached planes (see Figure 4.9) come in many forms and can easily be added after the pop-up is assembled, as they are most often flat pieces of paper glued to the side of another element. A tent can be used for the supporting structure to hold an attached plane away from the side of an element (see Figure 4.9). There are also additional elements that are easily constructed by modifying those that are provided. For example, moving arms are indirectly available by adding an attached plane to a beak. As mentioned earlier in this chapter, the v-fold can be converted to an angled tent by the method shown in Figure 4.15. Indeed, there are many possible variations on v-folds, some of which could have been included as separate forms, but all of which can be constructed using the provided simple v-fold as a starting point.

With respect to the design functions of the software, there were capabilities that were not included for the same reasons. For instance, only two decorating options were included: the painting of planes in a single color and the drawing of colored lines. This is in no way limiting as

the designer is free to further embellish her pop-ups in a variety of ways. Pop-ups can be imported into other programs to be decorated with textures or photos, straight lines can be cut as curves, and surfaces can be decorated with various art materials or have additional pieces added to them.

Although the software tool aids the design process, the final jobs of cutting, folding and gluing were left for the user, even though it is possible to use a laser cutter or a knife machine to cut out pop-ups.¹ This, however, is not desirable as children need to learn how pop-ups are put together and gain experience with tools and materials.

One of the general principles mentioned previously was to minimize user encounters with error conditions. Trade-offs must be considered in decisions involving error reporting. One of the ways in which beginners learn any skill is by making mistakes, discovering their mistakes (or having them pointed out), and correcting them. On the other hand, if errors are constantly reported, the beginner can become frustrated with the process. There are two questions that arise. First, should the user be able to produce a non-functional pop-up with the software? Second, if such problems are allowed to occur, should the user be alerted to their presence? It has been noted that there are two ways in which the design of elements can produce a pop-up that does not open and close properly: not adhering to geometric constraints and the collision of multiple elements. Using a computer for design allows the geometric constraints to be checked and enforced. Therefore, it seemed beneficial to silently enforce constraints in software in order to eliminate this class of errors. This decision removes the opportunities for the user to be forced to either learn the constraints or to produce non-functional pop-ups, but it makes the software much more usable. Likewise, collisions could be identified, but the presence of a movable 3D representation of the pop-up allows the user to observe when a collision occurs in most cases. Thus, no error reporting was included in the software.

Concise and thorough documentation for the software can assist the user who does not have an experienced paper engineer on hand. It should include information about how to construct the final pop-up from the design produced, pointers to other sources of pop-up construc-

¹ A laser cutter was used by the author on one origamic architecture design as a test, and worked quite well.

tion advice, and photos of designs made by other user of the program. In addition to advice and sources for students of the craft, the documentation for Popup Workshop 2.0 (see Appendix C) includes curricular references for teachers as well.

In spite of the stated purpose that this software to be used by children, few design decisions were driven specifically by this purpose. There were two reasons for this. First, an overall desire already existed to make the software simple to use. Simplicity of use is not an issue only for children; simple software works for adults as well. Second, there was some uncertainty about the ages of the children who might use the software. Reports of pop-up making in the classroom (see Section 3.3.2) included children as young as six for Johnson [58] and as old as high-school aged for Simmt [108]. However, there was some doubt about the range of these ages for general pop-up making as very young children might find the craft too difficult and older children might think that it was “for babies”.

There were however a few decisions based on children using the program. It has already been mentioned that error conditions were avoided or left to the user to detect in order to minimize frustration. It was also decided that the ability to read should not be a prerequisite to using the program. For this reason, buttons are labeled with icons while the tool-tips, which offer supplemental information, use the written word. Consistency of operation was a major design consideration. For example, all elements are added in the same way, and the change, delete and replicate functions use the same sort of operation, with small squares appearing on points for the user to choose. Finally, although x- and y-coordinates for the mouse are given, a grid may also be used for positioning corners of the elements. Thus, understanding Cartesian coordinates is not necessary.

5.2 Design History of Popup Workshop

Java was chosen as the programming language for Popup Workshop primarily to provide portability. Design was done on the Macintosh, but it was desired that a user could use any operating system on any personal computer. In addition, Java is freely available and has a large

user community. This last consideration is important for future development as it is hoped that the software can be released to the open source community. Finally, Java has (in Swing) a graphical interface environment in which the use of the mouse for drawing could be supported, and the Java 3D libraries simplified the process of showing animated pop-ups. Java was used from the beginning of the design for Popup Workshop.

Version 1.0 of Popup Workshop was made for the Macintosh only and included just the three 90° elements: the step, the beak and the angled step. Since only 90° elements were included in the program, there were no extra pages for attached pieces. The graphics in the Viewer Window were somewhat primitive as perspective was calculated for a static object. Although the pop-up could be opened and closed, no rotation was available. All of the capabilities of editing pop-ups were provided (change, delete and replication of elements) and all decoration options were present, and therefore the interface looked quite similar to later versions. The File menu items were not present, therefore no capabilities to save or load files or to export graphics were available. Printing had to be done by capturing the screen. The points of the elements used for opening and closing the pop-up were computed using a constraint system, but the algorithm used random hill-climbing. This provided acceptable results, although it was slow when many elements were on the pop-up. Although Version 1.0 was crude, it was capable of allowing designs to be made, and proved the viability of constraint programming for the calculation of opening and closing the pop-up. Version 1.0 also provided a proof of concept for enforcing the geometric constraints of elements. Several test cards were made with the program, and it was decided that future versions would include only minor changes to the user interface.

In Version 1.1, support was added for Windows, a faster algorithm was implemented for opening and closing the pop-up animation, and an x- and y-coordinate display was added to the Editor Window. Probably the most important addition was the **File** menu that provided the ability to print pop-ups, and to save them in forms that could be opened both in the software, and as graphical images. These additions required the selection of appropriate file formats.

Section 4.3.3 discussed the desirability of saving designs in a compact, text-based format

that allows the user to revisit previous designs to change or improve them or to share designs with other users of the program. Extensible Markup Language (XML) was chosen for Popup Workshop as it is a flexible, readable format that can be adopted to the task of saving pop-up designs. In addition, Java provides classes for parsing XML. That it is human-readable is an advantage as well for the developer, as it allows examination of the pop-up designs produced and provides some debugging ability. More detail on the format of Popup Workshop save files can be found in Section 5.4.2.

It is also useful to be able to share designs with those who do not have the software or to print designs without using the software. In addition, a standard graphical format can be imported into software tools for additional decoration, size changes, or other alterations. Many graphical formats would be appropriate, but the Joint Photographic Experts Group (JPEG) format is a standard, nonproprietary format that can be displayed and manipulated by many graphical tools.

Aside from these improvements, the program was largely unchanged in Version 1.1, as the interface had been found useful, and the 90° elements previously included were kept. Some small amount of user testing (further described in Chapter 6) was done with a few 5th grade students, some middle school students in a summer program, and an undergraduate intern. During that testing, it was realized that better animation that could be viewed from multiple angles would help users identify and avoid collisions between elements. Also, the lack of 180° elements, while not crippling, did not allow children to produce pop-ups that looked like those they were used to seeing in professional pop-up books. It was also realized at this time that messages to suggest what action might be taken after a button was selected would help the user, as the students (who were old enough to read) had difficulty with the click and drag method of drawing for the first few elements they made.

Building on this information, Version 2.0 added two 180° elements and took advantage of the Java 3D libraries to completely rewrite the viewer. This allowed for rotation of the pop-up in the viewer and the addition of more realistic lighting made it easier to see what elements were

doing when the pop-up was in motion. Since the elements could now be viewed from any angle, it became necessary to cut out those areas in the planes that the 90° elements produce. Help was added, and the terms used for elements were standardized to their current form. Version 2.0 was used for the testing described in Chapter 6 and is detailed in the following sections.²

5.3 User Interface

There were several design decisions that affected the interface and should be enumerated here. First, the design of the pop-up is created on the 2-dimensional representation (the pattern), and the 3-dimensional representation reflects those changes at the same time. This allows the user to learn the notation for 2-dimensional patterns and also to see the design as it will exist when it is constructed. The mouse is used to add and manipulate elements in the pop-ups. Existing design systems use either the keyboard (Pop-Up Card Designer [113]) or the mouse (Glassner [36, 37]). The keyboard option seems only usable for the simple case where a single element (step) is being created. Since the desire here was to allow the user to create several types of elements and easily manipulate them, the mouse allows more options and control.

Some of the more important interface decisions concerned the methods for adding elements and for editing elements already present. All actions are chosen by selecting buttons that are grouped into three tool palettes. In the first tool palette, the button corresponding to the desired element is selected and the element is then drawn using the mouse. To do this, the cursor is placed near a fold or seam (it does not have to be directly on the fold or seam), the mouse button is held down and the corner of the element is dragged into position. Only one side of the element needs to be drawn as the element produced is symmetric. The simple shapes drawn are a rectangle for parallel elements and a triangle for angled elements, thus reinforcing the differences between these forms. Elements can be altered later to be made asymmetric if desired. The second palette of buttons allows for changes to be made to the elements. These buttons allow the user

² Both versions 1.1 and 2.0, and the documentation for each, are available for Macintosh and Windows users on the Popup Workshop web page [48].

to change the position of an element's corner points, as well as delete or replicate an element. Once again, all the operations in this palette operate in the same way. Small squares appear on all corners of the elements and the user can pull them (for change) or click them (for replicate and delete) to effect the desired action. The third palette contains tools for decoration. These include buttons to change the fill or drawing color, fill planes with color, draw lines, and show or hide the grid lines.

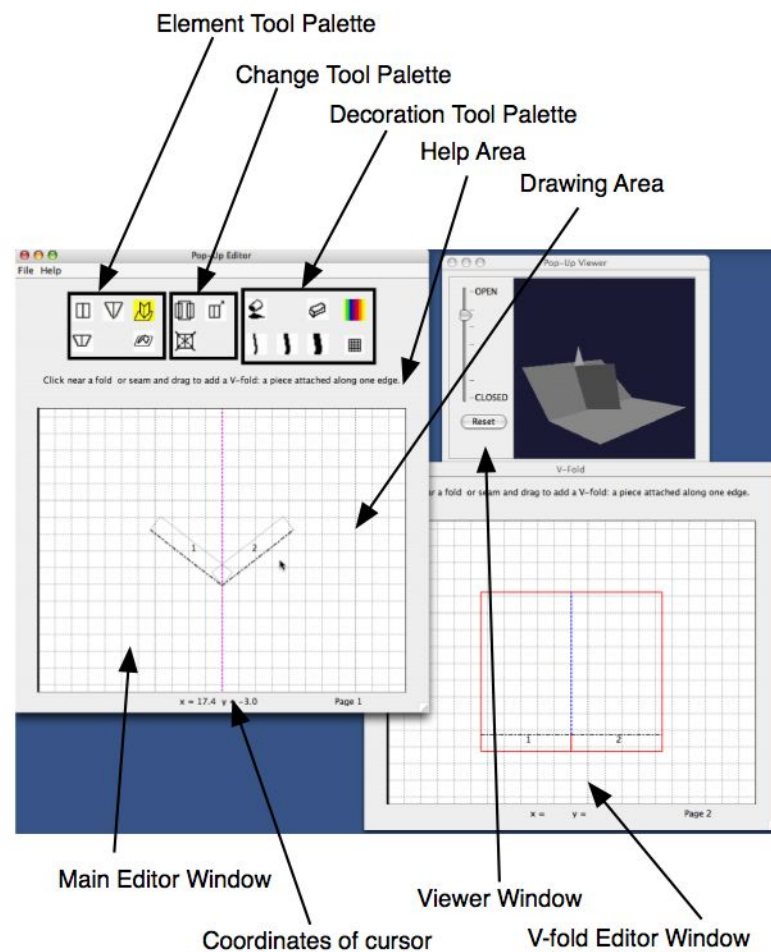


Figure 5.1: Popup Workshop Windows and Palettes: Popup Workshop with the user adding a v-fold to the base page. The base page is in one Editor Window, with the v-fold that will be attached to the base page in another. The Viewer Window displays the 3-dimensional representation of the pop-up.

The interface has been kept simple without being specifically oriented to younger children.

Simplicity allows reduced cognitive load and quick learning of the interface. Actions and results have been made as consistent as possible. For instance, all elements are drawn by placing the mouse near a fold or seam, then clicking and dragging. Change, delete, and replicate all manipulate the same small boxes to produce their result. Menus are kept standard (with respect to other software that the users may have encountered) whenever possible. Help and documentation use a simple name for each element, and the names are used consistently.

Figure 5.1 shows an example of Popup Workshop being used to design a pop-up with a single v-fold element. The following sections give an overview of the operation of the software from the user's perspective.

5.3.1 Editor Window

The Editor Window has a drawing area where the pattern for the pop-up is drawn as a 2-dimensional form. This area has a grid for positioning elements that can be toggled on and off, and displays the x- and y-coordinates of the cursor when it is within the drawing area. This coordinate system places the origin at the center of the 8.5 inch by 11 inch drawing area with each grid square representing 0.5 inch. Because of the screen resolution, the actual size of the drawing area on the screen can vary, and will be scaled at print time to fit within the print area of the printer used.

There are no error messages produced by the user's actions in the Editor Window as each element is limited by geometric constraints that are constantly enforced. For instance, trying to make an element so big that it does not fit on its base planes will result in the element being made only as big as will fit. Trying to add an element that is too small, for instance one with a zero-length width, will result in no element being added. The click and drag operation for adding elements only works when the starting point is near an acceptable fold or seam. This means, for example, that a user will not be able to draw a 90° element on a seam, since this would require a cut be made across the glued line.

There is always at least one Editor Window. The main Editor Window appears when the

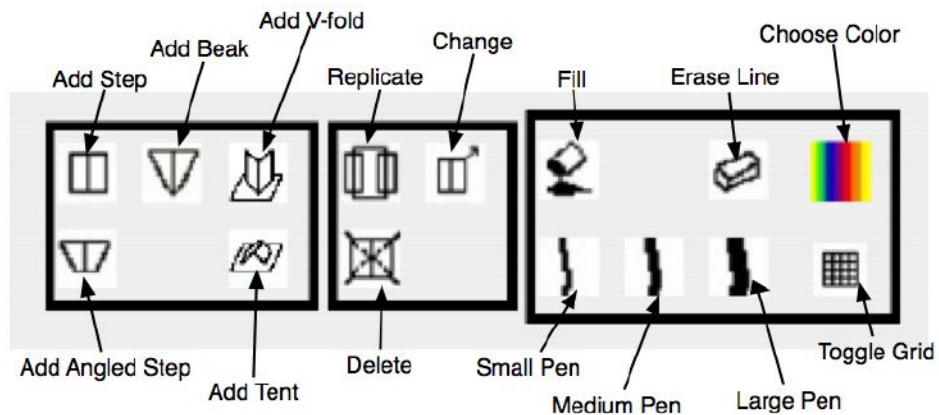


Figure 5.2: Popup Workshop Palette Buttons: The buttons available in the tool palettes of Popup Workshop. The left palette contains buttons for adding elements, the center palette buttons allow changes to the design, and the right palette is for decoration operations.

program starts, and persists until the program terminates. In addition, there will be an additional Editor Window created to display each extra piece for 180° elements if any are added. These extra windows act just like the main Editor Window in that elements and decoration can be added, changed, and deleted. For instance, in Figure 5.1 an element could be added to the center fold of the v-fold in the V-fold Editor Window, to the gutter in the main Editor Window, or to the seams of the v-fold in either window. Each Editor Window has a page number and any extra pieces are given numbered gluing tabs that match the numbers on the corresponding gluing bases to which they attach.

Within the drawing area, cuts are represented by red solid lines, valley folds by magenta dashed lines, and mountain folds by blue dashed lines. This use of dashed lines for folds and solid lines for cuts is a standard notation for paper engineering patterns, although the color choices to indicate the direction of folds may be unique to this software and colors were chosen to be obvious and easily visible when printed. As there is no standard notation for seams, they are indicated by dashed black lines.

There are three tool palettes located at the top of the main Editor Window that contain buttons labeled with icons to represent their actions. When the user moves the cursor to a button

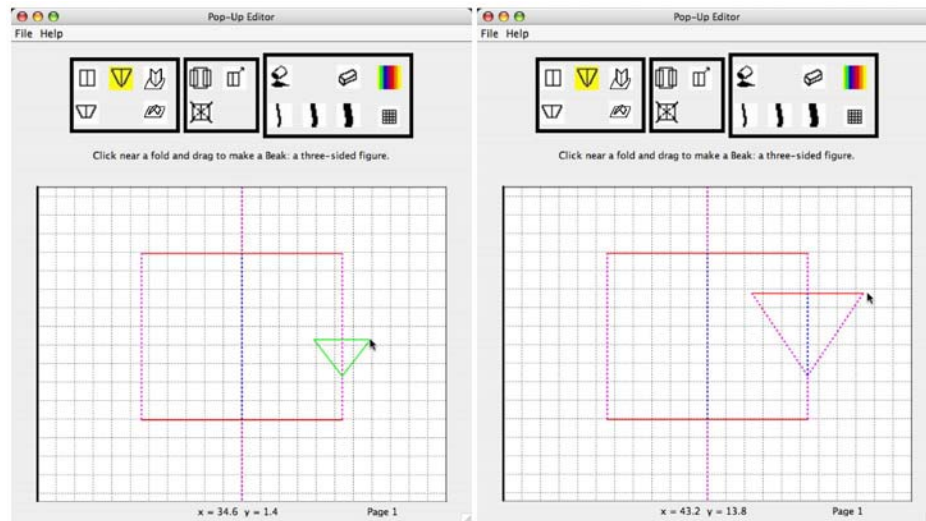


Figure 5.3: Adding an Element: Adding a beak element by clicking near a fold, dragging the outline to the desired size (left) and releasing (right).

a tool tip appears to explain what the button does. When a button is selected, a message appears in the help area that tells the user what action the program expects. Figure 5.2 shows the buttons available in the tool palettes. Extra windows for additional pieces do not have separate tool palettes but use those in the main Editor Window.

The Element Tool Palette (left in Figure 5.2) contains buttons that allow the user to add an element. The available elements are the step, beak and angled step (90°) and the v-fold and tent (180°). Figure 5.3 shows the process for adding a beak element.³ When the button is selected it changes color. The user then positions the cursor near a fold (or a seam if the element can be placed on a seam) and clicks and drags to draw the outline of the new element. As detailed in Section 5.4.3, the new element is added with its geometric constraints and starting heuristics (symmetry, for instance) satisfied.

The Change Tool Palette (center in Figure 5.2) contains buttons for moving points of an element, deleting elements, and replicating elements. For each tool, small boxes are drawn at

³ Examples of the action of various buttons is shown for 90° elements as they are simpler. The only difference for 180° elements is that a new window is added or removed as appropriate. Changes and additions may be made in the window containing the extra piece in the same manner as they are made on the main page.

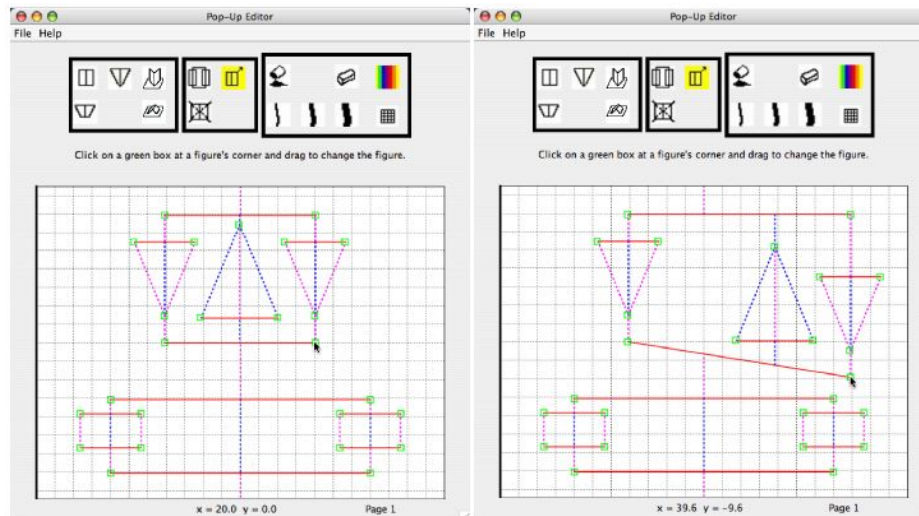


Figure 5.4: Changing an Element: Dragging the green handle on a corner of the element moves the point. Constraints are continuously satisfied, and any elements on top of the changed elements are also changed to remain on their parent folds.

corners of the elements in the drawing area that serve as handles to modify or select an element.

When the Change button is selected, green handles appear on the corners of all elements in the current design. The user can click on one of these handles and drag it to the location desired. The constraints for the element are automatically satisfied as the element changes. For instance, in Figure 5.4 the location of the point on the same side of the parent fold as the point being moved also changes in order to keep the folds parallel. The center fold also moves if needed to keep the element foldable. In addition, all elements on top of the changing element are moved so that they remain on their original parent folds.

When the Replicate button is chosen, blue handles are placed at the elements' corners. By clicking on any of these handles, the element is replicated on all folds of the element under it that are of the same type as its parent fold (valley fold, mountain fold, or seam). Figure 5.5 shows the replication action being applied twice, first for the larger box, and then for the smaller box that sits on it. In this example, the chosen element is replicated on all of the valley folds of the element below as well as being replicated on all additional copies of the element below it. If there are no matching folds (the element being replicated is on a center fold, for instance) or the element has

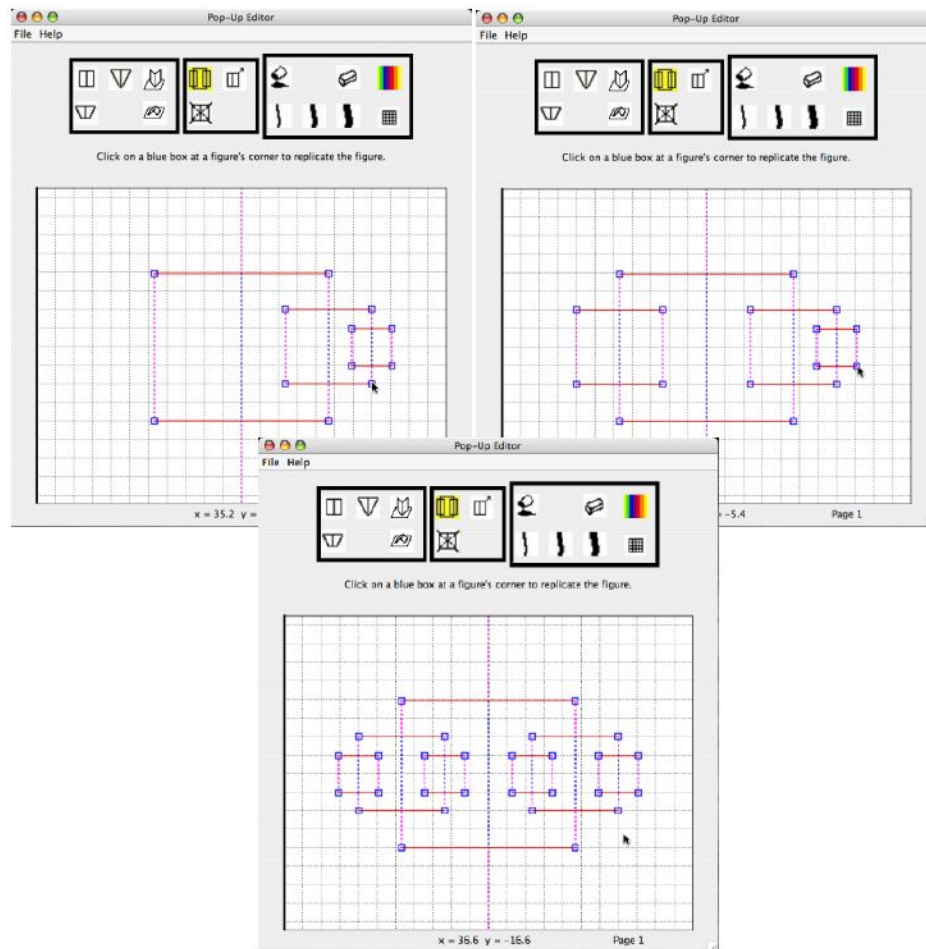


Figure 5.5: Replicating elements: Clicking on the blue handle replicates the element onto each matching fold of the element beneath it, in this case each valley fold.

already been replicated, clicking on the blue handle does nothing. The presence of additional elements on the matching fold does not inhibit the replication.

When the Delete button is chosen, red handles are placed on the elements' corners. By clicking on one of these handles, the element chosen is deleted. Figure 5.6 shows the deletion of the lower large step. If an element is deleted, all elements on its folds and seams must also be deleted, as well as the elements on their folds and seams, and so on.

The Decoration Tool Palette (right in Figure 5.2) contains buttons for filling areas with color, drawing lines, erasing lines, selecting the color for fill or lines, as well as displaying or hiding the grid.

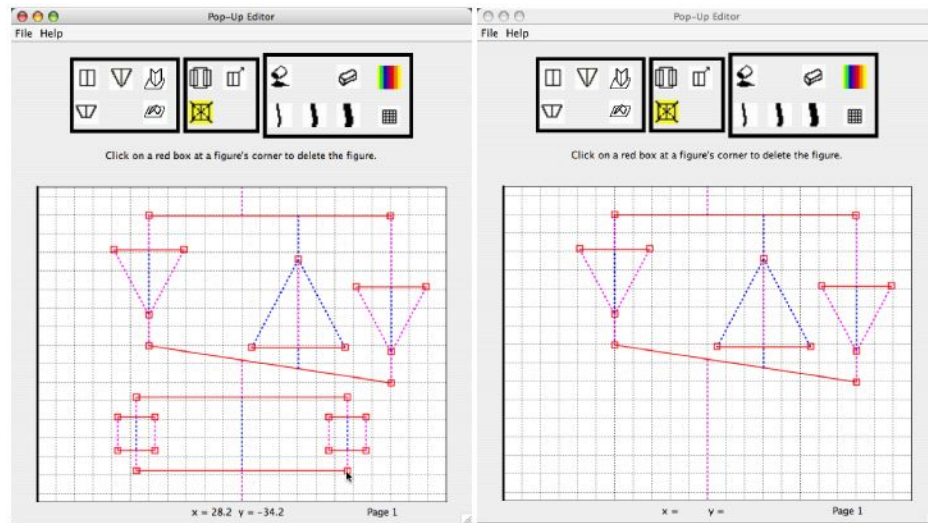


Figure 5.6: Deleting elements: Clicking on the red handle deletes the element and any elements on top of it.

When the Color Selector button is chosen, the color picker is displayed. This palette is standard for Java applications and provides several ways in which to indicate a color. The number of colors is dependent on the current display settings. When a new color is selected it becomes the border color for all tool palettes, and will be used for both drawing lines and filling areas.

The Grid Toggle button turns the grid in the drawing area off or on. Turning off the grid is desirable when printing the pattern.

There are three buttons to select drawing tools that produce lines of different widths using the currently selected color that can be drawn with the mouse. The Eraser button adds red handles on the ends of all lines and a handle is clicked to remove the chosen line.

The final tool is the Fill button. Any plane of an element or the base page can be filled with the currently selected color by choosing this button and clicking on the plane. Fill colors can be erased by filling the area with white.

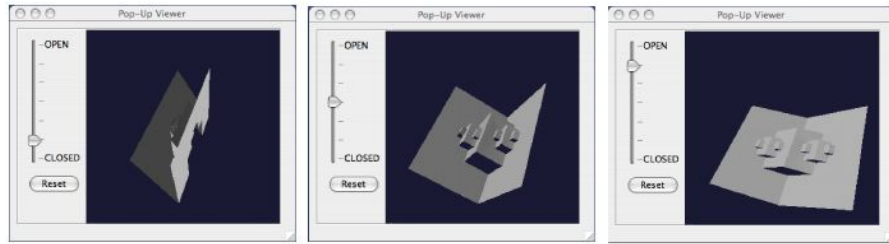


Figure 5.7: Viewer Window: The the slider control can display the pop-up in any position from completely open to completely closed as shown in these three examples of the motion of one pop-up. The Viewer window provides real-time information about the motions of the elements. The pop-up can also be rotated to any orientation.

5.3.2 Viewer Window

The Viewer Window displays a 3D representation of the current pop-up that can be manipulated by the user. Clicking on the 3D image and dragging the mouse will rotate the pop-up in any axis to allow the user to view it from any angle. The pop-up can also be opened and closed by using the slider control at the left side of the window. Figure 5.7 shows a pop-up being opened and closed in this manner. Any manipulations can be undone and the image returned to its default starting position (open 90° and facing directly toward the user) by clicking the Reset button below the slider.

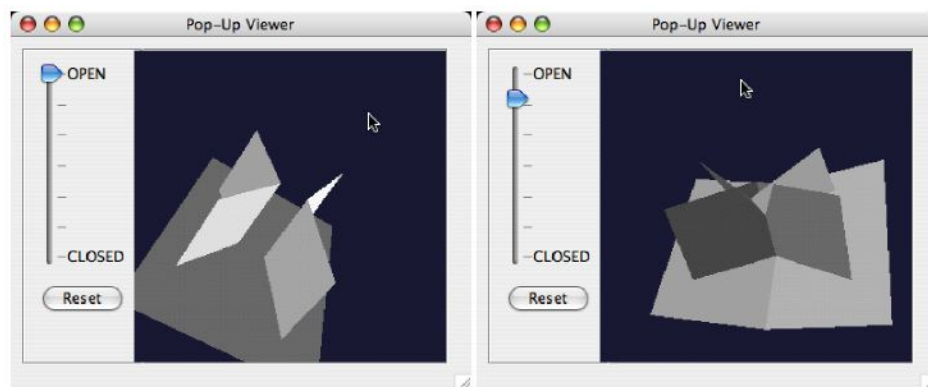


Figure 5.8: A Collision Between Elements: This is an example of a case where collision between elements occurs. When fully opened, the v-folds do not collide. Use of the open and rotate functions make the problem obvious.

In Popup Workshop, a pop-up that does not close correctly can be produced if there are collisions between elements. These will usually be obvious in the Viewer Window, as shown in Figure 5.8. Collisions are allowed for two reasons. First, to help the user learn to identify and judge such conditions. Second, it is possible that the colliding elements can be altered as they are being assembled, and that they may produce exactly what the user desires.

5.3.3 Menu Operations

To simplify the operation of Popup Workshop, all menu items are grouped into only two menus: **Help** and **File**.

Currently, the **Help** menu has only one menu item, **About**. The About Box displays version and developer contact information. The menu exists primarily as a placeholder for future help functionality such as providing a searchable version of the documentation.

The **File** menu contains menu items that are common to the File menus in other programs. In general, menu items are only available if they make sense in the current state of the design process, and the user is given the opportunity to save the current pop-up if a choosing a menu item would cause the current work to be lost.

New, the first menu item, creates a new pop-up from scratch. In any situation in which the current pop-up has been changed since the last save, the user is asked if she wishes to save the current pop-up before replacing it. **New** is not available if the pop-up has just been created and is blank.

Open opens a saved pop-up. This allows a user who has previously saved a pop-up to continue work on the pop-up later, or to share it with other users. **Open** is always available. If changes have been made since the last **Save**, the user is asked if she wishes to **Save** when **Open** is chosen.

Save, and **Save As** are the next two menu items, and create files for the current pop-up that may be accessed with **Open**. **Save** is only available if changes have been made in the pop-up since the last **Save** or **Save As**. **Save As** is always available. For instance, if the current pop-up was

not previously saved **Save** is not available, but **Save As** is.

Export Image saves the Editor Window contents as an image. There may be more than one image saved, as each additional piece is stored in a separate image. A user can export a pattern created with Popup Workshop and later print the pattern from a computer that does not have Popup Workshop installed by opening the image in a graphics program. **Export Image** is always available.

Revert to Last Saved allows the user to delete all changes since the last **Save**. This menu item exists only if a saved version of the current pop-up exists. The user is warned via a dialog box to indicate that the current pop-up will be changed to the older version so that she can confirm the operation.

Print prints each page of the pop-up design onto a a separate piece of paper. This option is always available.

Exit terminates the program gracefully and is always available. The user is given a dialog box allowing a **Save** if any changes have been made since the last save.

5.4 Program Design and the Nature of Pop-ups

One important consideration in the design of Popup Workshop was to allow for future expansion and, in particular, that adding new elements should be as easy as possible. This requirement was applied to the selection of data structures, to the organization of the elements' class structure and methods, and to the selection of a method for animating the pop-ups.

In addition, there were no deliberate attempts made to optimize the code for speed or to refactor the code. Thus, there are blocks of repeated code, for instance between an element and its corresponding inverted form. However, the desire was to make it good enough, knowing that these early versions of the program do not have to be extremely small or fast. In practice, most pop-ups that the children made had only a few elements, with a very complicated one having at most 7 or 8 elements. In user tests, the most complicated pop-up made was Daisy's alien (Figure F.1) and it proved difficult for her to cut and fold. Even this pop-up with 26 elements did not

cause any speed problems for the user when opening and rotating it in the viewer, although the operation was visibly slower than on simpler examples.

Note that there are two uses of constraints in Popup Workshop, and one should be careful to distinguish between them. First, there are geometric constraints that apply to each element type. For instance, all the folds on a beak must meet in a single point. These geometric constraints must be considered when adding and changing an element. Second, for the opening and closing of the page Popup Workshop uses a constraint system to calculate the point locations for each element, instead of using a direct mathematical calculation.

The following sections discuss the most important details of the internal design of Popup Workshop. The first, Section 5.4.1 discusses the data structures and classes used, as well as the overall design. Section 5.4.2 provides details of file formats chosen for both graphical output and saved files. Section 5.4.3 discusses the geometric constraints that apply to each element type. Finally, Section 5.4.4 describes the algorithm used in the constraint system for opening and closing the page in the 3D viewer.

5.4.1 Classes and Data Structures

The selection of Java as the language in which Popup Workshop is written was made primarily on the criterion of portability. The desire was to produce software that could be easily run on many operating systems. However, the Java language proved a good choice in another way as well, as the structure and construction of pop-ups map neatly to Java classes. A pop-up is comprised of a set of elements, each of which has certain folds, cuts, seams, and geometric constraints. It is helpful to assume that any element “knows” how to open itself and change itself. The pop-up domain is also recursive, as the removal of any element forces the removal of all elements on top of it, and the change of any element means that elements on top may very likely have to be changed, as will any on the new changed elements. Java’s support for this type of recursive construction was very helpful.

Popup Workshop consists of 43 Java classes. Some of these classes are used for the Swing

interface, for windows and palettes, or for specialized functions such as XML parsing. The remaining classes are concerned with the pop-up design itself and it is these classes that will be briefly outlined here, along with the most important of their members and methods.

Two classes exist to provide basic geometric components and methods. `Point3D` is a class representing a single point, and the class `LineFeature` connects two `Point3D`s to represent a line segment. `Point3D` has x-, y-, and z- coordinates. For the 2D representation of the Editor Window the z-coordinate is always given the same value. Both `Point3D` and `LineFeature` contain methods that are used to obtain geometric values. For instance, the `Point3D` class contains methods to find whether two points are the same (to a given precision) and whether the point is on a given line. The `LineFeature` class contains methods that do similar operations for a line segment. Finding the midpoint, line angles and intersections, and determining if lines are parallel are a few of the methods provided for `LineFeature`.

The `ValleyFold`, `Cut`, `MountainFold`, and `Seam` classes inherit from `LineFeature` and are necessary to build an element. A great deal of the development effort in `Popup Workshop` was devoted to defining relationships between classes. For instance, a fold or seam needs to link to the two planes of the elements on either side of it. The `LineFeature` also has a method to return those planes.

Therefore, the `Plane` is another important class, and represents a plane on an element. The `Plane` contains a list of `Point3D`s around the edge (in 2D coordinates) and the current coordinates of each of the points for the current angle of the page (3D coordinates) Planes are required to change shape, that is, cut themselves out, when a 90° element is place on them. A beak, for example, cuts a triangular section out of each plane on which it sits. The `Plane` class has a list of boolean values that indicate which points were in the original plane when it was built (not cut out.) These are necessary when the element on top is deleted or changed and the original outline of the plane must be restored.

Elements are represented by the `Structure` class, with `AppliedStructure` (for 180° elements) and `SlitStructure` (for 90° elements) inheriting from `Structure`. Each individual element class in-

herits from one of those two classes. There are 9 element classes: DoubleSlit (step), InvDoubleSlit (inverted step), and so on. Each of the element classes contains such data as the folds, cuts, and seams appropriate to the type, its Planes, and the Planes lying below it. All Structures contain methods to open, change, and delete themselves. Deleting and changing elements are recursive operations. The changed Structure finds all Structures on its folds or seams, and asks them to change as well and in turn, they do the same.

The main data structures are located in the class PopUp. This class contains linked lists of Structures (the current elements), ParentFolds (the fold on which each element sits in the same order as the elements), Planes (the planes making up the elements), and Pages (the base page and any pages added by the 180° elements). The list of Structures is kept in order by appending to the list when a new Structure is added, and removing Structures from the list when they are deleted. This allows a single pass to open all of the Structures to the current page angle. The ParentFold list is searched when replication is done. Since the Plane stores its 3D coordinates at the current opening angle, the Plane list is the source of current pop-up data for the Viewer. Java3D takes the list of points for each plane and builds the current image of the complete pop-up. The PopUp class also holds data applicable to the entire pop-up, such as the current page angle. The PopUp class initiates such actions as adding an element, changing the opening angle, and drawing the design to the screen.

5.4.2 File Formats

Section 5.3.3 described the menu items used to write files. The Export menu item exports the pop-up design in a graphical form so that it can be exchanged between users or imported into graphics programs such as PhotoShop. The Save menu item, on the other hand, saves the pop-up in a form that may be re-opened in Popup Workshop. Both methods allow users to share designs.

The Export menu item writes a file in the Joint Photographic Experts Group (JPEG) format. JPEG was chosen for its ubiquitous use as a file format in many graphics programs, common use on the Web, and the fact that a JPEG image can be easily written in Java. A BufferedImage class

can be painted exactly as the screen is painted, with 8-bit RGB color components packed into integer pixels. This buffer is then written to the file with class `ImageIO.write`, that allows “jpg” as a parameter. This produces an image of 800x650 pixels, with resolution of 72 ppi.

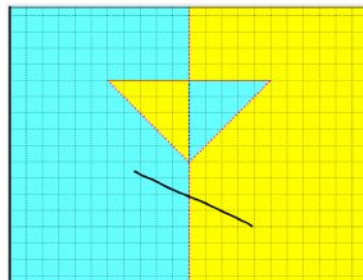
In order to save a pop-up for future work, Extensible Markup Language (XML) is a logical choice. Pop-ups are modular, consisting of elements with particular attributes (corner points, plane colors, parent folds) that lend themselves to a nested structure. In addition, XML files are relatively small text files, ideal for email and other modes of transfer. Some debugging was accomplished during development by examining save files, since they are human-readable. An additional reason for the use of XML is the existence of classes to parse XML in Java.

The organization of tags in a save file is shown in Figure 5.9. A pop-up is delineated by the *popup* tag pair. The version parameter indicates the version of Popup WorkShop writing the file. Within this pair, there are three areas. First, *mainpage* identifies the colors of the planes of the base page of the pop-up. There is no other information currently saved for the main page.

Second, a list of all the elements is delineated by the *structurelist* tags. Within this list, *structure* tags enclose each element. The type parameter is an integer indicating whether an element is a beak, inverted beak, step, etc.. An element consists of a list of *outerpoints* (the positions of the corners of the element in the order used in the element constructor), items designating the left and right plane colors, the left and right gluing tab colors, and the beginning and end points of the parent fold (so that the parent fold can be identified when the element is added), and the page on which the parent fold is located.

Third are the lines drawn as decoration. The list of lines is delineated by the *drawnlinelist* tag pair. The information for each line consists of the thickness of the line, the color, the page on which the line occurs, and a list of the points defining the line.

The elements are stored in this save file in the same order as in the linked list kept in the `PopUp` class. This allows the constructors for each element to be called in turn in the same order. Once the parent fold is located on the correct page, the outer points are the primary information used in constructing a new element. Since the elements are added to the save file in list order,



```

<?xml version='1.0' encoding='utf-8'?>
<popup version='2.0'>
  <mainpage leftcolor="-10027009" rightcolor="-256">
    </mainpage>
    <structurelist>
      <structure type="2">
        <outerpoints>
          <point>
            <x>0.0</x> <y>5.2</y> <z>105.0</z>
          </point>
          <point>
            <x>25.0</x> <y>20.0</y> <z>105.0</z>
          </point>
          <point>
            <x>25.0</x> <y>20.0</y> <z>-105.0</z>
          </point>
        </outerpoints>
        <leftplane>
          <color>256</color>
        </leftplane>
        <rightplane>
          <color>-10027009</color>
        </rightplane>
        <lefttab>
          <color>-1</color>
        </lefttab>
        <righttab>
          <color>-1</color>
        </righttab>
        <parentfold>
          <point>
            <x>0.0</x> <y>42.5</y> <z>105.0</z>
          </point>
          <point>
            <x>0.0</x> <y>42.5</y> <z>-105.0</z>
          </point>
          <page>1</page>
        </parentfold>
      </structure>
    </structurelist>
    <drawnlinelist>
      <line thickness="13">
        <color>16777216</color>
        <page>1</page>
        <point>
          <x>16.6</x> <y>8.0</y> <z>105.0</z>
        </point>
        ...
        <point>
          <x>19.2</x> <y>24.8</y> <z>-105.0</z>
        </point>
      </line>
    </drawnlinelist>
  </popup>

```

Figure 5.9: Tags in a Popup Workshop Save File. The pop-up design in the Editor Window is shown on the left and consists of a beak and one line with fill colors on the planes. On the right is the resulting XML from a save. Some of the points for the line have been removed to simplify the example.

and processed in that order when the file is opened, the lower elements are in place before the upper elements are added.

5.4.3 Geometric Constraints of the Elements

Section 4.1.2 introduced the concept of geometric constraints required for proper opening and closing of elements. In Popup Workshop, these geometric constraints are satisfied for all elements at all times. Keeping the geometric constraints satisfied insures that the pattern always represents a foldable design and eliminates the need for a foldability check on the entire design. If an element is changed, those changes are constrained to keep the element foldable. For instance, in the beak element the center point must lie on the parent fold. This means that when the point is changed, the user must only be able to slide the point up and down that fold. Sometimes the change in a point will necessitate a change in other points. For instance, if a fold line must remain parallel to another fold line, and one endpoint of the fold line is changed, both end points must move in order to keep the fold lines parallel. Whenever a new element is added, the geometric constraints are satisfied. For instance, the center point of the beak is on the parent fold from the time the element is constructed.

In addition, there are certain starting conditions that are followed in Popup Workshop. These are not geometric constraints, but rather useful requirements that establish the initial form of the element. These starting conditions arise either because of the way the element is “drawn” on the pattern, or in order to allow for further changes. For instance, in sweeping out the beak element with the mouse, the cursor moves one of the side points. The other is moved automatically to produce an isosceles triangle. The newly produced beak, then, starts with equal angles at the sides; it is symmetric about the x-axis. Beaks are not constrained to be symmetric and the user can alter the element later to be asymmetric. Another example is in the production of the piece on the extra page of the v-fold. There are no constraints that affect the shape or size of this piece, other than the requirement that the seams must be the same length as those seams to which they are to be glued on the original page. The starting condition is to make the extra piece a centered rectangle with enough room on the extra page to make changes.

To simplify the geometry of the elements, Popup Workshop assumes that cut lines on the

elements are straight line segments, even though the user can vary their shapes at construction time.

Although there are 5 elements that the user sees, in actual fact there are 9 classes of elements in the code as four of the elements have inverted forms. The following sections indicate the geometric constraints, starting conditions, simplifications for Popup Workshop, and the conditions in which an inverted element will be used for each of the 5 elements that a user can produce.

5.4.3.1 The Step Element

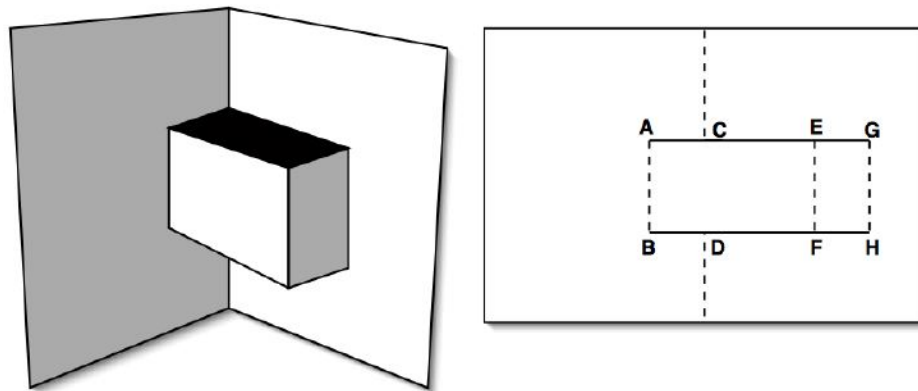


Figure 5.10: The Step Element in Popup Workshop, showing the points important for the constraints.

The step element (Figure 5.10) is a 90° parallel element. It is constructed with two cuts across the parent fold, two side valley folds, and a mountain center fold.

In order to fold properly, the basic constraints are:

- $\overline{AB} \parallel \overline{CD} \parallel \overline{EF} \parallel \overline{GH}$
- The distance from $\overline{AB}$ to $\overline{CD}$ = the distance from $\overline{EF}$ to $\overline{GH}$
- Points A and B must lie on the left base plane. Points G and H must lie on the right base plane.

When an element of this type is added in Popup Workshop the starting conditions are:

- The distance from $\overline{AB}$ to $\overline{CD}$ = the distance from $\overline{CD}$ to $\overline{GH}$ and the beginning shape is a rectangle centered on the parent fold.
- Since the second constraint above holds, $\overline{CD}$ and $\overline{EF}$ coincide.

For the purposes of Popup Workshop, points A, C, E, and G lie on the same line segment, and points B, D, F, and H also lie on a single line segment. The inverted form of the step differs only in that the parent fold is a mountain, rather than a valley fold. This means that the two side folds are mountain folds and the center fold is a valley fold.

5.4.3.2 The Beak Element

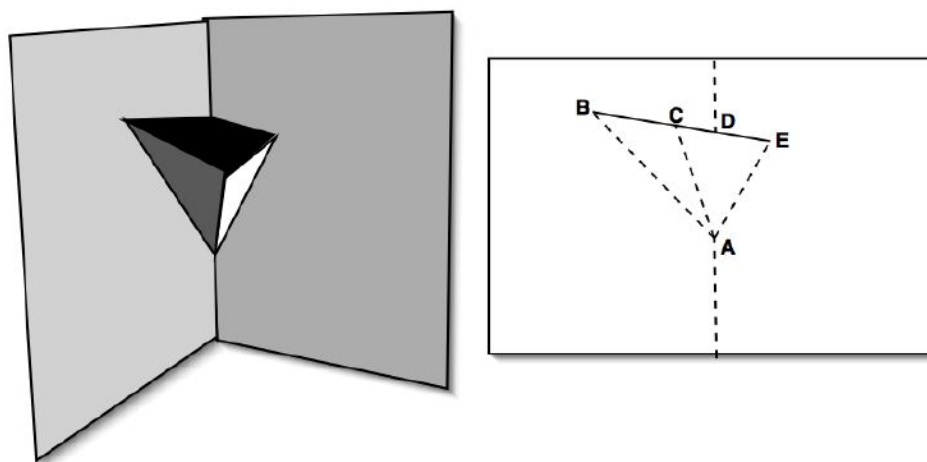


Figure 5.11: The Beak Element in Popup Workshop, showing the points important for the constraints.

The beak (Figure 5.11) is a 90° angled element. It is constructed with one cut across the parent fold, two side valley folds, and a mountain center fold.

In order to fold properly, the basic constraints are:

- Point A must remain on the parent fold, although it may move along it.

- $\angle BAC = \angle DAE$
- Point B must lie on the left base plane. Point E must lie on the right base plane.

When an element of this type is added in Popup Workshop the starting conditions are:

- Point C = Point D.
- The triangle BAE is an isosceles triangle, with $\angle ABE = \angle AEB$.

For the purposes of Popup Workshop, B, C, D, and E lie on the same line segment. Also, the triangle BAE can point up or point down, and this orientation can be changed. The inverted form of the beak differs only in that the parent fold is a mountain, rather than a valley fold. This means that the two side folds are mountain folds and the center fold is a valley fold.

5.4.3.3 The Angled Step Element

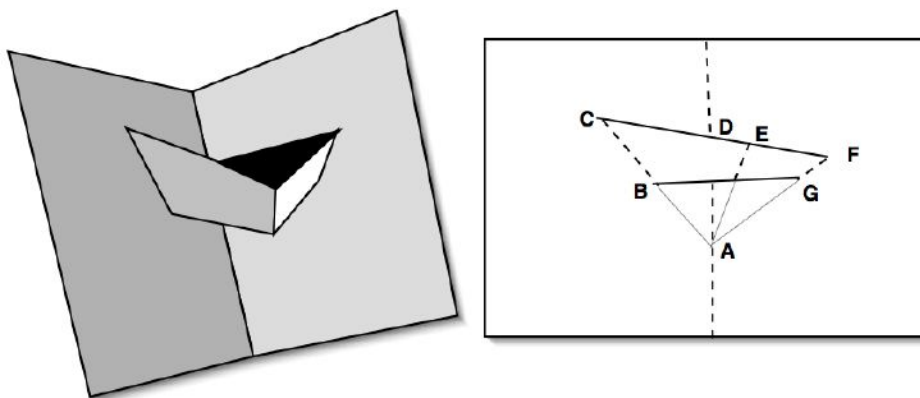


Figure 5.12: The Angled Step in Popup Workshop, showing the points important for the constraints.

The angled step (Figure 5.12) is a 90° angled element. It is constructed with two cuts across the parent fold, two side valley folds, and a mountain center fold. It is essentially a beak with the point removed and therefore many of the constraints are the same as the beak.

In order to fold properly, the basic constraints are:

- Point A must remain on the parent fold, although it may move along it.
- Point B must lie on $\overline{AC}$, and point G must lie on $\overline{AF}$, although they may move along the lines.
- $\angle CAD = \angle FAE$
- Points B and C must lie on the left base plane. Points F and G must lie on the right base plane.

When an element of this type is added in Popup Workshop the starting conditions are:

- Point E = Point D.
- The triangle BAE is an isosceles triangle, with $\angle ACF = \angle AFC$.
- Point B is the midpoint of $\overline{AC}$, and point G is the midpoint of $\overline{AF}$.

For the purposes of Popup Workshop, points C, D, E and F lie on the same line segment. Also, the triangle CAF can point up or point down, and this orientation can be changed. The inverted form of the angled step differs only in that the parent fold is a mountain, rather than a valley fold. This means that the two side folds are mountain folds and the center fold is a valley fold.

5.4.3.4 The V-fold Element

The v-fold (see Figure 5.13) is a 180° angled element. It is constructed with an extra piece glued to a v-shaped seam that is on either a mountain fold, a valley fold, or a seam. The extra piece has a mountain center fold.

In order to fold properly, the basic constraints are:

- Point B must remain on the parent fold, although it may move along it.
- $\overline{AB}$ is the same length as $\overline{GE}$, and $\overline{BC}$ is the same length as $\overline{EH}$, since the lines are the seams on which the piece is glued.

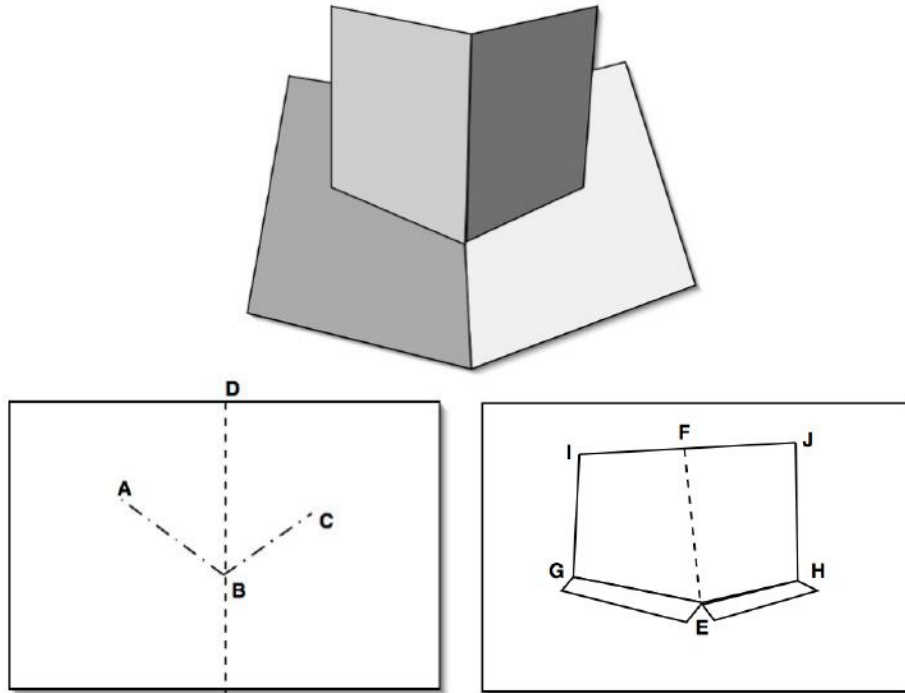


Figure 5.13: The v-fold in Popup Workshop, showing the points important for the constraints.

- $\angle ABC < 180^\circ$. If the extra piece is glued straight across, the fold cannot move. In practice, if the angle is close but not equal to 180° , folding may be inhibited. Popup Workshop uses the rule that it must be less than 170° .
- $\angle ABD + \angle CBD < \angle GEF + \angle HEF$. Once again, if the two angles are too close, there may be folding problems. Popup Workshop keeps at least 10° difference in the two angle sums.
- $\angle HEF = \angle CBD + x$ and $\angle GEF = \angle ABD + x$ for some x .
- Point A must lie on the left base plane. Point C must lie on the right base plane.

When an element of this type is added in Popup Workshop the starting conditions are:

- $\angle GEH = 180^\circ$.
- $\overline{AB}$ and $\overline{BC}$ are the same length, and $\angle ABD = \angle CBD$.

- The piece on the extra page is calculated to lie more or less in the middle of the page in order to give the user room for changes. $\overline{GE}$ and $\overline{GH}$ are known from $\overline{AB}$ and $\overline{BC}$. Points I and J are $1/4$ of the page height down from the top margin, and Points G and H are $1/4$ of the page height up from the bottom margin. The piece is centered horizontally.

For the purposes of Popup Workshop, points I, F, and J lie on the same line segment. Point F may lie on line $\overline{TJ}$ as shown, or if it is very slanted because of the constraints, or if points I or J are moved to the other side of the centerline, F may be on $\overline{TG}$ or $\overline{JH}$. The inverted form of the v-fold points up (at point B) rather than down, and the center fold is a valley fold instead of a mountain fold. Since $\angle ABC$ cannot be 180° , the point up and point down forms cannot be changed into one another, and therefore must be added separately, another reason for having one be the inverted form.

5.4.3.5 The Tent Element

The tent (Figure 5.14) is a 180° parallel element. It is constructed with an extra piece glued on each side of either a mountain fold, a valley fold, or a seam. The extra piece has a mountain center fold. Its constraints are quite similar to the step, with added constraints related to the fact that it has an added piece.

In order to fold properly, the basic constraints are:

- $\overline{AB} \parallel \overline{CD} \parallel \overline{EF}$
- $\overline{GH} \parallel \overline{TJ} \parallel \overline{KL}$
- The distance from $\overline{AB}$ to $\overline{EF} \leq$ the distance from $\overline{GH}$ to $\overline{KL}$. This prevents the tent from stopping the motion of the parent fold before it reaches 180° .
- The distance from $\overline{AB}$ to $\overline{CD}$ + the distance from $\overline{GH}$ to $\overline{TJ}$ = the distance from $\overline{EF}$ to $\overline{CD}$ + the distance from $\overline{KL}$ to $\overline{TJ}$.

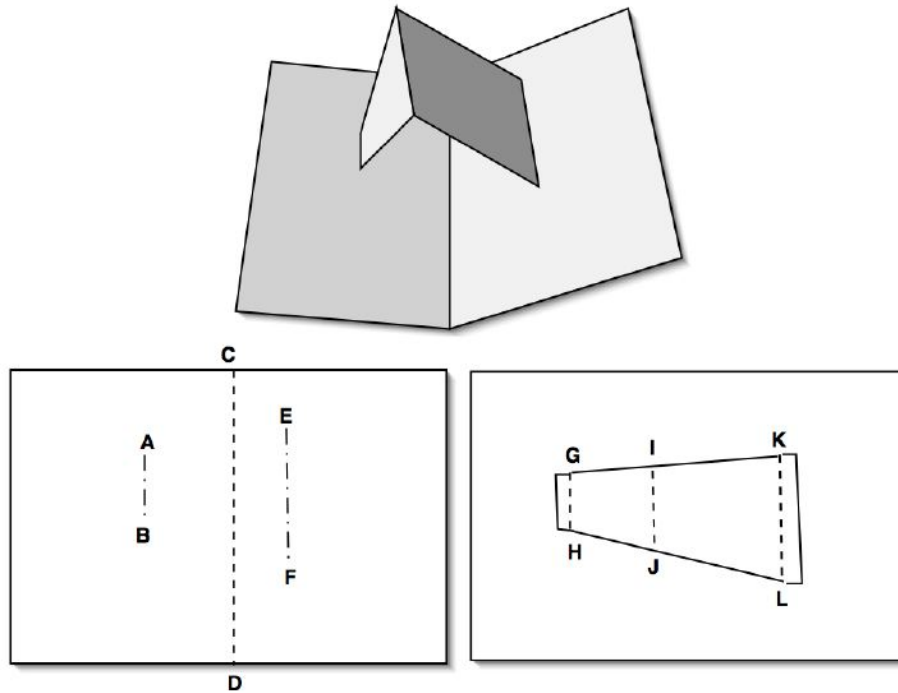


Figure 5.14: The Tent in Popup Workshop, showing the points important for the constraints.

- $AB = GH$ and $KL = EF$. That is, the seams on each piece must be the same length.
- The seams must also be offset in the same way. That is, (y-coordinate of point A) - (y-coordinate of point E) = (y-coordinate of point G) - (y-coordinate of point K).
- Points A and B must lie on the left base plane. Points E and F must lie on the right base plane.

When an element of this type is added in Popup Workshop the starting conditions are:

- ABFE is a rectangle. Because of the constraints, GHLK is also a rectangle.
- The distance between $\overline{AB}$ and $\overline{CD}$ = the distance between $\overline{EF}$ and $\overline{CD}$.
- The distance between $\overline{GH}$ and $\overline{KL}$ is 1.5 times the distance between $\overline{AB}$ and $\overline{EF}$.

If this causes the extra piece to extend beyond page boundaries, it is shortened to fit.

- The piece on the extra page is centered on the page horizontally and vertically in order to give the user room for changes.

For the purposes of Popup Workshop, points G, I, and K lie on a line. In addition, H, J, and L lie on a line. There is no inverted tent.

5.4.4 Constraint Methods in the Opening Algorithm

From the previous research on simulation of pop-ups discussed in Section 4.2, it is apparent that the most difficult single problem in designing tools for the paper engineer is the calculation of the positions of the elements during opening and closing of the page. Several methods have been proposed for this. Lee, Tor and Soo [66] suggest calculating the angles of the sides of the element, but limit their discussion to only two types of 180° elements, and develop different methods for calculating angled and parallel forms. Mitani and Suzuki [75], working with the limited subset of 90° elements used in origamic architecture are lucky in that a one-to-one mapping exists between the 3D and 2D forms, and a simple trigonometric relationship allows an easy calculation for any point. Glassner's [36, 37], solution utilizes the intersection of 3 spheres, leading to a complex, but more generalized solution.

In Popup Workshop a different approach to the problem has been implemented: a constraint system approach. Glassner identifies the possibility of using a constraint solving algorithm, then dismisses it:

Constraint systems are flexible tools for solving complex problems. But they have three big drawbacks for this application: they are typically large and difficult to debug, they are notoriously sensitive to numerical instability, and they can get stuck while searching for a solution and end up with no solution at all. [36, p. 82]

To the contrary, in Popup Workshop, a constraint system has been found to work well. There are several reasons for this. First, it is not necessary to locate the opened position for a given point on the pop-up to a great degree of precision. The Viewer Window is not large, the user needs

only a rough idea of the what the result will look like, the positions are rounded to integer pixel locations during the display process, and finding the point to a rough approximation produces an animation that is good enough. Second, this is a situation in which the physical reality of the paper guarantees that there will be a solution. (In fact, there are always two solutions, as will be shown, for a given element in a given position and this does cause some difficulties.) Third, the algorithm for finding a given point is small and has been found easy to debug. Since every point is found with this algorithm, the entire process uses less code than considering the special cases that might be produced by each element. Finally, and related to the previous point, new element types can be easily added. There is no need to find the mathematical relationships between the points, as the same method can be used.

The Structure objects (each representing an element) are arranged in a linked list. Since they are added in order of their addition to the pop-up, there is a guarantee that when opening and element all of the elements below the current element are already opened. The opening algorithm progresses through the list in order, recalculating the point positions in each Structure before moving to the next.

The base page is a special case as it is assumed that the spine of the book remains fixed in position and the left and right pages move by the same amount. Therefore, when the page is fully opened the points assume their original values. In addition, points on the gutter do not change as the page is opened, so the x -, y - and z -coordinates of the other points are found by using the relationships:

- θ = angle of page opening in radians
- a = x coordinate of the gutter
- b = z coordinate of the gutter
- c = x distance from the point to the gutter, perpendicular to the gutter
- $x = a - |(c * \sin(\theta/2))|$ (if the point is on the left side of the gutter)

- $x = a + |(c * \sin(\theta/2))|$ (if the point is on the right side of the gutter)
- y is unchanged
- $z = b + |(a * \cos(\theta/2))|$

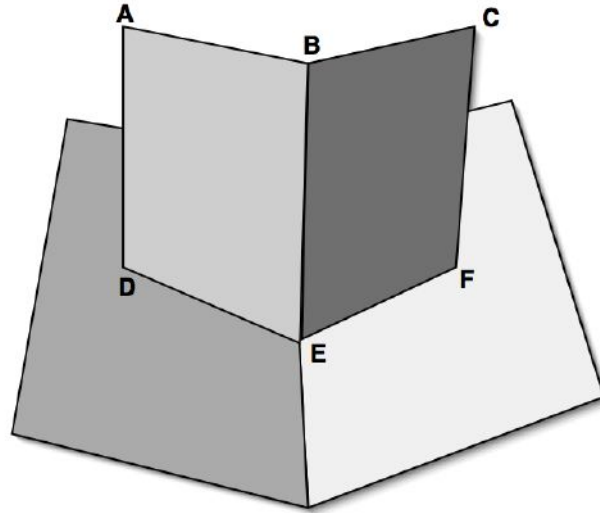


Figure 5.15: Example of Anchored and Unanchored Points: In this v-fold, A, B, and C are unanchored, and D, E, and F are anchored. The distances from A to B, D, and E, C to B, E, and F, and B to D, E, and F are always constant.

Each element consists of *anchored points*, that are parts of the planes beneath the elements that have already been opened, and *unanchored points*, that are not part of the underlying planes. Since the paper is assumed to be rigid, each unanchored point on a plane must remain at the same distance from the anchored points on that plane. For instance, in Figure 5.15 points A, B, and C of the v-fold are unanchored and points D, E, and F are anchored. If D, E, and F are known, A, B, and C may be found from the fact that distances on the planes do not change. B may be found from the fact that it remains at the same distance from D, E, and F at all times. In the same way, A remains at a constant distance from D, E, and B, and C does likewise from E, F, and B.

As a matter of fact, the same method can be used to find the positions of D, E, and F by using their distances from the corners of the plane on which they sit. Finding the positions of all

the points in an element is done by first locating the anchored point positions, and then using those points to locate the unanchored point positions.

```

Given: thisPoint           //starting value (guess)
        pointA, pointB, pointC //three points that we need to position it to
        distA, distB, distC    //distances that we want thisPoint to be from
                                //points A, B, and C respectively
        precision              // how close we think is close enough
        totalRepeats           //when do we want to say we've failed

Do:   Set newPoint to thisPoint
        Set newDistA to distance of newPoint from pointA,
        newDistB to distance of newPoint from pointB,
        newDistC to distance of newPoint from pointC,
        Set distAOff to abs(distA - newDistA)
        distBOff to abs(distB - newDistB)
        distCOff to abs(distC - newDistC)
        for(0 to totalRepeats)
            if(distAOff, distBOff, and distCOff are within precision)
                return newPoint
            else
                pick largest of distAOff, distBOff, distCOff and do:
                    make a line from newPoint to corresponding pointA, B, or C
                    move newPoint until the distance is correct (distA, B, or C)
                    recalculate newDistA, newDistB, newDistC for changed newPoint
                    recalculate distAOff, distBOff, distCOff
        return newPoint //the best we could do

```

Figure 5.16: Algorithm for Placing Opened Pop-up Points (Pseudo-code): The simple, greedy algorithm used for each point in an element. The algorithm uses triangulation and iterates until the distances to the new point match to the precision desired, or the number of iterations passes a limiting value. At each step, the worst fit distance is adjusted to the correct value.

The problem with finding the positions of the points on an element, therefore, always resolves to one of finding a new point such that the original distance from that point to three other points remains the same when the three points are moved. The open method in the element itself can take into account which points are anchored, and which points should be used to find the unanchored points.

A simple routine is used for finding the position of all points in any element. The first algorithm tried (in version 1.0) used random hill-climbing. This was found to converge slowly, and was replaced in version 1.1 by the current greedy algorithm shown in Figure 5.16. Briefly, if the point is not at the correct distance from all three points, it is moved away or toward the worst fitting point until that distance is correct.

When opening and closing the pop-up in the Viewer Window, the starting position of a

point is usually the last position of the point, as it seldom moves far from its last position as the position of the slider control is passed to the program frequently. If the element is being opened for the first time, a position is chosen heuristically that is at least in the vicinity of where it should be. For instance, in the case of the v-fold in Figure 5.15, the starting position for B is chosen with the same x- and y-coordinates as E, but with a z-coordinate equal to the distance EF plus the z-coordinate of E, in order to set the starting position out from the base planes in the correct z direction. It has been found that the starting position is important, as it influences the speed with which the algorithm converges on the correct location.

The algorithm is sufficiently fast, and in user tests speed was not a problem. 90° elements in particular converge quickly, and most points are found within 50 iterations when opening and closing a step element. V-folds and tents are somewhat slower, perhaps because their movement is more extreme, especially in the case of v-folds. The animation of these elements can exceed the iteration limit (currently 5000) but still produce an acceptable view of the pop-up. Additional refinement of the starting point heuristics and adjustment of the precision and iteration limits could improve this performance.

The only current problems arise because there are two stable states for any element. For 90° elements, these are the usual opened configuration and the case in which the element does not “pop out”, that is, it remains as part of the original page. This seldom causes a problem, as this is easily recognized (the unanchored points are in the same plane as the anchored points) and corrected. Occasionally, if the 90° element is on a v-fold that takes it far out of the original planes of the page, this will become an issue. V-folds and tents, on the other hand, have a stable state that is on the opposite side of the page from the desired state, as if the element were attached to the back of the page or supporting elements, and this can occasionally be the state found. These aberrations were not a problem in user testing as they occurred infrequently, and the children were amused rather than confused by the resulting configuration.

There are several ways in which these problems might be cured. One way, for example, would be to transform the anchored points to a position that makes the base for the element

oriented similarly to the base page, and to check whether the found points were on the correct side of the anchored points. Another solution could be to find both positions and disambiguate in some manner later. This problem has occurred for other researchers. Glassner, for example, keeps track of the side on which the element sits, as his intersection of spheres method also finds two possible points for the tip of a v-fold. These display problems have no effect on the function of the completed pop-up as the pattern can still be constructed correctly.

5.5 Summary

The Popup Workshop interface consists of one or more Editor Windows and one Viewer Window. The Editor Window is where the pattern is drawn using the mouse, and from where the pattern is printed for cutting and folding. Five buttons in the Element Tool Palette are used for selecting which element to draw: step, beak, angled step, v-fold or tent. Once the element type is selected, the user adds an element by placing the cursor near a fold or seam and then clicking and dragging. Once elements are added, they may be changed, deleted, or replicated onto matching folds of the element beneath them. There are also simple decoration tools that create filled planes and drawn lines. The Viewer Window shows a 3-dimensional representation of the element that can be rotated and opened or closed. Menu items allow printing the pattern for construction, exporting a JPEG version of the pattern, starting a new blank pop-up, saving the pop-up for reuse in Popup Workshop or opening a previously saved version.

Popup Workshop was written in Java, primarily for portability. The class structure, however arose naturally due to the modularity of pop-ups. The basic unit is a structure, and structures (elements) are kept in a linked list in the order in which they are added. This allows all elements to be processed for new locations when the opening angle is changed by simply traversing the structure list. The methods for changing and deleting elements are recursive to allow any elements above the changed or deleted element to be changed or deleted as well.

There are two uses of constraints in Popup Workshop. First are the geometric constraints that apply all elements. These are enforced during the construction of an element and all changes

to it, so barring collisions between elements the pop-up will properly fold. In the Viewer Window constraint processing is used to calculate new point locations when opening and closing pop-ups, since distances along a plane between points do not change. This allows the calculation of new point locations for each element to act in the same way.

In Chapter 6, the user testing activities for Popup Workshop will be described, including discussions about the users, the methods, and the results. Assessment of the results will be based on the previously introduced craft framework of knowledge, skill, and appreciation.

Chapter 6

User Testing

Previous chapters have discussed the craft of paper engineering and the design of software to aid children in learning this craft. In order to evaluate the usefulness of this software, children were given the opportunity of working with it. Chapter 2 describes a framework not only for understanding and developing software for craft learning, but also for assessment of the learning process, and it is with this framework in mind that the user testing was planned and organized. The framework divides craft learning into knowledge, skill, and appreciation, each of which can be evaluated in a variety of ways. For example, knowledge can be assessed by questioning the craftsman about methods, tools, or even the history of the craft or its practice by others. Skill may be seen as actual tool use or manipulation of the materials or by the quality of products of the craft. Appreciation, although more difficult to judge, can be assessed by observations of the judgement of the craftsman of works by others, or the use of such observations in her work.

This chapter begins with a summary in Section 6.1 of early informal use of the software and how this led to the final design of the formal user tests. Section 6.2 describes the methods used in the formal testing, including the test environment and procedures, and the methods of analysis. The users are described in Section 6.3. The outcome of this testing is compiled in Section 6.4, and reflects the results in the areas of knowledge, skills and appreciation as well as the user's reactions to the software, additional pop-ups constructed outside of the test sessions, and what they did with their pop-ups after the testing. Finally, Section 6.5 reflects more deeply on the use and limitations of the testing methods.

Several of the appendices may be helpful to the reader and will be referenced in this chapter. Appendix D contains a list of tools, materials and books that were available to the users during user testing. The questions asked of users during the first and last sessions, and in the email follow-ups are listed in Appendix E. Photographs of all of the pop-ups produced by the users along with a brief summary of each test session are included in Appendix F. Finally, Appendix G presents a series of tables summarizing the use of elements and decoration for each user's pop-ups, along with the inspiration for pop-ups where that is known.

6.1 Informal Testing

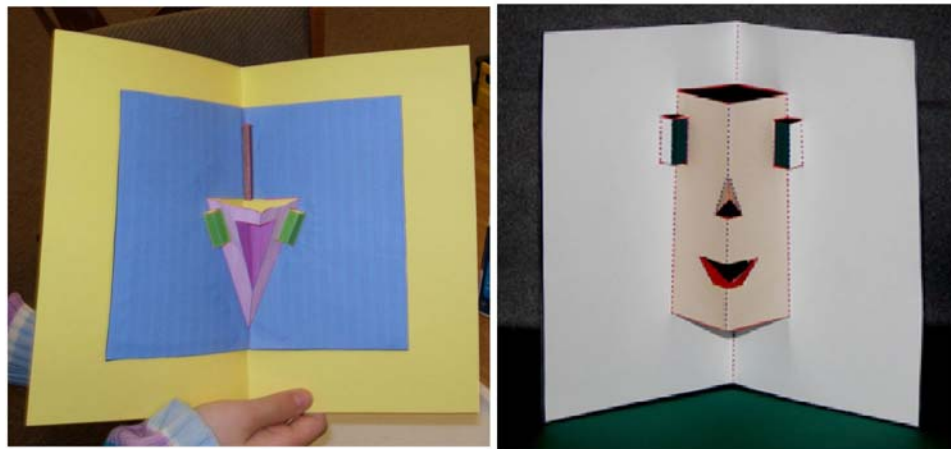


Figure 6.1: Pop-ups made during the informal studies: These pop-ups were made by 5th grade girls using an early version of Popup Workshop.

Before describing the formal user testing that is the primary subject of this chapter, some discussion of early informal user tests should be undertaken for three reasons. First, this testing helped to guide the design of the software, particularly during the transition from Version 1.1, used during informal testing, to Version 2.0, which was the version used for formal user testing. These changes made in Version 2.0 are more completely described in Section 5.2 and include a new Viewer Window with better 3D representation of the pop-up and the addition of 180° elements. Second, the informal testing showed that children were interested in using the software,

could use the software, and were able to cut and fold the resulting pop-ups to produce finished pieces. Finally, this informal testing guided the design of the final formal user testing. In particular, it became obvious during this process that testing would require users within a wider range of ages, making more pop-ups over a longer period of time, using a greater range of element types and a with a more complete pop-up making environment available.

Those readers desiring more information on the early testing, including photos of a variety of the pop-ups produced and a description of the software at Version 1.1, should consult Hendrix and Eisenberg [47] and Hendrix [46].

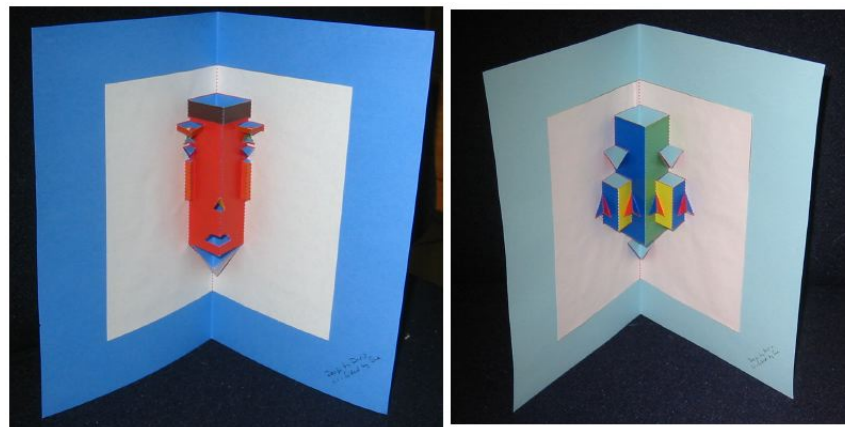


Figure 6.2: Pop-ups made during the informal studies: Two pop-ups made by middle school children in a summer program.

Early tests were done with 5th graders at an elementary school in Boulder, Colorado. The tests were conducted with several students who had been chosen to participate in a test of Hypergami (see Eisenberg [28]). This was a classroom setting with a small group of children, five of whom worked independently to produce one pop-up each. Two of these are shown in Figure 6.1. One other 5th grade student from Eagle, Colorado also made one pop-up. In addition, five middle school students enrolled in a summer program made one pop-up each. Two examples are shown in Figure 6.2.

Several pop-ups were also made during this period by adults using the software. An undergraduate intern made six pop-ups, a graduate student made a single pop-up, and the researcher

produced several. Two of these are shown in Figure 6.3. These pop-ups were primarily created to determine the limits of the software, identify bugs, and test on both Windows and Macintosh operating systems.



Figure 6.3: Two pop-ups Made in Informal Studies: Pop-ups made by (left) undergraduate and (right) graduate level college students.

6.1.1 Observations of Children During Informal Testing

No specific questions were asked of participants in the informal testing, but the users appeared motivated to make pop-ups and interested in the results. The 5th graders were more enthusiastic than the older, middle school users judging by the numbers of volunteers, and the excitement shown by the younger children.

The users had no difficulty with the program itself. The younger users needed a bit more instruction, as they seemed reluctant to simply plunge in. The most common problem was that the cursor needed to be placed near a fold when adding a new element. But after a few minutes this difficulty disappeared.

Actual construction of the pop-ups presented no great problems, although very small elements were difficult to fold. This difficulty was seen more with the older users, as they tended

to make more complex designs with smaller elements. Part of the folding difficulty arose because the tools available to the users were limited, and included no craft knives or tools to score the folds. The paper used was printer paper rather than card stock which, while generally easier to fold, is too thin for many pop-ups, particularly 180° elements which require more stiffness. Since there were no 180° elements available in the early version of the software, printer paper did not present a real problem, but needed to be backed with a stiffer paper after the pop-up was made.

Younger users experienced more difficulty when deciding which way to fold an element. This improved as the work proceeded, and it might be assumed that over time the difficulty would disappear if the users made more pop-ups.

A "face problem" was noticed. Users (particularly the 5th graders) wanted to make faces. Often the first thing said by the user was, "Can I make a face?" 90° elements can be used to make faces, but a problem can arise with the making of the eyes. Since elements must be placed on a fold, eyes can be placed on the side of the head or nose, but not (if composed of pop-up elements) between the nose and the side of the face. In addition, the decorative materials provided to these users were limited to pens and pencils, and this added to the problem. (For more information on this face problem, and how the children solved it, see Hendrix [47].)

A number of other observations were made. These included the fact that non-adult users did not alter the shape of cuts in the designs or add additional material to the pop-ups. The only exception to the latter was the addition of a tongue to one mouth. This was done with the help of an instruction book that the researcher happened to have with her at the time. When working with the software, the children commonly used fill colors, but the line drawing tool was almost never used. In virtually every case the designs created were symmetric. There were no 180° elements available, which limited the type of designs that could be produced. The 5th graders noticed that the x- and y-coordinates of the cursor were given, but none used them to position elements.

When working with the software, the users did not use the Viewer Window very much. Since the representation could not be rotated and was not a particularly good 3D model of the final pop-up, it meant that colliding elements might not be found, and indeed were not found in

at least two cases. Also, one user produced a design that did not open as elements were on an extension of a fold rather than the fold itself. The viewer did not clearly show the action, or non-action in this case, of such a pop-up.

Finally, the desirability of making multiple copies became evident. Although the users took their copies home, the researcher was able to make a copy from the exported files to study later.

6.1.2 Influence of the Informal Tests

The most important results of the informal user testing led to software changes that addressed the limited set of available elements and the usefulness of the Viewer Window.

No information could be gleaned from those tests about how users might handle 180° elements. These are important, as they constitute the major components of commercial pop-up books. These elements require gluing pieces onto the base page, thus adding complexity. The absence of 180° elements tended to limit the types of pop-ups that were being created, so two basic 180° elements were added as a result of this testing.

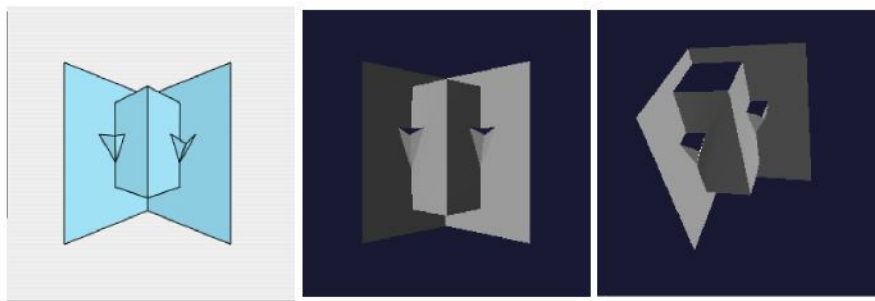


Figure 6.4: Comparison of the Viewer Window in software versions: The Viewer Window in Version 1.1 (left) was statically oriented and colored to suggest shading. The Version 2.0 Viewer Window provides a more realistic view of the pop-up (center) and rotation (right).

The initial Viewer Window proved to be a problem. First, the orientation of the pop-up was fixed, allowing opening and closing of the pop-up but not rotation, which is needed to fully examine the pop-up for element collisions. Second, the 90° elements were shown, but not the areas behind them. That is, the users could not see the holes created by the element. Third, the

shading on the representation was simply made by shading all left planes with one color value, and all right planes with another value, rather than having a light source produce true shading of the pop-up. The differences between the Version 1.1 and the Version 2.0 representation of the pop-up are shown in Figure 6.4. The shading problem and the lack of rotation were solved by adding the Java3D libraries to the code base. The "cutting out" of the planes beneath a 90° element proved more difficult to correct, as planes needed to be mended when an element was changed or removed. This was solved by marking the original points of the plane so that the original plane could be restored.

One of the features that became obvious in reviewing the informal testing was that it included users only 10 years old and older. The motivation shown by the 10 year olds, the ease with which they learned how to use the software, and their ability to manipulate the paper, even without the best of tools, was an indication that younger users could participate in the activity, and this needed to be tested.

The informal testing occurred in unstructured environments, either classrooms with several users working at one time or, in the case of adult subjects, totally unobserved. This limited the researcher's ability to observe the users at work in any detail and there was no ability to engage with a single user or record the activity without interruptions. Formal tests were therefore designed to accommodate single users with videotaping for detailed study.

The fact that only one pop-up was produced per user meant that it was not possible to observe changes over time. For instance, it has been noted that the users did not add attached planes or alter the shape of cuts in their pop-ups, which begs the question about what might have been seen with additional pop-ups. As another example, some users had difficulty at first in knowing which way to fold a given fold-line and this seemed to lessen with time. There was no indication about how this difficulty might further change with more pop-ups. For these types of reasons, formal testing was planned to have users make at least four pop-ups.

It has been noted that one of the users in the informal tests added a tongue to a mouth in his pop-up following an example in an instruction book that the researcher happened to have. For

the most part, however, users did not have access to any supplementary materials. In addition, the limited set of tools and lack of stiffer paper constrained the results. It was decided that for the formal user testing, the environment would include a set of books, both commercial pop-ups and instruction books, an array of tools, various colors of card stock, and decorative materials. This environment is more completely described in Section 6.2.1.

6.2 Formal Testing Methods and Environment

As the previous section indicates, early studies with Popup Workshop uncovered several deficiencies in the software and testing methodology that needed to be addressed. First, a more capable version of the software was required that would allow the users to make 180° as well as 90° elements. A more functional Viewer Window with the ability to rotate the 3D representation of the pop-up was seen to be needed as well. The 2.0 version of the software provides both of those features.

Second, recruiting users from a greater range of ages, in particular younger children, would help to establish the usefulness of the software for not only upper elementary and middle school aged children, but for those in the early grades as well. Those users needed to participate over longer time periods and make several (at least four) pop-ups in order to see not only if their interest continued but if their skill and knowledge levels changed over time.

Third, formal testing would require a work environment which included a sufficient set of good quality hand tools, a large variety of materials, and reference materials which could support pop-up creation, stimulate the user's appreciation of the pop-up world, and allow for the observation of that appreciation.

Fourth, it was decided to have some type of pre- and post- testing assessment tasks to specifically evaluate users' knowledge gain.

Finally, it was determined that videotaping the user sessions would allow for a more thorough analysis of the results.

All of these things were accomplished for the formal testing. The following sections de-

scribe the environment, the methods used, and how the data were collected and analyzed.

6.2.1 User Sessions and Environment

Popup Workshop as tested consisted not only of the software (see Chapter 5), but the complete environment in which the testing occurred. Children had access to reference materials consisting of both commercial pop-up books and how-to books on pop-up making. The pop-up books were chosen to represent a variety of styles, complexity, and paper engineers. The how-to books ranged from Valenta [123] which is suitable for very young children to Carter and Diaz [14], a book which includes examples of, and constraints for, a wide variety of elements. Diehn's [26] book on bookmaking for children was available as well, in the event that children wanted to make books out of their designs. Children were given time during sessions and encouraged to look at books.

The complement of available tools included craft knives and a cutting mat for use by the 3 older children, while the 6 and 7 year olds used scissors only. An embossing tool was at hand for scoring along folds to allow a smooth fold, something that was not available for early informal trials. This was particularly important here as the paper provided was card stock which, while difficult to fold without scoring, is more appropriate for pop-ups, particularly 180° elements, which must be sturdy enough to stand up from the page. A range of art materials was present as well, ranging from markers, crayons and colored pencils to googly eyes and sequins. Appendix D is a complete list of the references, materials, and tools available to children in this environment.

All users worked singly with the researcher during sessions in order to allow them to concentrate on their work and to have the full attention of the researcher. The researcher occasionally made suggestions to the users or provided guidance when asked for help, but for the most part children worked through their designs alone. Sessions lasted one hour for the youngest children, but the older children occasionally worked for up to two hours in a session.

6.2.2 Pre- and Post-testing Assessment

The data obtained from the sessions included the pop-ups users made and user comments about pop-ups and Popup Workshop. In addition, tests and surveys were made at the beginning and end of testing and a follow-up questionnaire was sent to users several months after the testing was completed. The pre- and post-testing activities were designed to understand how the children thought about the way pop-ups were constructed, their vocabulary changes, their opinions about the software, their prior experiences with pop-ups and paper crafts in general, and what they thought about the testing, their pop-ups, and the software at a later point in time.

During each user's first session, several questions were asked in order to get acquainted with the user and to gauge each user's experience with pop-ups. This process was informal and took the form of a conversation, although the same topics were always included. During the final session, the questioning was oriented toward the child's experience with the software and the pop-up design process in general, including a retrospective of their previously-made pop-up designs. Lists of topics for both question sessions are available in Appendix E.

In addition to these conversations, two standardized cognitive tests were given to each child, with the first half of the questions of each presented during the first session, and the second half during the last session. These tests were the Card Rotations Test and the Paper Folding Test described in Ekstrom, et. al. [30]. The Card Rotations Test, designed to test spatial orientation, presents a shape, and asks which of eight other shapes shown represent the same shape rotated, or the shape turned over (mirror image) and rotated. The Paper Folding Test, purportedly a test of visualization ability, shows a piece of paper being folded and one or more holes being punched through the folded paper. The person taking the test chooses which of five drawings represents the paper when unfolded. These particular cognitive tests were chosen as they use the mental manipulation of paper shapes, a valuable skill when envisioning a functioning pop-up.

It was suspected that these tests would probably not show any changes in these cognitive areas over the short time in which testing was done. However, they were cognitive areas that could

prove important to skill acquisition in pop-up making, and it was thought that the tests might be an indication of the potential of each child at the very least. In addition, the time investment (3 minutes per half-test) was minimal. The test results are further discussed in Section 6.3.3.

The most important element of the testing was a discussion about actual pop-ups conducted with each child. The same three pop-up books were looked at in both the first and last sessions. During these sessions, the child was asked to talk at length about how one of the pop-ups in each book worked and how it was made. The same pop-ups were used in both sessions with each child. This discussion provided the bulk of the data concerning knowledge and appreciation of pop-ups.

The three pop-up books chosen were representative of three levels of pop-up making, ranging from a pre-school or early elementary school book to an example designed with older children and adults in mind. They range in difficulty of the design and complexity of their pop-ups, as well. These books were previously mentioned in connection with the frequency of occurrence of pop-up elements in Section 4.1.2 as they serve as good examples of the range of commercial pop-ups available. The particular pages of each book examined in the user testing are described here and were picked because they contain interesting uses of the elements that are available in *Popup Workshop*. While 180° elements such as tents and v-folds were common, 90° elements are rare in commercial pop-up books. The only example included in these pages was a beak with moving arms attached to it.

First, *Snappy Little Farmyard* [109] is a fairly simple, but cleverly made pop-up, one in a series of books for young children. The page selected to be analyzed by the children (see Figure 6.5) contains both a tent (the covering over the pig mechanism illustrating a fence and gate) and a v-fold for the pig. The v-fold is hidden and cleverly folded and braced to give an upward motion to the pig.

Second, *Haunted House* [85] was chosen for its use of interesting mechanisms. It is aimed at children of elementary school age, but is more complex than *Snappy Little Farmyard*. The page selected shows, among other things, a gorilla. Two tents make a fireplace grate and furniture. The

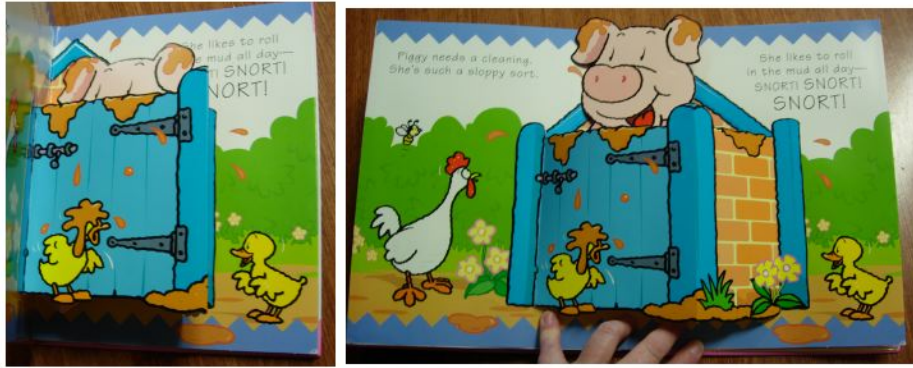


Figure 6.5: Assessment pop-up 1: The pig from *Snappy Little Farmyard*. A tent forms the fence and conceals the mechanism that raises the pig, which is a folded v-fold.



Figure 6.6: Assessment pop-up 2: Gorilla page from *Haunted House* contains tents, a beak and attached moving arms. The motion of the gorilla's arms during opening is shown.

gorilla has a moving arm mechanism placed on a beak built into the larger tent.

Raggedy Ann and Andy and the Camel with the Wrinkled Knees [41] is hard to categorize in terms of the age of children who might read it. In some sense, it is an art book for adults. However, the story is presented in the book by way of gatefolds and would be enjoyed by a young reader. The pop-ups are quite complex but are built largely from simple elements with many attached planes. The page used in the testing has two large pop-ups in addition to small pop-ups in the gatefolds. At the rear of the illustration a v-fold lifts an attached plane representing animals and bushes through the use of an extension (which could be considered a tent). At the front, three



Figure 6.7: Assessment pop-up 3: Scene from *Raggedy Ann and the Camel with the Wrinkled Knees*. Two views are provided to show the front and back parts of the scene. The front part consists of an angled platform made from two v-folds supporting a field of flowers. Figures are attached to the v-folds and slotted through the flowers. In the back, a v-fold lifts an attached plane.

characters are attached to two v-folds that combine to make an angled platform. These v-folds are hidden by a table-like sheet of flowers.



Figure 6.8: Assessment comparison pop-up 1: *Alice in Wonderland: A Pop-up Adaptation*, paper engineered by Robert Sabuda [13]. This version of the tea party is modeled after the original Tenniel drawings for the book, and shows a very strong 3D representation.

Some subjects are more frequently encountered in commercial pop-ups than others. Animals, for instance, appear in many of the pop-ups provided for the children in the test environment, including 5 books on dinosaurs alone. This set of pop-ups also included two versions of *Alice in Wonderland* [13, 12]. As Figures 6.8 and 6.9 illustrate, these books are very different in style and in the construction of their pop-ups. During the last session of user testing, all but one of the children were shown the pop-ups of the tea party from both books and were asked to compare them in order to elicit any thoughts they had on their differences and which they liked best, in order to determine if some indication of their ability to appreciate the pop-ups made by others would emerge.



Figure 6.9: Assessment comparison pop-up 2: *Alice in (pop-up) Wonderland*, paper engineered by James R. Diaz [12]. This tea party has a very cartoon-like style, and the table is modeled in a foreshortened, semi-3D manner.

After the user testing was complete with all subjects, a follow-up questionnaire was sent to each. The questions were sent on August 7, 2007, approximately 4 months after the last session with the last user to finish, and almost 11 months after the last session with the first user to finish. This was done via email, since two of the subjects had moved and were unavailable for face-to-

face meetings and email was available to everyone. All of the subjects responded (or rather, their parents responded with their answers.) The purposes of the follow-ups were primarily to look for long-term effects of the testing and to find out what had happened to their pop-ups. Questions were asked about their favorite pop-ups, whether they had done any pop-up making since the user tests, and what had become of the pop-ups they made. The full list of questions is reproduced in Appendix E.

6.2.3 Data Collection and Analysis

The data collected during user testing included videotapes of all sessions. These were converted to DVD, and notes with times for key events were made for all the DVDs. In addition, transcripts were made of important parts of session, particularly for the questions and pop-up book analysis done during the first and last sessions. The transcripts were used to examine the vocabulary used for the elements.

The children took their pop-ups home when they were completed, but photos were taken of each pop-up to provide a persistent record. These photos and descriptions of each session with each child are collected in Appendix F. In addition, the software design for each pop-up was saved in both XML and JPEG formats. The features of each pop-up were counted and categorized and the results are summarized in the tables of Appendix G. These features include the number of each type of element used, the total number of levels, the symmetry, decoration used, additional elements added by hand, and where the ideas came from for each pop-up.

Finally, the cognitive tests were scored, and the answers to the follow-up questionnaire were compiled.

6.3 The Users

An attempt was made to recruit children by distributing posters to schools and placing them on bulletin boards. In the end, however, the users came from families of colleagues (Daisy, Ursula and Richard) and from a family with an older sibling who had taken part in another study

in our research group (Peggy and Emily).¹ Daisy and Richard are sister and brother. Peggy and Emily are fraternal twins.

Table 6.1 lists age and gender information for the children. The children fell into two age groups with Ursula and Richard in the young group (6 years of age when testing started) and Daisy, Peggy and Emily in the older group (11 or 12 years old when testing started). Peggy and Emily turned 12 during testing, so the two groups will be referred to as the 6 year olds and the 12 year olds.

User	Age	Gender	Birth-date
Daisy	12	F	January 1994
Ursula	6	F	September 1999
Richard	6	M	December 1999
Peggy	11	F	December 1994
Emily	11	F	December 1994

Table 6.1: A summary of information about the users. Users are listed in the order in which they started participating.

There were some differences observed in the user tests relating to the children's ages that should be mentioned. First, when cutting, the 12 year olds had access to craft knives while, because of safety concerns, the 6 year olds were limited to scissors. Since the scissors make it difficult to cut slits in a sheet of paper, the researcher sometimes helped by starting cuts on slits for the 6 year olds. Second, the 6 year olds were less inclined to experiment with the software when first starting to use it. They preferred to have the researcher demonstrate or help them through some of the software's functions first. The 12 year olds all started to experiment without any guidance. Third, both of the 6 year olds made a pop-up by hand at the start of the sessions. This seemed to put them at ease, allowed them to demonstrate their paper skills (particularly in the case of Richard, who knew how to make a step), and satisfied their desire for immediate contact with physical materials. This last was most obvious in the case of Ursula, who seemed to prefer working with paper to working with the computer. The 12 year olds seemed more

¹ Pseudonyms are used throughout for users.

interested in the software when they first began testing. Finally, the 6 year olds could not read, at least when they began testing. This meant that they were not using the help or tool tips available in the software, which may explain some of their hesitation in using the software at first. In addition, they could not write text on their pop-ups. Richard did ask the researcher to write some captions on his pop-ups for him. In general, the 12 year olds needed less guidance or help, which is not unexpected.

6.3.1 Users - Data About Sessions

Table 6.2 summarizes the beginning and ending dates and amount of testing for each user. The number of sessions ranged from 5 to 13. The 6 year olds were limited to one-hour sessions but the 12 year olds had a few longer work periods. Richard had the fewest sessions and spent the least time in testing as his family was preparing to move. Emily worked for the greatest number of sessions and the most total time as she extended her testing sessions to finish the book on which she was working.

Table 6.2 also helps to establish the time required for a child to make a pop-up. The users spent 43.2 hours in testing sessions, making 42 pop-ups, which would point to a bit over 1 hour for a pop-up. However, the total pop-up making time was less than 43.2 hours, as most of the first and last sessions were spent on pre- and post-testing activities and discussions of their backgrounds and the software. And, of course, children are capable of spending some session time looking at books and off-task. Taking this time into account, the true average time is probably closer to 45 minutes per pop-up. But pop-up making is a highly variable activity. Emily's moose (see Figures F.3, F.4, and F.5) or Daisy's owl (see Figures F.32, F.33 and F.34) are examples of pop-ups that required a great deal of time to make. The time required varied greatly by child as well. Ursula averaged almost 2 pop-ups in one hour, mostly because she did not like to spend much time on the computer, but wanted to print quickly and get the paper in her hands. Peggy spent a great deal of time designing her pop-ups and adding additional handmade elements, and therefore took 8 sessions to make 4 pop-ups. Although the time to make a pop-up varied greatly,

it was a reasonably quick process and one which could fit into a class period in most cases. This underscores pop-up making's utility in the classroom.

User	First Session	Last Session	No. Sessions	Hours	No. Pop-ups
Daisy	07/03/06	09/29/06	7	8.5	7
Ursula	07/07/06	11/17/06	8	7.5	14
Richard	08/02/06	10/06/06	5	4.5	7
Peggy	11/05/06	02/04/07	8	7.0	4
Emily	11/05/06	03/24/07	13	15.7	10

Table 6.2: A summary of information about the user sessions. Users are listed in the order in which they started participating along with the number of sessions, total time spent working on pop-ups in hours, and total number of pop-ups made.

6.3.2 Users - Prior Experience

In terms of prior experience, all the users had done some sort of crafts before. Daisy had made a doll-house from cardboard and wood. She had also participated in a previous study in our research group which involved making an automaton (a dragon) from wood. Ursula had worked with paper a great deal, creating her own projects. For instance, she made a large (about as large as she was) unicorn from folded and glued paper. Richard liked to draw, and mentioned this as his favorite part of school. Peggy said that she made crafts as gifts for the holidays or when her sister (Emily) wanted to make something with her. She indicated that Emily was “the crafty one”. Emily sewed stuffed animals, wove, and was taking an art class and working on an oil painting at the time.

More specifically, three of the children had made some sort of pop-up before. Richard demonstrated his style of pop-up making (steps with attached planes, see Figure F.15) during his first session. Although he made steps, he was unaware of beaks. The opposite was true of Peggy and Emily. They often made small pop-up cards to use on presents that utilized beaks. They had not used steps before.

In addition, Ursula was aware that pop-up making was possible for kids. She mentioned

that a friend had made a frog using a beak. She wasn't certain how to do this, however, and this was the first thing that she asked to see during the user testing.

All of the children had previously used computers although the type and amount of use varied among them. They all mentioned using them to play games, with Richard and Peggy seeming to be the most dedicated computer game-players. For drawing, Ursula had used Kid Pix, and Emily and Peggy had used SketchUp.

User	Paper Folding			Card Rotations		
	Start	End	Sum	Start	End	Sum
Daisy	-1.00	6.25	5.25	52	47	99
Ursula	0.25	4.00	4.25	15	24	39
Richard	1.00	1.25	2.25	9	6	15
Peggy	3.25	3.00	6.25	40	56	96
Emily	7.75	7.50	15.25	47	43	90

Table 6.3: Cognitive Test Results: User scores for the Paper Folding (Visualization) test and Card Rotations (Spatial Orientation) test. Half of each test was administered before and half after the user testing sessions.

6.3.3 Users - Results of Cognitive tests

Table 6.3 summarizes the results of the standardized cognitive tests administered to the children, the Card Rotations Test and the Paper Folding Test. The first half of each test was administered in the first sessions, and the second half in the last sessions. This is the suggested way of using these tests, and they are divided into two parts for this purpose.

Standardized tests were included as part of the testing for several reasons. First, such tests have been used previously by other researchers in the area of craft software user testing [28, 8], and they have reported useful insights from such tests. Second, the time involved was minimal, three minutes per test per section. Third, it was anticipated that the tests might be used to classify the users into groups exhibiting differences in pop-up making ability. Although the tests were administered both before and after the craft work, the small amount of time that the children would be working should not produce any change in such basic attributes, so no change was

expected. Rather the two separate administrations of the tests were considered a check on the results, which should be similar. The tests were therefore administered in order to see if those children who did better on the tests were better able to learn the craft.

These particular tests were chosen because it was thought that spatial orientation might be an important area of cognition in pop-up making and, as the shapes created in making pop-ups often rotate in place, the Card Rotations test might be particularly apropos. Similarly, the Paper Folding test explores the ability to spot the result of several operations performed on a piece of paper. Being able to visualize such results seemed logically related to the ability to make pop-ups.

An important caveat relates to the ages of the users. The tests are not specifically designed for children, so the ages of the participants might invalidate the results. Certainly, comparing the 6 year olds directly to the 12 year olds would be inadvisable, as one would naturally expect age alone to create differences in scores. There are no specific scores which might be expected from users of any age, so that one cannot look at a score in isolation, but must compare scores between the users.

Daisy and Ursula had much lower scores in the first test administration of the paper folding test than in the second administration. This was probably in part due to nervousness and confusion over the directions, as the paper folding test is a difficult task. Otherwise, the scores do not seem to show any measurable improvement between the first and second administrations as expected. The tests certainly showed a difference between the two age groups, in that the total scores of each 6 year old were below the total scores of any of the 12 year olds.

Of note is Emily's very high score in the Paper Folding test which was over twice the score of any other participant. Emily had done the most craft-work, including art, was probably the most dedicated reader of the group, and wanted to be a writer when she grew up. In addition, Emily made the most pop-ups, continued user sessions the longest, and made a connected story from her pop-ups. These facts say nothing about the cause of Emily's high Paper Folding Test score. It is impossible to say if Emily's visualization score is high because she has done so many crafts, or that she does crafts because it is something at which she excels.

There is also a distinct gap between the test scores of the 6 year olds, with Ursula clearly out-scoring Richard. However, it is hard to make any claims about these two children. Both children had a history of making paper objects on their own. Richard did not make as many pop-ups, but he was moving and had to leave the testing. Also, Richard showed little interest in the cognitive tests, and tended to stop working on them before time was called.

In short, whether because the tests themselves are meaningful or because of the small sample size, the standardized tests produced no results that were of use in understanding the learning of paper engineering by children.

6.4 Results

In Section 2.3, a framework for the study of craft was developed and the analysis of the results presented here is based on that framework. These results are divided into areas related to the competencies of knowledge, skill, and appreciation in order to assess the performance and craft learning of children in the user testing as detailed in Sections 6.4.1 to 6.4.3.

Since these results relating to the craft competencies may not always address specific parts of the software, Section 6.4.4 is devoted to the remarks and answers to questions from the users about their experiences as well as observations about their use of the software. In addition, since the users provided feedback after the testing, parts of this section discuss the answers to the follow-ups, particularly as they reveal the later fates of the pop-ups made during the study, and additional pop-ups made after (or in one case, during) testing.

6.4.1 Craft Knowledge

In Section 2.3.1, craft knowledge was identified as one of the fundamental competencies of craft. Assessing knowledge is relatively straightforward, as tests or discussions with the learner can uncover the quantity and quality of the learner's knowledge. During the first and last sessions the users spent time examining commercial pop-up books and discussing how they worked in order to provide some insight into their understanding of pop-up action.

To more easily assess this knowledge, a small subset of pop-up craft knowledge was chosen for evaluation. The particular subset chosen for evaluation was the identification and naming of pop-up elements, which is both important and observable. Elements (see Section 4.1) are the basic building blocks of pop-ups and it is reasonable to observe how children identify elements in order to arrive at an understanding of their learning. Consistent names were used for elements in both the user tests and the software. This allows a comparison to be made with the names the children used during their discussions of the target pop-ups.

Pop-up	Daisy	Ursula	Richard	Peggy	Emily
<i>Farmyard</i> Tent	"tent fold thing"	"tent"	-	-	"tent thing"
<i>Farmyard</i> V-fold Variation	P, "v-fold"	"v-fold"	-	"weird v-fold"	"bent-up v-fold"
<i>Haunted House</i> Tents	"tent fold"	-	"tent thing"	"step and another step"	"tent" (says step then corrects)
<i>Haunted House</i> Beak with Moving Arm	"triangle"	"v-fold"	-	"v-fold"	"beak v-fold"
<i>Raggedy Ann</i> V-folds with Platform	"v...", P	-	-	"two v-folds"	"v-folds"
<i>Raggedy Ann</i> V-fold with Attached Plane	P	P	-	"v-fold and a little step"	"v-fold"

Table 6.4: Element Names in User Tests: The element names used by each child in the final session are shown in quotes. "P" indicates that the child used the software controls to indicate the type of element instead of using the name, correctly identifying the element in each case. "-" indicates that no element name was used.

During the first session, children did not use element names, although they could describe the construction and motion of pop-ups. They had not been exposed to element names yet via the program, and this demonstrated that, most likely, they had not encountered these names anywhere else. Children, even the younger children, could explain pop-ups without a vocabulary of element names. They often used gestures to show the motion, and talk about folds and connec-

tions. As an example, here is Richard (6 years old) explaining the *Raggedy Ann* pop-up (Figure 6.7) in his first session.

Richard: Hm. Ok. *[He looks under the flowers.]* When this closes...um...when this closes *[closes the book]* it pushes them down and these things *[fingers on front v-fold]* go down like...go down like that. And then when you open it, it *[hands on flowers]* goes up, and then it causes it to go up *[runs his fingers up the characters]*.

Researcher: Mmmm. How about this one back here *[points to animals]*.

Richard: Hm. It's um..this one, how it is, is it connects *[indicating connection between v-fold and attached plane]* and it's kind of like mine *[The pop-up with steps that he has just made]*.

This is quite a complicated pop-up, but Richard spots the important parts: the v-folds supporting the platform, the character's connection with the v-folds, and the connection between the v-fold and the attached plane in the rear portion of the pop-up. Richard was the most adept of the children in this first session, but not unique. Peggy, for instance describes the same pop-up:

Peggy: *[closes, opens, looks at it from the back. Opens and closes again, touches characters. opens and closes.]* So the dolls in front here, they're folded so like they have a little tab under them, like it goes like that *[makes right angle with two flat hands.]* and so, when you close the book. they just fold down, on top of the tab, so it's really a pretty simple pop-up, but like it's really cool, and there's slits in the flowers so it looks like they're standing in the flowers. And then these guys *[in back]* are basically just a fold, and when you close it they fold in and when you open it, the page opens, and they're kind of forced to stand up. And then the bush is attached to this.

Researcher: And the bush is attached here.

Peggy: But you notice that they're more 3D, because that way it's not just standing on its own.

The last observation of Peggy's, that the separation of the bushes into two parts makes the scene more 3-dimensional, is a particularly cogent one.

During their last session, children did refer to elements by name, and Table 6.4 summarizes the results. In some cases, the children noted the type of an element by pointing to the software control on the computer screen, and this has been noted where it occurred. This was seen in the

cases of Daisy and Ursula because the program was running during the time they talked about the pop-ups, and was therefore convenient. But in most cases the elements were identified by name.

Some of the children identified more elements than others. There are three possible reasons for this. The first is time on task. Emily spent far more time working on pop-ups than the other children, and did the best job of identifying elements. She showed a great improvement in her ability to describe pop-up action during testing, and it is interesting to compare her reaction during the first and last sessions to the *Farmyard* pop-up (Figure 6.5). In the first session, Emily was reluctant to talk about the pop-up, and in fact did not describe it other than to talk about the number of pieces:

Researcher: So how does this one work?

Emily: Some really complicated folds. [*She looks down in the tent.*]

Researcher: OK, So first of all, how many pieces has it got?

Emily: Like, two or three million.

Researcher: Oh, not that many!

Emily: One. two. three. four?

Researcher: Well, OK. We've got this one [*points to tent*] of course. What about the inside?

Emily: I think...this looks like one piece [*points to the v-fold*] and this [*points to the pig*] is one piece.

Researcher: Yeah he is, he's glued on there, isn't he?

Emily: So it's like 3 pieces.

Her description in the final session was brief, yet more detailed and accurate:

Researcher: So how does that one work?

Emily: It's a tent thing, and yeah, there's a v-fold under there. A bent-up v-fold.

Richard had the shortest time of any of the children to work on the pop-ups, and he displayed the least vocabulary change. Part of this may be due to a second indicator of whether vocabulary is learned: the elements used during testing. Until his last pop-up, done after the description of the pop-up books was complete, Richard had not made a v-fold, and most of the

example pop-ups were based on v-folds. Another example is Daisy, who had made no tents. She did use the word “tent”, but called it a “tent fold”.

Finally, the younger children (Ursula and Richard) in general used less of the element vocabulary than the older children. This may be in part related to their inability to read the help text and tool tips in the software that were a vehicle for vocabulary learning in the 12 year olds.

The most common mistakes made with element terminology was switching the names of elements within the categories of angled and parallel elements. This can be most clearly seen in the *Haunted House* pop-up, where the base of the moving arm (a beak) was called a v-fold, and the tent was called a step. In all cases where an element’s name was given incorrectly as another element’s name, the switch was between 90° and 180° element names. There were no examples of children switching the names between the parallel and angled elements. It may be the case that the angled/parallel distinction is more important than the 90°/180° distinction. Also, since the software draws the shape of the elements the same for 90° and 180° elements, with angled elements drawn as triangles and parallel elements drawn as rectangles, the software itself may reinforce this similarity for the users.

Identification of elements by name occurred at times other than just during the post-testing activities. For instance, Ursula correctly identified several v-folds during her 5th session while looking at other pop-up books. Of particular interest is the answer given by Emily to a question in the follow-up email several months after testing. She was asked if she had made any pop-ups since the test sessions and answered, “I made a castle with a knight in front of it. The castle was three layers of v-folds going straight up. the knight was also a v-fold.” The terminology had remained with her. It appears that all of the users learned at least some element names during their sessions, and therefore that their knowledge of pop-up vocabulary increased.

Another indicator of increasing knowledge about paper engineering that was not specifically tested for was the users’ ability to select an appropriate element or set of elements for a particular purpose. This is harder to measure, and opens up the difficult question of what is “appropriate”. Perhaps a better way to describe the process is to refer to the ability of the users

to obtain the effect that they wanted. This can be a difficult target in paper engineering, even more so with movement than shape, and there were numerous cases in which the design did not work out as the users wanted. One example, was Peggy's inability to make a cloud that would move over a sun that is discussed in Section 7.3.1. However, in other cases the desired effect was achieved, usually in one of three ways: by experimentation, by locating an example, or the by using a previously-used element. Experimentation, in particular the use of prototypes, is most clearly illustrated by the pull-tab Emily constructed on her *Moosey McMooseMoose* pop-up. (See Section F.5 and in particular Figures F.32 through F.34.) Experimentation, of course, is not so much a demonstration of knowledge acquisition as a vehicle for it. The knowledge gained about pop-ups is more clearly demonstrated by the fact that children often were able to know where to find an example or instruction on how to produce the effect that they wanted. For instance, Daisy, in making her *Owl*, remembered a pop-up of a Toucan in *Very Lazy Lion* [116] and used that body as a model for her owl. Children also reused certain elements or combinations of elements, especially when they liked their first use of them. For example, Ursula enjoyed her *Turtle Gymnast* (Figure F.10) enough that she used it as a model for her *Fat Upside-down Bunny Gymnast* (Figure F.11) and showed much more confidence in constructing the second v-fold figure. Peggy liked the v-fold as a platform enough to use it in three pop-ups. Users thus showed an ability to use similar construction in later pop-ups.

6.4.2 Craft Skill

The skill competency was defined in Section 2.3.2 as that portion of craft learning that must be practiced, that cannot be learned from observation or written directions. This can include the use of tools and materials as well as the process of design itself.

Skill can be assessed either by watching the performance of a craft, or by looking at the resulting craft objects. Section 6.4.2.1 focuses on the pop-ups made by the users to see if they show changes in skill. This object approach to the question of skill development was chosen in part because this method presents some interesting problems in how to analyze pop-ups, objects

which have not previously been examined in such a way. It also allows all of the pop-ups to be examined at once, an undertaking of much greater difficulty with direct observations of the user's actions, considering the amount of data generated by videotaping. In Section 6.4.2.2, some additional observations of tool and material use are made. It is possible as well to use the observations of a more limited set of children during their work, and in Chapter 7 this will be the focus.

6.4.2.1 Skill Assessment Through Craft Objects

Because of the modular construction of pop-ups, with the elements being the components, it is possible to organize the pop-up data around the general categories of element use and alteration, decoration, and symmetry.² Some of these categories revolve around pop-up complexity. The first category of such measurements is the type and number of each element, not only elements created in the software, but those added by hand. Second are alterations made to the elements, such as changing a cut line, removing portions of an element, or extending an element plane. A third measure of complexity is the number of levels in a pop-up. Figure 4.12 illustrates how the levels in a multi-level pop-up are determined and Tables G.1 through G.5 indicate both the highest level created in software for each pop-up, as well as the highest finished level if additional levels were added by hand. Fourth, symmetry is another characteristic to examine in children's pop-ups and Tables G.6 through G.15 indicate the symmetry of each pop-up in four categories. First, the design in software may be symmetric and remain so when the pop-up is complete (S). One such pop-up may be seen in Figure F.1. Second, the original design in software may be asymmetric (A), and remain so when complete. Figure F.9 is an example of such an asymmetric design. Third and fourth, the original design may be symmetric, but the card may be turned on its side when finished, making it vertically asymmetric as viewed (St) or may be altered by adding decoration or extra elements such as attached planes (Sd). These last categories are

² In examining the pop-ups produced by each child, Appendix F with the photos of the pop-ups should be consulted. In addition, Appendix G contains tables with the construction details of each pop-up for each child. Tables G.1 through G.5 detail the numbers and types of the elements used and the number of levels, while Tables G.6 through G.15 contain a summary of alterations made to elements, additional elements not made in software, decoration methods, symmetry, and where the idea for the pop-up came from.

not mutually exclusive. One pop-up which exhibits both of these asymmetries is shown in Figure F.15. Finally, decoration can be evaluated, whether computer coloring, coloring with markers, crayons or colored pencil, and items like sequins or googly eyes added to the pop-up.

Most of these data are simply indicative of complexity. An important question to ask is whether complexity equals skill. The answer, of course, is that it does not. However, complexity often requires skill. It is true that one element, properly made, simple, and perfectly adapted to the design can be evidence of great skill in paper engineering. It would be remiss to concentrate on the above data and ignore the quality of work that goes into a pop-up, or the applicability of a given element to the task. The goal here is to navigate between the Scylla of measurable but possibly meaningless data and the Charybdis of subjective views of quality to reach some understanding of how the skill of the users has changed.

Beginning with a general discussion of the work and progression of each child, focusing on the features of the pop-ups produced and how they changed over time, will establish the general pattern of work for each user. Rather than visiting the users in order of testing, age will be used. The 6 year olds are described first, followed by the 12 year olds. These views of each user are followed by general observations culled from looking at the users overall.

Ursula, one of the 6 year olds, was less concerned with the software in general than the other users were. Her aim was usually to use a few (sometimes only one) element, use no computer coloring, and print as quickly as possible. She wanted paper in her hands rather than a design in software. Ursula began in what might be described as her "bunny period". Most of her designs revolved around bunnies and turtles. She discovered the utility of the v-fold with her third pop-up, and returned to that element several times. Ursula did not make many multi-level abstracts, and therefore her pop-ups tended to be one-level for the most part. She made only one asymmetric pop-up, *Bunny and Castle* (see Figure F.9), and it was surprisingly good in all respects, with two 180° elements and an attached plane. Ursula had a long recess in her testing sessions between session 6 and session 7. When she returned for her two final sessions, she had left her bunny period behind and produced the most interesting abstract of her sessions, the

Totem Pole (see Figure F.14). While this was not the most complex pop-up she had made in terms of number of elements or level, the decoration and quality of her work seemed to have taken a major step.

Richard had the fewest sessions. He also came into the testing with the best ability to make pop-ups, as he demonstrated in his first session with the *Alien and His Ship* (Figure F.15), made by hand with steps and attached planes. Although his test time was short, Richard proved an excellent pop-up maker. He did not use a large number of elements, nor as many levels of elements as, for instance, Ursula did. But he produced only one truly symmetric pop-up, using flaps, decoration and rotation to vary the form of the pop-ups. He also, in *Volcano Camp* (Figure F.17), added an entirely free-form element, the lava flow on the mountain, which he allowed to fold naturally when the page was closed. This pop-up was also interesting in that Richard had a clear idea of what he wanted the finished pop-up to look like. His last pop-up, the unfinished mountain scene (Figure F.19) captured the essence of a very complex commercial pop-up from which he was inspired. Overall, Richard's pop-ups were showing an increase in both complexity and quality.

Peggy made the smallest number of pop-ups, only four, but her work was very detailed and very complex from the start. She showed interest in the mechanisms involved, using an angled platform made from a v-fold in her second pop-up (and repeated in her third and fourth), and a wheel in her last. She spent more time with the "how-to" books than any of the other children, and usually let the form of the elements dictate the subject and design. All of her pop-ups displayed at least 2 levels, and she used a mixture of symmetry and asymmetry. Peggy did a great deal of hand-work, which was the reason she produced fewer pop-ups, and the results were more complex as a result.

Emily was the storyteller of the group. Her pop-ups fit together naturally into a book, with each new character being related to the last. Because of the large amount of time she spent, 13 sessions, Emily showed the most development of any of the users. Her first pop-up was a simple 90° face. She worked with only a few elements in any given pop-up, which she chose carefully

to illustrate the character she was working on. But she also went beyond the software and used a pull-tab mechanism, a coil, and added hand-made v-folds to make ears for her elephant. In addition, she used a v-fold as a platform, probably taking the idea from her sister. Her work was largely symmetric on the computer, with later decoration (such as attached planes and flaps) adding asymmetry. Only her last two works were asymmetric. Emily showed a great increase in skill, primarily illustrated by *Bart the Elephant* (see Figure F.36) in which she added two layers of v-folds for the ears. Emily showed a love of bright colors from the start, and her use of color in all her pop-ups was very striking. She was, after her first pop-up, the user who brought the most colored paper to her pop-ups³.

Daisy was unusual in that she made mostly abstract or semi-abstract pop-ups using 90° elements. Her first pop-up contained the greatest number of elements of any that the children made in the testing. However, she found that the small beaks that comprised most of the design were very hard to cut and fold. There is, therefore, an immediate change in her pop-ups beginning with the second one. From that point on she used fewer, larger elements, except for her last pop-up that was produced when she was able to handle smaller elements. She tended to have a high number of levels because of the general form of her pop-ups. The one exception is her *Owl*. This pop-up came from a suggestion by the researcher that she try to illustrate a story. The result was a very realistic, and very large, owl. The most interesting feature of the owl was the talons, which were not foldable. This made the owl into a paper sculpture rather than a true pop-up. Daisy was the only user to produce such an object. An advance in her skill is shown by looking at her last pop-up. Although this was another abstract with 90° elements, it is much more interesting in design than her first, and a cohesive whole.

Each child used each of the elements provided by Popup Workshop at least once. Table 6.5 summarizes element use over all of the children and is drawn from the tables in Appendix G. That 90° elements were the most used is not surprising as they are the easiest to produce.

³ Both Peggy and Emily are featured in Chapter 7, with a more detailed look at the first pop-up and one later one that each made.

However, all of the children did use 180° elements on occasion, and even the youngest had no trouble making and designing with them. Ursula, in particular, was fond of the v-fold.

Perhaps the most surprising fact, and one which shows the users' ability to move beyond the software, is the addition of hand-made elements. For the development of skill in paper engineering, it is highly desirable that children be able to augment the designs that the software can produce and learn to modify and add elements of their own. Most of these elements were attached planes, but in several cases flaps (particularly used by Emily and Richard), wheels, coils, and pull-tabs were added as well. There were also a few non-standard elements, such as the lava on Richard's *Volcano Camp* or the talons on Daisy's *Owl*. The last were actually non-foldable additions.

Aside from Daisy, who used many elements in her first pop-up and then retreated to fewer because of the cutting and folding difficulty, there was no consistent change in the number of elements used by the children over time. This may be because the children were beginning to focus on getting the appearance and motion they wanted rather than just building in intricacy.

User	Beaks	Steps	Angled Steps	V-folds	Tents	By Hand
Daisy	31	29	15	3	3	6
Ursula	14	7	4	4	3	10
Richard	2	6	1	3	1	14
Peggy	1	5	2	5	4	8
Emily	7	7	4	4	1	40
Total	55	54	26	19	12	78

Table 6.5: A summary of the elements used by each child. The elements made by hand were attached planes, flaps, wheels, pull-tabs, coils, and non-standard elements.

Once again, there is no particular progression in the number of levels for any one user. The most levels designed with the software was 4 in Daisy's final pop-up (see Figure F.6). This observation is useful in future planning of software for pop-up design, as it indicates that the number of levels will probably be small in most cases.

The data also show that children appreciate symmetry. Of the pop-ups made in testing,

20 were in category S (symmetric), and 16 in Sd or St, while only 6 were clearly designed to be asymmetric. Since two of the asymmetric designs contained no computer created elements, it is quite possible that symmetry arose as much from the use of the computer as from the children's sensibilities. After all, the elements are drawn symmetrically to begin with, and children did not use the Change feature as much as might be expected. The Replicate feature also encourages symmetry. Asymmetry seems to be a product of skill development, however, as more designs which deviate from strict S type were seen toward the end of testing.

From the examination of the artifacts, there is no one measure in all of the children that indicates the development of skill in pop-up making. However, when each user's work is examined, it is clear that skill had increased. Each child learned to use some element (a v-fold for Ursula) or combination (the v-fold platform in Peggy's case) to add to their repertoire of design techniques. In addition, all of the children added elements and attached planes, modified elements, and in other ways went beyond the bounds of their software designs, which shows a certain development of the feeling for how pop-ups are constructed.

6.4.2.2 Observations on Tool and Materials Use

Pop-ups are not usually made from the common papers employed in children's crafts. Regular printer or drawing paper is too thin to stand up properly, especially for 180° elements. Figures 6.1 and 6.2 show pop-ups made of 90° elements with a backing of construction paper added later that illustrate that printer paper is sometimes usable. Construction paper folds poorly and cracks, so it is also not particularly suited to the craft. Pop-ups are usually, and most successfully, made from card stock or other stiff paper that can be hard to fold. Card stock was provided to the users for their pop-ups as a default paper, and the children had no difficulty in working with it. The only other paper used was the base page for Daisy's *Owl*, which required larger sheets of paper for which she used scrap-booking paper that resembled a night sky.

All of the users modified elements or added their own elements, including attached planes as well as flaps and other element types. In the process, they picked up a number of skills related

to the use of materials. First, most seemed to understand that material added to extend the plane on an element worked without problems. Examples are Ursula's *Bunny and Castle* (see Figure F.9), and Emily's *Howard the Giraffe* (see Figure F.30). Second, they learned that material could be removed from an element, as in Richard's *City* where a door was cut in the building. Third, and related to the last principle, is that cuts can be altered when making elements. For instance, the slits cut for 90° elements do not have to be straight and the same is true for the unglued edges on 180° elements. Ursula discovered this with her alteration of the tops of v-folds in several pop-ups for instance, such as her *Bunny's Picnic* (see Figure F.8) where the v-fold is cut into the shape of the bunny. And finally, at least Emily and Richard discovered that folds could be made in handmade elements simply by closing the page and letting the fold happen in the right place. Richard used this technique in *Volcano Camp*. These are all important ways of dealing with paper in the production of pop-ups, and were acquired naturally by the children as they were needed.

While many tools are common to paper engineering and other paper crafts, pop-up making differs from those crafts in which children usually engage in one particular tool, the tool to score folds. Because of the use of stiff card stock, in order to make folding easier and allow the folds operate more smoothly, the fold needs to be scored before being folded. This is done by pressing a tool that is neither too sharp nor too wide along the fold to compress the fibers of the paper. The children were provided with two tools for this purpose, a ball-point pen that was out of ink and a dual-tip embossing stylus. They all rapidly learned to use the tool, reached for it automatically, and scored all of their folds, preferring the embossing stylus. They quickly learned that unscored folds would cause difficulty. The older children were much more adept at this process; the younger children would often score folds irregularly or too softly.

6.4.3 Craft Appreciation

In Section 2.3.3 appreciation was identified as the ability of a craftsman to assess the work of others, to knowledgeably enjoy the results of craft, and to use the work of others as a guide. In this section, two criteria are used to assess the work of the children in the user testing sessions for

changes in appreciation. First, the source of their ideas is identified in order to determine if they used other pop-ups to aid in their designs. Second, their comparisons of two different commercial pop-ups representing the same scene are investigated.

Artists and craftsmen usually begin their exploration of a craft by copying the work of others. At the very least, their desire to make objects comes from seeing the work of others. This may be done in a piecemeal fashion, seeing a particular method, material or design used by another and incorporating it into their own design, the particular shape of a handle on a pot, for instance. It may also be done in an effort to make an accurate duplicate of the original, often as a part of training to master techniques and materials as they work on the development of their own style. Such admiration for and imitation of the work of others is part of the growth of appreciation, and among other things drives the ability to develop one's own style within the tradition and limits of a craft. The question of where the users in this study got their ideas is therefore a question of their development of appreciation as they sifted the information available and chose how to design and construct their own pop-ups.

The ideas for the subject and those for execution of the pop-up are usually separate. For instance, in making her *Owl* (see Figure F.5), Daisy chose the subject from a book that she was reading at the time, but for its execution she looked at several pop-up books featuring birds, went to the Web to obtain pictures of owls, and changed the design as she worked on the computer. For many of the abstract pop-ups, the design developed out of play with the software and a name was attached to the result later. An example of this is Ursula's *Totem Pole* (see Figure F.14). Overall, most of the inspiration for the execution came from pop-up books, how-to books, the Popup Workshop software, and the work of other test subjects. One particularly interesting result of the user's time spent with the software was that more pop-ups developed from experimentation with the program than from any other source. Out of 42 pop-ups, 24 derived at least some inspiration from play with the software. This suggests that access to the software can influence the way that children learn the craft by reversing the usual process. That is, in the early stages of experimentation with the software, the idea of the subject of the pop-up is put on hold, and the

user plays with the mechanics of a design that may or may not gain identification with a subject until later.

While there are many resources available to the budding paper engineer, three that were used extensively by the users were paper engineering instruction books, professional pop-up books, and other children. One example influenced by instruction books is a pop-up made by Peggy, who spent a lot of time looking at the instruction books, and particularly at *The Elements of Pop-up* [14] where one of the elements featured is a wheel with a moire pattern. Peggy wanted to make a wheel like it, and this became the basis for her pop-up *Sun and Tree* (see Figure F.25), to which she also added a slider that she learned to make from *Pop-O-Mania* [123].

Richard did not use v-folds in any of his pop-ups until the last session. During his final look at the sample pop-up books, he was very taken with a pop-up in *Raggedy Ann* showing a mountain and soldiers that was made from 3 nested v-folds. He spent a lot of time examining it, and as there was some time left in the session, tried to copy it. The resulting pop-up was not completed, but Richard captured the essentials of the form in three nested v-folds, and began cutting them to make a mountain (see Figure F.19).

Finally, users also built upon the work of each other. The original methodology did not envision interaction between the children, but with two pairs of siblings, this was inevitable. In fact, it happened with each sibling pair. Richard's sister, Daisy, was fond of making abstract designs, and Richard made the abstract pop-up in Figure F.17 for her, as an obvious copy of her style. The technique of using a v-fold as a platform for a folding structure was developed by Peggy, who used it in three pop-ups. Her sister Emily picked this up for *Tap-dancing Cow No. 47* (Figure F.31). If the children were working in groups, it is likely that much more of this interaction would have occurred.

The second criterion used to assess appreciation was the users' comparisons of the two *Alice in Wonderland* tea party pop-ups shown in Figure 6.8 (referred to here as *Tea Party 1* [13]) and in Figure 6.9 (*Tea Party 2* [12].)

Ursula found it difficult to compare the pop-ups and needed prompting to look at them

carefully. This was a difficult task for a 7 year-old.

Ursula: I like this one. *[Points to Tea Party 1].*

Researcher: OK. Why do you like that one?

Ursula: But here I like this one. *[Points to Tea Party 2].*

Researcher: Why?

Ursula: I don't know.

Researcher: Well, let's see. What's different about them?

Ursula: This one *[Tea Party 1]* doesn't have any floppies like this one does *[Tea Party 2]. [She plays with flaps.]*

Researcher: Yes. There's no flaps on this one. This one does have this, though *[indicating gatefold]*. That goes up on the side. But what about the table? Is anything different about the tables?

Ursula: Uh.

Researcher: And...

Ursula: This one is more of a box *[Tea Party 1]* and this one isn't *[Tea Party 2]*.

Researcher: Yeah, that one's not as much of a box, is it? And...how about the characters, how about the people, there's her, and there's her *[indicating Alices]* and the rabbit...

Ursula: She's more white. *[Indicating Tea Party 2 Alice.]*

Researcher: She's more white, yeah.

Ursula: And she's more ? *[Tea Party 1 Alice]*

Researcher: Think she's unhappy?

Ursula: She looks more like a human *[Tea Party 1]*.

All of the children were able to point to some obvious differences: the box form of the table in Tea Party 1 and the more cartoonish nature of the drawing in Tea Party 2. And they were unanimous in choosing Tea Party 1 as their favorite. It appears that realism, characters that look like the illustrations they have seen before, and a more 3D appearance won out over an exaggerated style.

Daisy: Well, this one *[Tea Party 1]* the table kind of *[pause]* I like this table cause it goes up and you can see everything. This one *[Tea Party 2]* it kind of goes out. *[Moves her hand over it.]* I like that too, but I

like this one because you can see it all. And you can actually look inside and there's tea [*indicates cups on Tea Party 1*] and this one [*Tea Party 2*] they're just pop-up things [*indicating tea cups on Tea Party 2*] and if you look like that [*peers over*] it's like nothing.

Appreciation is more difficult to assess than the other competencies. It is slow to develop, and depends on the development of both knowledge and skill for its base. However, it appears that children evaluated and copied from other pop-ups and users enough to suggest that they were in the process of developing this competency to some degree. They were also able to pick out specific features of two pop-ups with a common subject to allow some comparison between them and to pick the one they preferred. This further indicates the development of appreciation in the users.

6.4.4 Other Observations

So far, assessment of changes in the user's craft abilities has been done using the competencies of the craft framework developed in Chapter 2. A few additional observations that do not fit precisely in this framework should also be made. The motivation of the users is an important measure as well. Observations of the users' reactions to and use of the software are notable, as are the additional pop-ups made concurrent with and after the testing sessions that demonstrated a high level of interest in the craft. Finally, the follow-up emails determined fates of pop-ups produced in the sessions and illuminated aspects of the social importance of children's craft items.

6.4.4.1 User Motivation

All of the users showed excitement about making pop-ups. Ursula's father indicated that she was talking about how interesting it was, something not so apparent to the researcher due to Ursula's shyness. Emily continued for extra sessions as she was working on a book and wanted to finish it. Richard had begged to do pop-ups in the testing when he saw his sister Daisy get involved. Even Peggy, who was not interested in continuing past the originally agreed eight sessions seemed taken with her last pop-up, and commented that it was nice to pretend to be a kid again.

Motivation was particularly apparent when the subject of the pop-up interested a user. One excellent example was Daisy's *Owl* (Figure F.5). Daisy had been doing mostly abstract or geometric face pop-ups when the researcher suggested she might want to illustrate a story. Daisy brought a book she was reading to the next session, *The Capture* by Kathryn Lasky [65]. The characters are owls, and the book's inside cover is illustrated with several species of owls. Daisy spent sessions 4–6 working on the owl, a total time of almost 5 hours. When completed, the owl was nearly 2 feet in width, and colored with colored pencils (a very time-consuming medium.) She said:

Daisy: *[After attaching the body]* Yes! Yes! And I'll probably have it on my wall, like in a place where it looks down at me! *[Holds it up in the air]*...

Daisy: *[After attaching the body and holding it up again.]* That is creepy and that is cool!

A further indication that the children were motivated and enjoyed doing pop-ups was that one of them made additional pop-ups concurrent with the sessions, and that several made pop-ups after the conclusion of the testing.

Emily made a pop-up book as a birthday present for her father, bringing it in to show at one of the sessions. Figure 6.10 shows two of the six pop-ups from the book. They are interesting in that the first is an asymmetric step, and the second is a series of steps, all made by hand. Emily had said that she had made cards for holidays before, but only using beaks, and we discussed this during her final session:

Researcher: So you said that you had only done beaks before.

Emily: Yeah. Sometimes I'd just like stick on some, but they didn't really pop. They just popped because the pressure of the paper.

Researcher: So you made the book for your dad, and I noticed it had some other things in it, did you get that idea then from doing this? *[the user testing]*

Emily: Yeah, very much.



Figure 6.10: Two Pop-ups Made at Home by Emily: Emily made a book of pop-ups for her father's birthday. These are two pop-ups from the set of six.

Several users also continued to make pop-ups after the sessions had ended. In the email follow-ups after testing concluded the following question was posed, and these answers were received:

Have you made any more pop-ups since? If so, describe the neatest one.

Daisy: No, I havent made any more, but I want to.

Ursula: *[Her father sent pictures of the pop-up in Figure 6.11, top.]*

Richard: Yes, but not using the software. *[And his father added: But he did make one with it. He makes lots of them for cards mostly sometimes just fooling around.]*

Peggy: no i haven't.

Emily: Yes. I made a castle with a knight in front of it. the castle was three layers of v-folds going straight up. the knight was also a v-fold.

Of the five users, three had continued to make pop-ups. Three of Ursula's pop-ups are shown in Figure 6.11. Two are Christmas cards, and are interesting in that they show changes from her pop-ups made during testing. This is to be expected as her artistic tastes and abilities had changed. This is particularly evident in the two pop-ups she made using Popup Workshop, in which she has integrated the 90° elements with the subject matter and used asymmetry (bottom left in the figure) with the package under the tree.



Figure 6.11: Three Pop-ups Made at Home by Ursula: The pop-up on the top was made without Popup Workshop, while the pop-ups below used the software.

6.4.4.2 Software Usage

There were two important features of the program, the replication feature and the pop-up viewer, that provide important functionality and information to the user. The replication feature allows the production of symmetrical designs, which is important when making abstractions of 90° elements. Replication makes it easy to produce abstractions such as Daisy's three pop-ups shown in Figure F.6 and these would be much harder to do by hand. Every child made at least one design using the replication feature. Daisy concentrated almost all of her effort on such

designs and mentioned replication specifically in her discussion of the program:

Daisy: ...And then also I like this, *[replication]* because

Researcher: I noticed you used it a lot.

Daisy: like if you do this you don't have to like *[pause]* instead of having to go like *[pause]* well instead of having to

Researcher: Replication you're talking about?

Daisy: Yeah, like try to make another one is really hard. You just go like this. And then also it shows you where you need to cut and that's really hard too.

There is no doubt that the tool was useful to the children, and influenced the type of designs made. However, it was found that the replication tool was hard to use at first. The problem is that there is only one situation in which an element can be replicated. There must be a matching fold on which the new element will sit, and the original element must not have been previously replicated. For instance, an element on the centerfold of a page has no matching folds and can therefore not be replicated.⁴ It took a bit of time and experimentation for the children to see what elements could be replicated and what elements could not. Part of this problem arises from the fact that the replication button puts markers on every corner of every element, not just those that can be replicated. If only the elements which could be replicated were marked, learning to use the tool might be easier.

Another important component of Popup Workshop is the pop-up Viewer Window in which the user can see the design dynamically in 3-dimensions. Users loved to play with the motion of pop-ups in the viewer and especially enjoyed twirling the designs. There were occasions when users were able to use the viewer to detect element collisions in a design, but those times were more rare than expected, and they seldom used the viewer to experiment with the form or placement of elements.⁵ For instance, one might expect a user to change the angle of the attached piece on a v-fold to see the change it makes in the elevation of the piece, but this was rarely

⁴ As an example of this case, in Figure 5.5 the large centered step cannot be replicated as there is no matching fold. Also, after replicating the smaller steps, they cannot be replicated again.

⁵ For two exceptions, see Chapter 7, which describes Peggy's use of the viewer to look at her design upside down while she was making it, and Emily's detection of collision.

done. It is possible that the testing period was not long enough for users to reach the point where this experimentation would have become common. Certainly the users changed elements less than had been expected. Still, the children enjoyed using the viewer like a game, and were quite pleased when they made it display a pop-up incorrectly, as can happen when the constraints lead to a wrong solution. Emily was one:

Researcher: So how about the 3D part, the viewer, did you find that helpful or not, I know you love to use it.

Emily: It was kind of helpful, but I think it's fun. It's funny when it messes up.

Researcher: *[laughs]* Which it does.

Emily: But its funny when you go like this *[twirling it fast]* cause it looks like one of those weird Cubism art things.

Several of the users mentioned that they would like the Viewer to have the same colors as the Editor. Peggy mentioned that as a possible change:

Researcher: So what didn't you like about it? I mean, I'm sure there are things.

Peggy: Yeah probably the fact that there was no color for this *[3D viewer]*.

...

Researcher: So, how about the 3D part? Did you use that very much, or feel that you, did you, did you look at that a lot?

Peggy: Well, I definitely looked at it, um, Cause I definitely like to see, I definitely like that you can see how it's going to look before you print it out, instead of printing and going "Oh, I didn't want it to look like that." Cause then you're sure you know that it's going to look like so and so, and it's going to have a weird thing growing out of it's nose. It's always nice to know.

6.4.4.3 Social Dimensions of the Pop-ups

Children's craft items represent more than the labor put into them, as a look at any parent's refrigerator will demonstrate. They are given as gifts, displayed in the home, kept sometimes into adulthood and beyond. I have a table that my mother bought unfinished for a quarter when she

was a child and finished herself. I will undoubtedly hand it on to the next generation. Children's crafts as social currency has been studied before [28]. Such items are more than art:

...from the aesthetic perspective, art objects have a purpose of their own—the unique ability of producing new visual experiences, feelings, and ideas. If a picture drawn by a child is cherished for this reason and not for what it looks like, the object is valued as a symbol of love or personal relationship, but not as art. [20]

Examples of pop-ups as social currency were seen during user testing. Richard made a pop-up in the style of his sister as a gift for her (see Figure F.17) and Ursula made a flag pop-up to give to her teacher on Veteran's Day (see Figure F.13). One of the informal test pop-ups was used as a Mother's Day card (see Figure 6.1, left). The maker's plan was to put flowers in the vase shape on the card. And finally, Section 6.4.4.1 describes the pop-ups made by Emily for her father, and by Ursula as Christmas cards.

An interesting question to ask is what happened to the user testing pop-ups. The children took them home after they made them, leaving only photos and computer files for the researcher. The answers to this question will reflect the children's feelings for the pop-ups, as this is a part of their social dimension. In the email follow-up, they were asked two questions to evaluate these feelings:

Which one is the one you like the best? How do you feel about it and why?

Daisy: I liked the owl, because it was so realistic and cool.

Ursula: *[sent picture of her and Turtle Gymnast]* I really like it because it's really cute.

Richard: The volcano one. I liked it because it was a big huge mountain and I like mountains.

Peggy: the one i like the best is the one where the sun had the wheel so it could change colors. i like it because all the other ones were just plain old pop-ups, this one was unique.

Emily: i liked my dancing cow best. I liked it because it was cute, difficult-ish, and had two parts. i also liked my moose because of the sliding smiley-face thing.

Which one is the one you like the least? How do you feel about it and why?

Daisy: I liked them all, I had no bad ones

Ursula: *[sent picture of white abstract]* I think it's just a design-not really interesting.

Richard: Can't remember

Peggy: i like the table one the least. I feel like i didn't really make it as good as it could have been and it really wasn't interesting.

Emily: I think I liked the mouse the least. I just don't think it was as fun to make as the others.

Users liked the pop-ups that took the most work (the moose smiley-face and the wheel for instance), were different, or contained subject matter that particularly appealed to them.

As to what happened to the pop-ups:

What has happened to the pop-ups you made? For instance, did you give any away, put them in a book, lose them, display them, put them up in your room, throw them away?

Daisy: I put some up in my room *[in Germany]* but some I put in storage in Boulder

Ursula: First I displayed them around the house *[for several months]*. Now they're displayed in my room.

Richard's Father: He packed them away with his stuff when we moved to Germany, some got tossed

Peggy: I have kept my pop-ups, I know where they are, first i put them with my magazines and then i gave them to my mom.

Emily: I think I put them in book form, but then i lost them. :(

Peggy and Emily's Mother: I have [Peggy]'s and they are in her 'memorabilia' box. [Emily]'s are stored in her room (she is not the most organized person in the world) and we plan on putting them into a complete book form.

For the most part, the pop-ups were kept, either on display or packed away safely. They have become items of social currency, as shown by the comment by Peggy and Emily's Mother, who has ensured that they are kept.

Pop-ups made by children provide excellent examples of the emotional and social investment children can put into the craft objects they create. Providing value to both the maker and

the receiver, they are easily produced, take the form of cards which are common gift items in our culture, and are easily stored and kept.

6.5 User Testing in Context

Stepping back from the results, this section looks at the user testing from a more personal perspective in order to evaluate the strengths and limitations of the methods used. I begin by looking at the influence of the design of the informal testing on the design of the formal testing to see if the suggested changes were reasonable, and to compare the results of the informal and formal tests. I then look at some of the methods and results of the formal tests to arrive at some understanding of how both could have been made better, including the thorny dilemma of the influence of the researcher on both the children and the results.

In Section 6.1, the early informal testing and its influence on the design of the formal user testing and software enhancements was described. In general, this influence was a positive one. In terms of the software, the more realistic viewer with its ability to rotate the image of the pop-up, and the addition of 180° elements were positive additions. Users in the formal testing used the viewer more often than during the informal testing since they liked to rotate the design, and consequently located collisions more easily. All of the children used the 180° elements, even the 6 year-olds.

More interesting perhaps were the informal testing's influences on the formal testing's methodology and the selection of its users. First, younger children were included in the formal testing. This was very useful in revealing that children as young as six could use the program, albeit with a bit more adult assistance at the start. Since young children are very interested in pop-ups, their ability to use the software broadens its utility to the entire range of school children's ages. Second, with a longer series of testing sessions and with more pop-ups made by each child, it was possible to see how the children gained knowledge, skill and appreciation-something that was not possible during the informal tests. For example, children in the informal tests added no attached planes, did not vary the shape of cuts, or add their own elements while all of the

children in the formal tests undertook these tasks. Third, closer work with single children in a controlled setting allowed for better observations of the children's actions and for interaction with the children to better understand their ideas and processes. Finally, the more complete pop-up building environment allowed the children to interact with more commercial pop-ups and instruction books, as well as providing access to more tools and materials.

There are two other interesting observations concerning the differences between the formal and informal testing. First, in the informal testing I observed that children encountered some difficulty in determining which direction the folds on 90° elements should be folded and there was no opportunity to see if this problem persisted over multiple pop-ups for each child. The formal testing proved that, in fact, it did not and children became quite proficient in folding the elements the right way. Daisy was the best at this, as she made quite a few abstract designs from 90° elements. Second, the "face problem", the problem of how to place eyes on a design of a face when all elements must be placed on a fold that was seen in the informal testing did not occur in the formal testing. There, children making their first designs often wanted to be able to place elements other than on folds, but when they saw that they could not, they found ways to cope with the design problem. There may be many reasons for this, but I believe that among the most likely were the more sophisticated pop-up making environment and the presence of 180° elements. The environment provided other ways to make eyes, in particular the presence of googly eyes which the children loved to use. There were also fewer faces represented in designs, largely because with 180° elements more design possibilities presented themselves. For instance, Ursula started with a v-fold bunny and not a face as seen most often in the informal testing.

The rich pop-up making environment had its downsides as well. Most importantly, that environment with its readily available books, tools, and materials was far more complete than any in which most children will ever work. Most children will not have access to so many pop-up books or instruction books, as they are expensive and time-consuming to collect. In many cases, children would probably not have multiple colors of card stock or a good scoring tool available. Even a pen with no ink can be difficult to come by, as I discovered when I tried to

remove all the ink from one. This was, therefore, an experiment in what children could do in an exceptional environment, but there is comfort to be taken in the fact that children in the resource poor environment of the informal tests made striking pop-ups nonetheless.

Obviously, part of both environments was the researcher and some of the progress that the children made had to have come from interactions between the researcher and the children. While I tried to insulate myself from the process there were occasions in which I became a primary conduit for information. For instance, while I tried to only answer questions as the children made their pop-ups, there were times this was not sufficient. In particular, the 6 year-olds needed more guidance, and discussions about the pop-ups in commercial books and the ones they were making than could be provided by question and answer sessions. Two examples of my influence (as opposed to that of the software) stand out and can be easily identified as such. First, the 6 year-olds could not read and therefore could not have read the tool tips and help that provided names for the elements. Although they did not do as well as the older children in acquiring domain vocabulary, they did learn some. Ursula was able to identify v-folds in two instances and a tent in the *Farmyard* pop-up book. Richard correctly used the term “tent thing” but did not identify v-folds, probably because he had not used a v-fold at that point. They must have obtained that vocabulary from me and not the software. Second, while all of the children were familiar with the materials and most of the tools they had access to, none had ever used a scoring tool and their introduction to it came through my demonstrations.

This is, of course, a problem that occurs whenever one works with users on a complicated task, but it is arguably more common with children. The observer becomes part of the experiment. And in a sense, this is not entirely bad. Paul Johnson, who has been mentioned in Chapter 3 as an educator in the area of pop-ups and bookmaking says:

All in all, I have learnt to be practical and not idealistic in classroom situations like these. One must have the sensibility to recognize when intervention is necessary. The young can have a limited faculty of concentration and immersion in what they are doing. It may be better on occasions to make something for them than to run the risk of losing their enthusiasm because

a peculiar technique cannot be grasped. [58, p. x]

While in these tests I did not “make something for them”, I cannot discount the fact that I was involved directly with them and not simply observing them.

Creating the classification matrices of the pop-ups in Appendix G was a useful exercise for looking at the results of the children’s pop-up making. It suffers from two problems. First, it does not get at the artistic merits of the pop-ups and there is probably no way to quantify that aspect, unfortunately. Emily’s *Tap-dancing Cow #47* is wonderfully charming and elegant, but saying that it was 2 v-folds, two attached planes and a flap cannot do it justice. Second, it does not provide the information needed to identify some common change among the children although it does show that each changed.

Another area that needs to be mentioned are the pre- and post- assessment tests. On the whole, the technique of asking the children to talk about the example pop-ups was extremely useful. These revealed each child’s vocabulary abilities and it was an excellent way to get them to talk about pop-ups. This can be difficult at times, as children do not want to vocalize their thoughts. Ursula, for example, was particularly quiet. For a few of the children I had pictures of their pop-ups and was able to ask them to talk about what they were thinking when they made them, which was sometimes useful. It would have been productive to have had all the pop-ups themselves so that they could talk about them as the effect of actually handling the pop-ups seems to promote verbalization. The technique of asking children to compare pop-ups was an idea that occurred to me during the formal testing. Therefore, it was not done at the start of the test sessions but only at the end. This might have been more useful if done at both times to see how the children’s abilities at this task changed over time. Finally, the email follow-up was very revealing, particularly their answers about which pop-ups were their favorites. Coming several months after the conclusion of the testing, the children were asked to reflect back on the work they had done which provided information not previously available.

As is the case with this type of work, some opportunities were missed such as obtaining

more information from the children as they worked, and some were muddled, as in the confounding of what my contributions were and the softwares were. In spite of this, the user testing was a valuable and productive exercise in seeing the children's pursuit of craft progress.

6.6 Summary

Informal testing of Popup Workshop was conducted in a classroom setting with 5th grade students, with middle school students in a summer program, and with adults. This informal testing helped to uncover issues with the software and to establish that testing would be best done over an extended period of time (at least 4 pop-ups in length), with a broader age range of children, in a richer standardized environment, and with a structured method of assessing changes in craft fluency.

The test environment included a range of tools and materials, Version 2.0 of Popup Workshop, and a variety of commercial pop-up books and instructional materials for reference and support. Each child worked individually with the researcher, and each session was videotaped. Photos of the pop-ups were taken and computer files produced by the users were saved. The users built pop-ups during one- to two-hour sessions, with 5-13 sessions per child.

Pre-testing activities consisted of two standard cognitive tests on spatial orientation and visualization as well as a discussion of each user's school and home interests and previous experience with pop-ups and other paper crafts. In addition, the researcher and each user looked at three commercial pop-up books, and one pop-up from each of these books was examined closely to allow the user to explain how it was made and how it worked. Examination of the books was also used during post-testing activities, along with discussions of the software and their experiences. In the last session, each user also compared two commercially-produced pop-ups dealing with the same subject. A final email follow-up questionnaire was sent several months after the sessions had concluded.

There were 5 users involved in the testing. The two youngest users, a boy and a girl, started at the age of 6. Three older girls were 11 or 12 when they began testing.

Craft knowledge was assessed by examining the use of element names. This was revealed by their discussion of the three pop-up example books. All users showed some knowledge of element names. The level of knowledge varied depending on the time a user had spent making pop-ups, their age, and the elements they had used.

The assessment of craft skill came from observations on tool and material use, and examination of the pop-ups created by users. It was hoped that the children would learn to modify elements and add elements or attached planes to their pop-ups. They all did so, although each child showed a different proficiency in and display of their acquisition of skills.

In assessing craft appreciation, primary data came from identifying the places where the users got their ideas. These ideas came from commercial pop-up books on occasion, and sometimes from each other. Users were also able to analyze the differences (although only at a high level) between the two pop-ups with the same subject. Appreciation takes time to develop, but they all appeared to have started.

Some general observations were made concerning the user's motivation in pop-up making and in particular other pop-ups they made during and after testing, on the way the children used the software, their opinions about their own pop-ups and what they did with the pop-ups after testing was over.

Finally, a more personal view was given regarding the differences between the informal and the formal user tests, the methods—what worked and what did not—and the influence of the researcher on the children and the results.

In Chapter 7, a more detailed look will be taken of two of the users, Emily and Peggy, who are twins and yet exhibited a great difference in their approach to and execution of their pop-ups.

Chapter 7

Two Users of Popup Workshop

Chapter 6 discussed the user testing of Popup Workshop including descriptions of the methodology, the users and the results. However, with 5 users making 42 pop-ups, the conclusions were largely drawn from the work of the children in aggregate. Individual children and pop-ups were mentioned as examples, but the analysis was based on an overview of the work all of the users did. As valuable as it may be to step back and look at the user testing from afar, it can also be a good exercise to take a more detailed look at a few pop-ups from a few children. This demonstrates how a particular child uses a particular method at a particular time and it allows a more intimate glimpse into the way children express their personalities through their pop-up making.

This chapter presents an informal case study of two of the test participants. It begins by introducing the users and defining some of the criteria for their selection in Section 7.1. Sections 7.2 and 7.3 follow the users through the creation of two pop-ups each with descriptions and observations of the process. The chapter concludes with an examination of the pop-ups described here using the craft framework of Chapter 2 and with a look at how each user incorporated the Popup Workshop software into her crafting style.

7.1 Overview

One approach to this chapter would be to take one child and chronicle her pop-up making experiences from start to finish. However, another method presents itself in the particular case

of the children participating in the user tests. This study was fortunate to have a set of fraternal twins as participants. These girls, Peggy and Emily, represent children of the same gender, age and family background. They both spent enough time in testing to show changes in their pop-up design and construction abilities. In addition, the girls were very different in their approaches and in the styles of the pop-ups they produced, making them good candidates for this type of evaluation.

The girls also had very different personalities. Probably most telling was that Emily was the “crafty one”, according to Peggy. Emily did crafts for fun. She was considered the artistic twin and, concurrent with the testing, she was taking a painting class. In contrast, Peggy indicated that when she did crafts it was usually because Emily pulled her into the activity. Peggy also expressed some lack of confidence when it came to artistic pursuits, often apologizing for her drawing ability, for instance.

Emily was interested in telling stories and said that she wanted to be an author when she grew up. Peggy on the other hand said that she had no particular vocational goals, since they would obviously change later on.

In terms of other personality traits, it was obvious from the start that Peggy kept her work area in order, putting markers away and throwing away scraps of paper. Emily, on the other hand, left her work area a mess of paper scraps, markers, and craft knives. Emily was very talkative. She and the researcher had long discussions about music, books, movies, and anything else that came into her head. Her work style was impulsive, quick and intuitive and she was always willing to try something, then redo it if it did not work. Peggy, however, was all business, and often quiet. She took a great deal of time thinking about each step and wanted to have things right the first time.

These personality differences were expressed in the pop-up making styles of the girls. Peggy was deliberate, organized, did not talk much and thought everything out before executing it. She did not mind following someone else’s directions, indeed she often preferred it. This was demonstrated by her choice in reading matter about pop-ups, which was most often instructional. Peggy was interested in mechanisms and each of her pop-ups became an exploration of one or

more elements. Peggy spent a lot of each session thinking about what to do next. She did not appear to spend time planning what she would do outside the sessions. This was probably because craft was not a big part of what interested her. Emily, on the other hand, was a crafty person, as her sister said. Peggy made a quite perceptive remark about her sister's work, "[Emily] had every single pop-up lesson thing, she had every single one planned. I can't believe that." Peggy was unbelieving because she was supposed to be the organized one. In fact, Peggy was wrong in one way. Emily did have every pop-up planned in that she knew what the subject of every pop-up would be and how it would fit into her story. However, in her work she was much more disorganized and free-form. Peggy planned. Emily just cut. She was more interested in looking at pop-up books than instructional books. Her work was story-driven, not element-driven.

During the user testing, Peggy made four pop-ups and Emily made ten. To keep this discussion a reasonable length, two representative pop-ups were chosen for each of the girls, one from the early period of testing and one from near the end¹. The two early pop-ups chosen were the first that each of the girls made. The later pop-ups were Peggy's fourth (and last) and Emily's eighth. Emily's last two pop-ups were either unfinished or did not use Popup Workshop, making her eighth pop-up the most useful example of her late work.

Section 6.3 summarizes basic data about the users and their testing, but it is worth repeating some of the information relating to Peggy and Emily here. Peggy attended 8 1-hour user testing sessions, which was the number that the researcher had told her parents was the minimum. This translated to about 7 hours of working on and with pop-ups. She did not leave the testing early, although she had that option, but she did not wish to continue for extra sessions as she had no specific projects in mind. In contrast, Emily was intent on making a book. This book was never bound, but each pop-up in her series was related to the others. Emily had a good idea where the book was going and wanted to continue after Peggy stopped. Emily therefore attended 13 sessions, some of which were two hours in length, and accumulated nearly 16 hours of work time, more than any other user. This should be kept in mind when the later pop-ups are examined.

¹ The entire course of their work during user testing can be seen in Appendix F

7.2 First Pop-ups

Both Peggy and Emily made their first pop-ups during their first sessions while exploring the software, and completed the folding and decoration during their second sessions. The researcher explained the controls and how they were grouped, and the girls each tried adding and changing various elements to their pop-ups, as well as using the replication and decoration tools. In spite of the similarity of these sessions, radically different pop-ups were created, and the differences in their working styles became apparent.

7.2.1 Peggy: Abstract Face

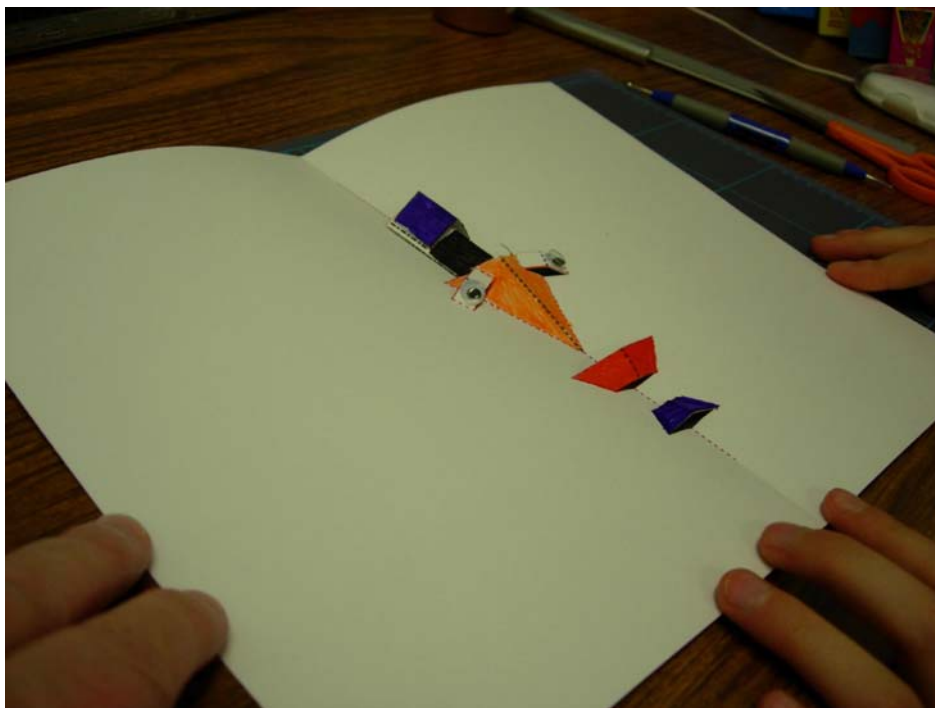


Figure 7.1: This is a view of Peggy's first pop-up that shows the double tent forming the hat (at the top of the design).

Peggy's first pop-up was an abstract face with all of the elements made with the software and then colored with markers. Figure 7.1 shows Peggy's first pop-up when complete².

² For more pictures of the pop-ups described here, and all other pop-ups that the girls made, the reader is

Peggy started the pop-up by creating a beak. She then used this beak to investigate change by changing the points on the beak, watching the effect of the changes in the Viewer Window. She colored the beak orange, then experimented with the replication feature by adding a step to one side of the beak and replicating it on the other side. The next element she added was the larger tent with the smaller tent on top of it. When she did this, the Viewer Window showed the smaller tent on the underside of the larger one, as it was using the alternate solution for the constraint problem³.

At this point, Peggy made two discoveries. First, she found that the tents could be colored with fill, but that the fill must be done on the tent itself and not on the gluing strip that is shown on the base sheet. This was a mistake that most of the children made on their first attempt to color a 180° element with fill. It presented no subsequent difficulties, but tended initially to be a surprise. Second, Peggy discovered that when the pop-up was completely open in the Viewer Window, the beak and steps disappeared into the page but the tents were still popped up. This was an important discovery that demonstrated a major difference between 180° elements and 90° elements. Although that difference played no direct part in the design of her first pop-up, it was an integral part of her next pop-up, *Table and Chairs*, enabling the backs of the chairs to come to an upright position with their seats folded down when the pop-up was fully opened. (See Figure F.22.)

At that point, while using the Viewer Window to observe the pop-up, Peggy turned the pop-up upside down and remarked that, “Actually, I like upside down better....Makes him look like a freaky old guy.” She was thinking of the tents as a beard, but upside down they became a hat. From that point on, although she would rotate the design to look at it from different angles, she always returned the Viewer Window pop-up to the position rotated 180°, and used that view to do her work, planning on turning the pop-up around. The Editor Window does not rotate, but by using the Viewer Window in this way, Peggy got the orientation of the pop-up that she wanted.

directed to Section F.4 for Peggy and Section F.5 for Emily.

³ See Section 5.4.4 for a description of why this scenario occurs.

She made a suggestion for changing the program at this point concerning the Viewer. She wanted a zoom feature that would allow her to examine the design more closely.

She used the change feature to tweak the sizes of the elements, then added the angled steps last. When the design was complete, she removed the fill colors that she had been using, declaring that the design was more interesting in white. Figure 7.2 shows Peggy's first pop-up as printed.

During the next session, Peggy cut and folded the pop-up and glued on the tents. This process presented no difficulties for her, although the small steps on each side of the beak took some time to fold properly. She attached the smaller tent to the larger tent before gluing them both onto the base page. In the process, Peggy tried the larger tent both as designed and rotated 180° , which would have put the smaller tent on the other end, but decided on the original design. Finally, she colored the pop-up using markers and added plastic "googly" eyes. She called him "Mr. Freddy" and said that he was an "alien guy". Overall, the pop-up took 46 minutes of actual work time.

This pop-up was unusual in several respects. First, it contains two 180° elements. Ursula used one 180° element in her second pop-up (the first one that she designed on the computer) but most children waited to use them until later in their sessions, and a tent on a tent construct was quite unusual in any case. This demonstrates Peggy's interest in the elements themselves early in the testing. Second, Peggy used the Viewer Window to reorient the design in progress and to plan for a pop-up that was rotated 180° from the Editor Window representation. No other child did this. Finally, the entire design was cut, folded and glued before Peggy added color. This is often not the most convenient way to decorate a pop-up, but it did allow her to see the results on the completed pop-up.

Peggy also demonstrated her general style of pop-up making with this first pop-up. Her interest in the elements themselves became obvious from the beginning. For example, she experimented with the way the centerline changed when she changed the sides of the beak, and with the difference between the step and the tent when the pop-up was opened. In addition,

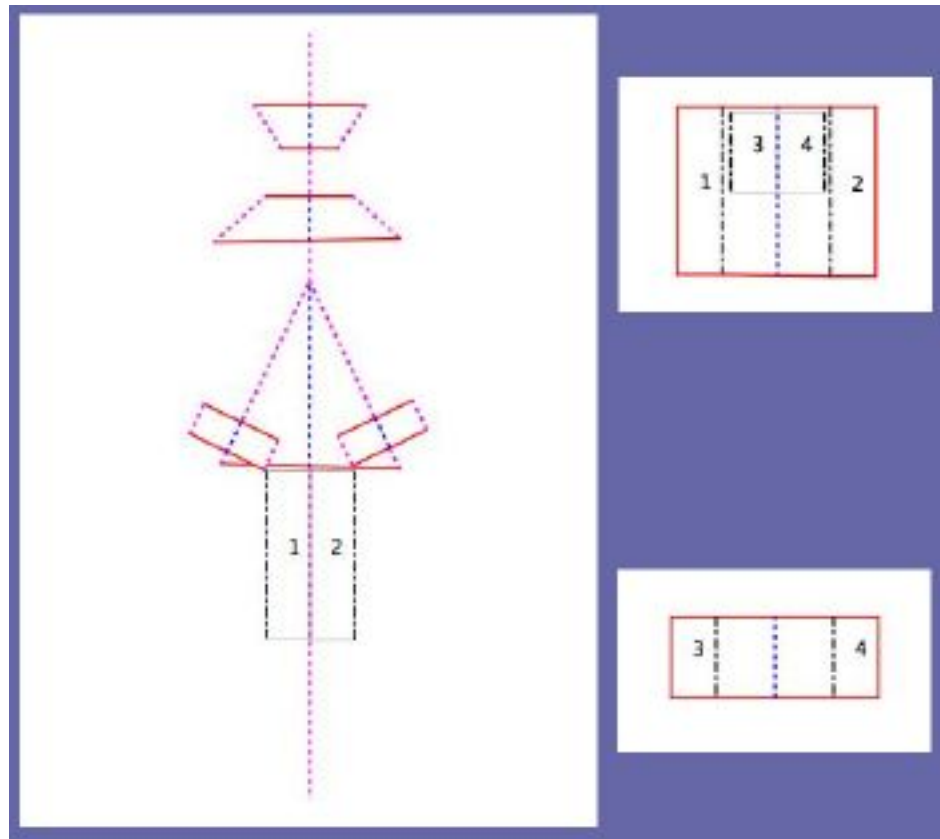


Figure 7.2: Peggy's first pop-up was printed in three sheets. On the left is the base sheet with two angled steps, two steps on a beak, and the base for the larger tent. Above right is the sheet for the large tent with the base for the small tent. The sheet for the small tent is shown below right.

Peggy was very deliberate and took her time in making the design, both with the computer and in her work by hand. She used the change feature a great deal, spending time changing the central beak and seeing what happened to the steps on its sides, and changing the size and position of the tents. Peggy read both the tool tips available for controls and in the help area, and used the Viewer to observe every change she made, rotating, opening, and closing the pop-up, which led to the inversion of this first design. In choosing colors and decoration, Peggy was deliberate in choosing colors for each piece and picking just the right size of googly eyes.



Figure 7.3: Emily's first pop-up, Freddy Squarehead. Note that she has cut around the hair at the top of the step so that it rises above the page with the face.

7.2.2 Emily: *Freddy Squarehead*

The first pop-up that Emily made was a face that she called *Freddy Squarehead*, shown in Figure 7.3. All elements were made with the computer, although the top of the large step was altered to follow the hair line in the final cutting, and computer coloring and line drawing was used throughout. Figure 7.4 is the image that Emily printed to make her first pop-up.

When Emily started experimenting with the software she discovered the color selector and the fill button first and colored the base page before doing anything else. She played with all of the elements, trying each in turn. In the process, Emily added a tent and another on top of it and a v-fold, but deleted them. Before deleting the v-fold, she tried to color it and discovered that she needed to add fill to the v-fold on the extra page, just as her sister had learned. When the design

was complete it contained only 90° elements.

Emily was very concerned with the colors, and spent a lot of time getting the design completely filled. She also discovered the computer-drawn lines as she was doing the fill coloring, since they are in the same area of tools. Emily used computer-drawn lines on four of her pop-ups, more than any other user, and this first pop-up showed her fascination with both these and the fill colors.

In drawing the character's hair and ears, Emily asked if she could cut around them:

Emily: Could I cut around his hair?

Researcher: Yes you could....I don't see why not. You can change that top part of the cut easily enough...

...

Emily: His ears don't need to cut out.

Researcher: His ears are on the fold so...

Emily: Could I cut them out?

Researcher: You know you could. You could cut them out and bend them up kind of up this way.

Emily: Hmmm. OK.

Researcher: That would work.

In the end, she chose not to cut around the ears and, although we concluded that she could have done so, they would not have moved. She also wanted to write words on the pop-up when it was complete.

During this first session, Emily showed a great interest in the tools and materials and particularly in the craft knives and the self-healing mat. She kept checking the mat to see if she could feel the lines she had just cut, trying to figure out how it worked, and trying to think of ways to damage it. Emily also used the knife to cut around the hair, even though she had scissors, and using them might have been easier. She continued this throughout the testing sessions, always using the knife. She also cut out small designs of animals on scrap paper as a time filler when she was thinking or allowing a pop-up to dry. Emily was also interested in the type of paper (card stock) that was being used, asking where she could buy it.

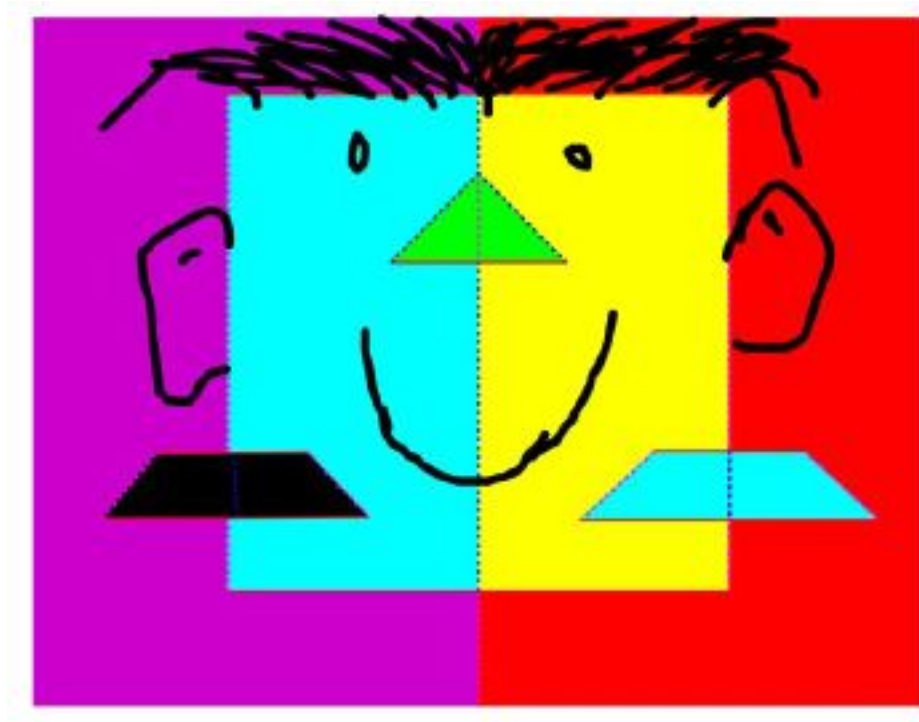


Figure 7.4: Emily's first pop-up was printed in one sheet. This contains a step, two angled steps and a beak. Emily used both software-drawn lines and fill colors in her pop-up.

Emily's style was much more free and quick than Peggy's. Instead of spending time thinking about which color to use, she tended to apply it to see if she liked it. This may be a result of her more extensive craft and art experience, particularly her experience in painting. This is reflected in the short amount of time it took for her to produce her first pop-up—just 33 minutes—with about half of the time spent learning and using the software and half spent cutting and folding the pop-up. It should be noted that her pop-up went together quickly as she had no pieces to attach and the elements were large.

Emily also demonstrated two qualities which would play a large role in her subsequent pop-ups. First, she was concerned with the story that a pop-up told, as evidenced by the writing of a caption on each pop-up she made, beginning with Freddy Squarehead, her first. Second, she was more concerned with the aesthetics of color and general shape than with the mechanical details of how particular elements work. She used the change feature and the Viewer window less

often than Peggy, being less concerned with the exact shape of the element. However, she was more inclined to change the way lines were cut after they were printed. In the case of her first pop-up, she changed the cut at the top of the large step to follow Freddy's hair.

7.3 Later Pop-ups

In Peggy's case, the selection of a second pop-up to contrast with her first was obvious. Her final pop-up was not only technically interesting, but was the pop-up that she picked as her favorite in the email follow-up. It does not have as much detail work as her campground (Figure F.23), but is perhaps the most aesthetically pleasing of all her pop-ups.

As previously noted, Emily was making a "book" in which the central character in each pop-up had some relationship with the character in the previous pop-up. Her final pop-up (Figure F.38) was a simple, although interestingly asymmetric, exploration of the software which she never completed. Her penultimate pop-up was the final page of the book and, although visually interesting, was designed and created without the use of the software, rendering it less useful for the purposes of comparison (Figure F.37). Her eighth pop-up, *Bart the Elephant*, is a complex pop-up made both by hand and with the computer and serves the purpose of comparison well.

Be aware that the comparisons are between Emily's first and eighth pop-up and Peggy's first and fourth. Emily had more experience with making pop-ups by the time she made Bart and this is obvious in the complexity of the piece.

7.3.1 Peggy: *Sun, Tree, and Cloud*

Peggy's final pop-up was the *Sun, Tree, and Cloud* shown in Figure 7.5.

Peggy's pop-up began with her desire to make a wheel. She was inspired by a wheel in *Pizza*⁴ that changed the ingredients on a pizza (with worms, bugs, snails and other disgusting

⁴ Both Peggy and Emily used several of the books provided as references for users. Two were pop-up books: *Pizza!* by Jan Peińkowski[86] referred to here as *Pizza* and *Animal Popposites* by Matthew Reinhart [92] referred to as *Popposites*. Instruction books used were: Barbara Valenta's *Pop-O-Mania: How to Create Your Own Pop-Ups* [123] and referred to here as *Valenta, Elements of Pop-ups* by David A. Carter and James Diaz [15] referred to as *Carter, Paper Engineering for Pop-Up Books and Cards* by Mark Hiner [50] referred to here as *Hiner*, and finally *Pop Up!: A*



Figure 7.5: The *Sun, Tree and Cloud* when complete. Note the rotating multiple-layer wheel and floating cloud. A central section of the tree's leaves can be moved with a slider.

ingredients). She spent time with *Valenta* and *Carter*, and particularly liked the moire pattern produced by one of the wheels in the latter. She soon settled on using the wheel as a sun in an outdoor scene. Peggy had developed a love of the *Carter* book and returned to it often during sessions.

Peggy thought about having a cloud that would move over the sun.

Peggy: Let's...Ooo...we could have a cloud pop-up!

Researcher: Yeah...

Peggy: A cloud pop-up here. Oo, Oo, I'm gonna get kind of complicated! We could have the sun over here [*points to the left side of the page.*] and it could spin in the middle and changes color, and we could have the cloud over here and we could move the cloud back and forth.

This idea presented difficulties as the sideways motion of such a cloud is difficult to produce. She and the researcher spent some time with instruction books and pop-up books looking Manual of Paper Mechanisms by Duncan Birmingham [6] and referred to here as *Birmingham*.

for a similar motion. (One of the elements examined in this process was the slider in *Valenta*, which was later used in this pop-up as part of the tree.) A bear paw made of an attached plane on an extremely shallow v-fold in *Pizza* seemed to offer the best solution, and Peggy moved on to consider a tree as part of the scene.

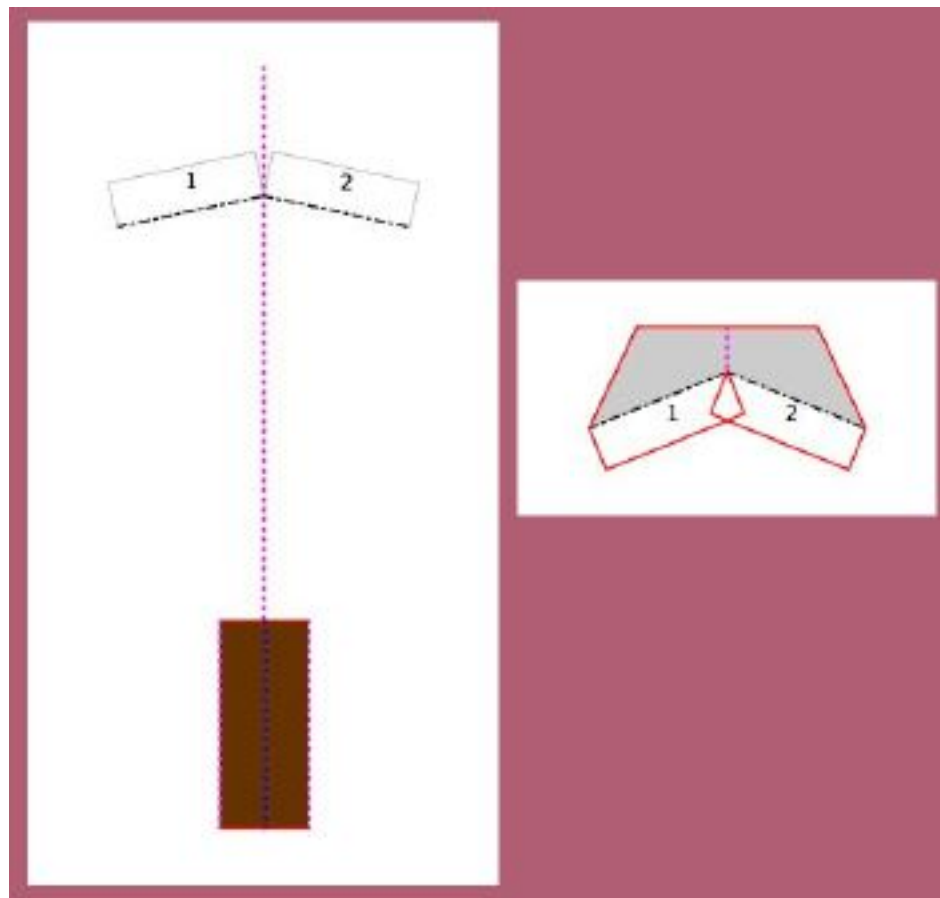


Figure 7.6: Peggy's last pop-up was printed on two sheets. On the left is the base sheet with the step that is the tree trunk and the base for the v-fold that will support the cloud. On the right is the v-fold itself.

Peggy added a trunk for the tree using a step, adjusted its size and colored it with the software. During this process, the researcher showed her the constraints for the centerline of a step. The v-fold for the cloud was added next. After a great deal of playing with the shape, she decided to print it and try it, as it could always be changed later.

There was a month-long break in testing for the Winter holidays, and when Peggy returned

to testing, she had lost much of the flow of her work. The cloud as originally conceived was to be on one side of a fairly flat v-fold. This would make the cloud “flap down” over part of the sun. When Peggy started work again, however, she placed the cloud over both sides of the v-fold, creating a platform element. This was a natural evolution, as she had used v-fold platforms in two of her previous pop-ups. The final result was not the sideways motion that she had originally wanted, but the cloud “floats” over the paper to produce a nice effect, and she was pleased with the result.

Peggy next turned to the sun. She decided to use oranges and yellows and collected the colored paper she needed. She used a compass to make the larger circles and a circle template to make the smaller ones. The first step was to cut the curved sections out of the base page that would allow the wheel underneath to show through. Peggy drew these shapes freehand. When cutting them, each cut-out section must be bounded by two lines. She found that she did not have an even number of boundary lines, which would leave an extra boundary line or uneven sections at the end of the process. Luckily, Peggy discovered this about half-way through the cutting process and was able to redraw the remaining cut lines to remove the extra line and make the sections all the same size.

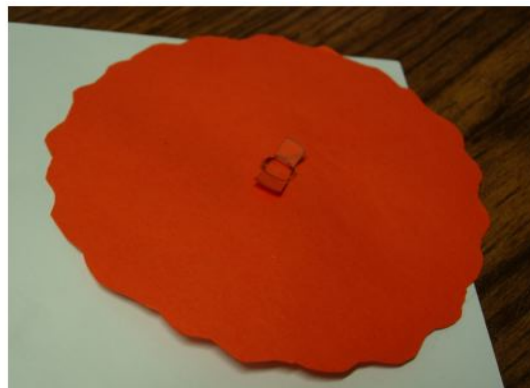
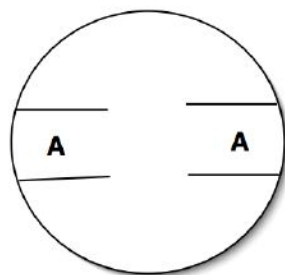


Figure 7.7: A paper brad holding the sun on the back of Peggy’s final pop-up: The brad is a circular piece, cut to produce four sections on the outer rim. Opposite sides marked “A” are folded out and placed in the hole of the wheel, then folded back in to hold the wheel on the brad, and the rest of the brad is glued to the back of the base page. The wheel shows through cutouts in the base page.

In making the wheel itself, Peggy used much the same process. The wheel could have been made from a solid sheet with the curved stripes glued on, but Peggy decided it would be easier to make two wheels, with one cut out to make the stripes. This time, she counted first to see that the number of cuts would produce the stripes she wanted. She also planned for the fact that the stripes on the circle had to curve in the opposite direction of those in the base page to produce the moire effect.

In the final session with this pop-up, Peggy attacked the construction of the pivot. The researcher had found examples of the construction of paper brads for attaching wheels in two of the instruction books, *Hiner* and *Birmingham*. *Valenta* included a wheel, but used a metal brad that would show on the center of the wheel and Peggy decided against it for that reason. *Hiner* and *Birmingham* used the same sort of construction, a small circle of paper, with cut lines to produce wings that would fit in a circle cut in the wheel. The only difference was that in *Hiner* the cuts were angled. Peggy looked at *Hiner*, but used the *Birmingham* brad in the end. See Figure 7.7 for a close-up of her brad on the completed pop-up and a diagram of the brad construction.

Adding leaves to the tree was done with markers, although Peggy also considered feathers or coils for the branches and leaves. She added a slider, a mechanism that she had seen in *Valenta* when looking for something to move a cloud sideways. The slider moves a patch of leaves in the tree from side to side.

The final stages of construction consisted of adding eyes and a smile to the cloud, and using sequins and gems to decorate the tree, the wheel, and make a flower garden. Peggy seemed to really enjoy this process. She saw the pop-up as a fun sort of outdoor scene that a younger child might make and remarked "I've been too busy being a 12 year old. I need to go back to being a 5 year old."

At 2 hours 17 minutes of work, this pop-up took considerably longer than her first effort. Much of that time was spent in deciding on the types of elements to use and constructing the wheel.

There are some important things to note about the construction of this pop-up. First,

Peggy was still element-directed. The original idea for the pop-up was the use of a wheel and the nature of the scene came later. Second, Peggy showed herself to be very good at following directions and at puzzling through complicated relationships of form. The brad that holds the wheel is not an intuitive construction, and the wheel itself presented interesting problems such as the number of cuts to make the holes for each wheel and the direction of the curves to produce the moire pattern. Third, although Peggy frequently declared that she could not draw and that her sister had the talent in the family, she created the curves for that wheel freehand and did an extremely good job at it. Fourth, she enjoyed making the pop-up. Particularly while decorating the final result she was smiling and playing in a much less serious way than usual. And finally, in dropping the original design of the cloud in favor of a platform, she demonstrated the way in which a craftsman might fall back on a familiar way of operating when things get puzzling—as the pop-up seemed to Peggy when coming back to it after a month’s absence.

This final pop-up of Peggy’s represents an advance over her first in several respects. First, in comparison with Peggy’s first pop-up, this design was made much more consciously. Her first pop-up originated with random experimentation with the software. During this process, Peggy discovered the similarity of the design to a man with a hat and proceeded to enhance the likeness. This later pop-up, however, began with both the desire to use a particular element, and the idea for the subject, an outdoor scene, with all the design aimed at creating that scene. Second, Peggy used handmade elements as a part of the design. In fact, the sun wheel was the originating idea for the pop-up. And finally, Peggy built on discoveries that she had made earlier in using the v-fold platform for her cloud.

7.3.2 Emily: *Bart the Elephant*

Emily’s eighth pop-up was *Bart the Elephant* (see Figure 7.8). Bart was built on the two printed sheets shown in Figure 7.9.

Emily had mentioned making an elephant several sessions earlier while working on her



Figure 7.8: Bart the Elephant with Emily's other characters living in his ears. Note the handmade ears in two layers of v-folds, and the folded v-fold for the trunk.

moose⁵. She wanted an elephant because she could have all the other characters she had introduced living in his ears. Her concept for the elephant at first was that the trunk would pop up and the ears stick out so that the other characters could be inside them. The pull-tab she was using for her moose pop-up took multiple gluings with waits in between to allow it to dry so she started on the elephant during these drying periods.

Emily suggested using a v-fold for the elephant's trunk and she and the researcher talked about v-folds to see if that was a good choice.

Emily: I kind of want something where his like trunk pops up like this [*elephant trunk motions*], and his ears go out like that and everyone is going to be in his ears.

⁵ The series of pop-ups for Emily's book began with *Freddy Squarehead*. Each character related to an earlier one. *Cinnamon the Cat*, who doesn't like Freddy, was next. The two unfortunate characters following were *Mr. Mousy*, Cinnamon's dinner, and *Mr. Mousy's friend Mr. Tweedy Mo*, eaten last week. This was followed by *Howard the Giraffe*, Cinnamon's aunt's second cousin twice removed. *Tap Dancing Cow #47* tap-dances on Howard's back. *Moosey McMooseMoose* is the cow's ex-boyfriend. They all live in *Bart the Elephant's* ears. The final pop-up shows all the characters except Cinnamon sliding down the *Slide of Ignorance*.

Researcher: Oh that's good!...Like a narrow v-fold?

Emily: Yeah, but it'd have to be all funny, you know, like, unless it's a perfectly straight trunk.

Researcher: That's true. It could be like off to the side or something...

Emily: Or could we do like v-fold, like, like this and another fold like that and another fold like that.

Researcher: You probably could. You probably could. Actually, I think you can take a v-fold and fold it.

Emily had used v-folds for the beak of her bird and as platforms under the cow, but had not experimented with them much. She wanted to fold a v-fold to simulate the curve of an elephant's trunk, and the researcher helped her locate a page in *Birmingham* which showed a v-fold that was folded once in the center. She deduced from this example that a v-fold trunk could be folded more than once.

Using the software, she added the trunk v-fold and made changes until it was the right size, length, and had the backward slope that she wanted. She used an angled step for the face at first, but by using the viewer she saw that it would collide with the trunk. Next, she tried using a tent for the face and it still collided with the trunk. The researcher suggested using a beak, as it would not stick up so far on the pointed end. She tried this and although it appeared to collide slightly in the Viewer Window, Emily decided that when the trunk was bent the elements would not hit each other.

At this point, Emily was also playing with ideas for the ears, using the software. Putting v-folds on the side of the beak was unsatisfactory as they did not look realistic. Emily played around with v-folds for a while and spent some time looking at the whale pop-up in *Popposites*, as it has flippers composed of multiple v-folds. She played a bit more with v-folds on the computer, but could not get quite the angle or shape that she wanted. Finally she announced:

Emily: But I've got an idea. An idea that's like....What I was thinking is like I just chop chop chop chop chop chop chop chop [*indicating the shape of an ear*] and I attach from like here [*the trunk*] with I don't know string or something to here so it gets pulled out.

Researcher: Oh. That's interesting.

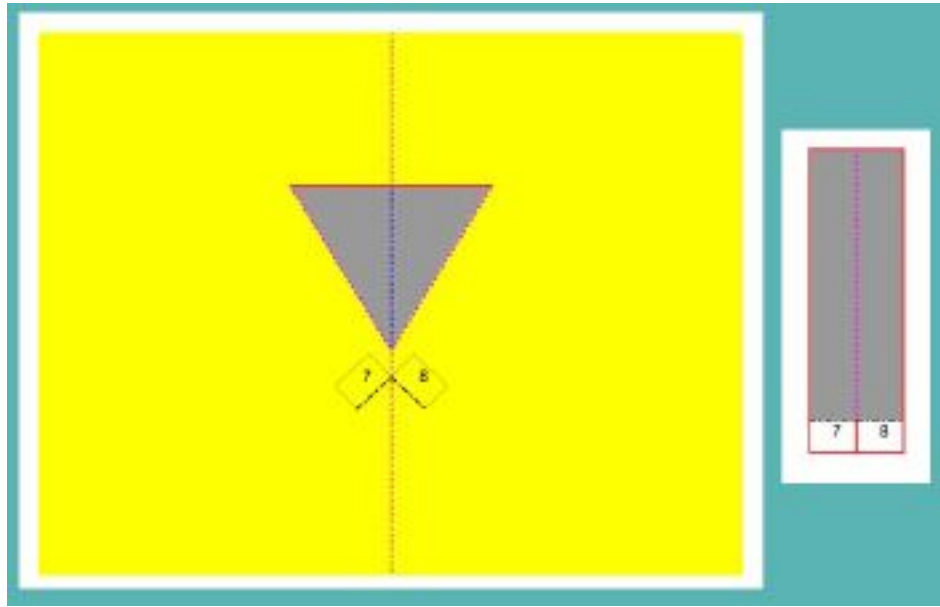


Figure 7.9: Emily's eighth pop-up was printed in two sheets. The base sheet on the left contains a beak and the base for a v-fold. The v-fold itself is shown on the right.

Emily: 'Cause the trunk goes out.

Researcher: The trunk goes out as you open it, right?

Emily: Uh. yeah. *[opening and closing the pop-up and looking at the Viewer Window]* So it would kind of pull the ears out.

Researcher: If you just added extra pieces you mean, and attached them with string?

Emily: Yeah.

This problem solved, she colored the elephant with fill colors and it was printed. The printer was low on yellow ink and the trunk piece printed well but the background did not. Quite a bit of time was spent at this point in finding a name for the elephant. "Bart" was leading the list of possible names at this point. Subsequently, the researcher printed the elephant when the printer had been fixed. This produced an extra printout of the trunk.

The extra printout of the trunk was used in the next session when Emily started to work on the trunk. Since the trunk was folded back on itself, the back of the sheet was visible and needed to be colored as well. Emily tried coloring it with markers, but it was not a good match, so she glued the two trunks together, colored sides facing out, which also strengthened the v-fold piece.

She folded the trunk and it did indeed work well. Emily used scotch tape as well as glue to fasten the trunk to the base page, as she was concerned that the small base of the v-fold would not hold with glue alone.

Emily mentioned that tusks would be nice, so she made some and attached them to the base on either side of the center fold. These are not standard elements, although they might be considered a form of attached plane. The tusks, being parallel to the center fold, fold back when the pop-up is closed. Emily decorated the background with smiley faces and wrote the text on the page.

When Emily started to think about the ears, she decided that having a head around the face would make it look better, not only as a way to connect the pieces, but also to hide the scotch tape at the base of the trunk. She made the head in two pieces, one to surround the lower part of the face, and one for the top of the head above the beak representing the face. The lower part of the head presented problems in cutting holes for the trunk, beak and tusks. The holes needed to be positioned exactly where the pieces would stick through the head. Emily solved this problem by marking the points at the end of the cuts with the knife while positioning the head over them. She added the elephant's smile as a final touch for the face.

Emily eventually decided against using the string idea for the ears and made v-folds instead. These were unusual in design and could not have been made with the program, as they attached to the base page and to the inside of the beak, rather than to the fold between the base page and the beak. It took some time for her to explain her idea to the researcher, who was stuck on the idea of the v-fold being on the outside of the beak:

Emily: ...I could do a v-fold that goes around this part [*the beak*] and then sticks up like that. Do you think that would work? Would it pop-up by itself?

Researcher: [*hesitantly*] It probably would.

Emily: Like especially if I glued one side to the back of this [*the beak*] and put a crease right here. [*along the beak fold*]

Researcher: It would have to fit either this way on here or this way on here. [*Indicating along the beak fold on the outside of the beak.*] It would

have to be on this fold.

Emily: But would it be possible to, um, to put one side attaching here *[outside on the base page]* and the other side going around there *[inside of the beak]* so it's kind of going around like this. *[cups both hands like a v-fold around the side of the beak]*.

Researcher: Oh...(pause) Yeah, it might be. Want to give it a try?

She and the researcher discussed the technique of not creating a center fold for the v-folds before they were attached, but instead allowing them to fold as the pop-up was closed. In this way the centerline is automatically created in the correct place even if the v-fold is asymmetric or off-center. Emily made two prototypes for the ears before making the ones she used so as to find the proper size and shape.

Since the other characters were to be placed in Bart's ears, Emily decided to make small pockets by attaching still more v-folds to the ears. She cut several sets by hand before they were the size she wanted. It was interesting that she used the knife to score the folds for the gluing tabs on these v-folds. This is a delicate technique, requiring careful knife-work to avoid cutting through the paper, but was faster as she already had the knife in hand. She attached the new v-folds for the ear pockets, closing the pop-up in order to produce the center folds in the correct place.

The final step in making Bart was to make small versions of all the characters that she had previously introduced, and gluing them to the ears.

This was an amazing pop-up as it contained several layers of elements, only two of which were made on the computer. It took 2 hours and 49 minutes of work, but over 2 1/2 long (2 hour) sessions as she was working concurrently on the moose at first.

Some important items to note are, first, that Emily was story-driven. She felt that she needed to connect all the characters before the end of the book, and Bart was the place to do it. Second, Emily had learned how to make a v-fold well enough to put two levels of v-folds for the ears and to fold one for the trunk. She not only bent the trunk v-fold, but attached the v-folds for the ears in a novel way, using the inside of the supporting beak. Third, she used the Viewer

Window in the software to determine that elements were colliding and to fix the problem.

The advance in design and construction over her first pop-up, designed entirely with the software and using only 90° elements, is remarkable. By her eighth pop-up, Emily was using a variation on the v-fold for the trunk and making v-folds by hand for the ears. The software had become only a tool to create the background color and a base for adding the rest of the elements that make up the bulk of the design.

7.4 Conclusions

In examining the construction of these four pop-ups, there are two vantage points from which to look. First, the framework of craft derived in Chapter 2 can be used to guide and structure the observations. Second, ways in which the software facilitated Peggy and Emily's paper engineering can be examined.

7.4.1 Craft Framework

Both Peggy and Emily exhibited increases in their knowledge of pop-ups during the testing sessions. In the case of v-folds, Emily was specifically suggesting v-folds for Bart's trunk and ears as she started designing the pop-up and she was also able to look at the whale pop-up in *Popposites* (a very complicated pop-up) as an example for how it could work. Peggy had learned how to make a platform using a v-fold while constructing her second pop-up and used it repeatedly thereafter, in particular in the construction of the cloud in her final pop-up. Both girls exhibited an ability to either know which element would produce the effect desired or to find one in the pop-up books or instruction books provided. For example, Peggy was not sure how to produce the sideways motion that she wanted from the cloud, but was able to find something approximating that motion in one of the commercial pop-up books. Emily thought that a v-fold might be foldable into her trunk, and was able to find confirmation in an instruction book, and extrapolate from one fold to two.

In terms of skill, for both girls the amount of embellishment added to the basic pop-ups by

hand increased significantly between the beginning and end. Much greater skill (and time) was applied to the construction of the later pop-ups, as seen in Emily's crafting of a double layer of v-folds for Bart's ears. Emily had become proficient in the use of the knife which she used to good effect in producing hand-cut v-folds for Bart's ears, as well as to cut out all of the characters to be attached. Peggy, on the other hand, showed a great deal of ability to copy a complicated design for a wheel that used multiple layers of colored paper, curved slits in the base page and colored bars on the wheel itself, and a paper brad to attach the wheel and allow smooth rotation.

Appreciation is much harder to evaluate than the other two competencies. However, three observations confirm its development in both Peggy and Emily. First, the later pop-ups had some purpose and the girls exhibited a desire to produce a particular product. In one respect, appreciation is indicated by a directed approach to the craft, a desire to proceed in a definite direction rather than to produce a random object. This comes out of an ability to envision the final product and to decide what should go into it. Emily demonstrated this by producing a series of pop-ups featuring related characters. Her pop-ups became part of an ongoing project, and as a result, when she came to Bart, she knew quite clearly what she wanted: a trunk that folded, and ears that flapped and held the other characters. Peggy, being more element-driven, wanted something that could be moved by hand, and ended up with both a wheel and a slider in her final pop-up.

A second characteristic of the growth of appreciation is the use of materials and ideas obtained from others, a development of an aesthetic that allows the craftsman to see the value in another's work and adapt what works for her. The girls used pop-up and instructional books and chose what they liked. Not surprisingly, this differed between them, with Peggy preferring instructional books, particularly *Carter*, and Emily looking almost always at the pop-up books themselves. Being sisters, they commonly played off each other. Emily adapted Peggy's v-fold as a platform idea and used it in her *Tap Dancing Cow #47*, while Peggy often asked what her sister was doing, although she did not copy from Emily. They would look at each other's pop-ups when they arrived for sessions and critique them.

Third, over the course of the testing, each developed her own style, part of the process of

growth in the craft. Emily's style was more pronounced, but she had longer to work, and working on a multiple pop-up project allowed her works to be more related. Emily's style consisted of story-driven ideas, usually one or two simple elements (although Bart was unusually complex), bright colors, and flaps hiding surprises. Peggy's style was element-driven, focusing on the mechanics of the elements and how that influenced the pop-up experience. Her pop-ups contained more complex combinations of elements and less use of color than did Emily's.

7.4.2 Software Interaction

There were some particular occurrences where features of the software were seen to support Peggy and Emily's pop-up making. The Viewer Window provided two important examples. Peggy designed her first pop-up upside down by viewing her Editor Window actions in the inverted Viewer Window. Without this, she might have eventually rotated the pop-up, but it would have been after the pop-up was printed. Emily used the Viewer to good effect when designing the beak that would be the elephant's face so as to avoid collision with the trunk. In this case, Emily could see the collisions as they occurred and make the corrections before printing.

Another important feature was the printing of the pop-ups themselves. In the case of these pop-ups in particular, Emily printed two trunks for Bart, since she later made some changes and reprinted the entire design. The extra trunk was fastened to the back of the first to produce a single trunk that was colored the same on both sides.

In discussing the effects of the software, one should finally note that it accommodates different interests and styles, as evidenced by the differences in Peggy and Emily. For Emily, the software provided bright colors, lines, and basic shapes that she could modify to make her characters. In Peggy's case, the change feature and the Viewer Window allowed her to experiment with changes in the elements that could be examined to see how the shapes and movement changed.

And finally, the software did not appear to keep Peggy and Emily from experimenting, designing beyond its capabilities, and developing their own elements and designs. Peggy extended

the v-fold to make a platform; Emily folded a v-fold for the trunk. For both girls, the first pop-up was largely an exploration of the software, and by the end, the software provided a base on which the hand work of pop-up building could proceed.

7.5 Summary

Stepping back from the analysis of Chapter 6, this chapter has taken a closer look at how two users made pop-ups, the changes in their pop-ups over time, and how the software facilitated their learning process. Focusing on a smaller segment of users and pop-ups allows a more detailed view of the pop-up making experience.

This chapter looks at the work of Peggy and Emily, who are twin sisters. Although they have similar backgrounds and are the same age, they have very different interests and personalities and presented a good basis for the comparison of the work of different children. Two pop-ups were selected from the work produced by each girl for more detailed study: the first that each made, as well as a later pop-up from each.

Both of the first pop-ups were made when the girls were first exploring the software. Peggy showed a more element-driven approach to pop-up design, producing an abstract face using an unusual configuration of one tent on another tent. She also spent a great deal of time experimenting with the Viewer Window, and in fact used the window to design the pop-up rotated 180°. Emily, on the other hand, was more captivated by the fill and draw tools. Her pop-up was colorful, and marked by an alteration to the top cut line of the large step.

The second pop-ups chosen were Peggy's fourth and final work, and Emily's eighth. Peggy made a sun from a wheel element that she copied from an instructional book, along with a cloud sitting on a v-fold, and a tree with a step for the trunk and a slider among the leaves. Emily's pop-up was of an elephant and was distinguished by its use of v-folds, both folded in the trunk and handmade layered v-folds for the ears.

There was development for both Peggy and Emily in the competencies of knowledge, skill, and appreciation as gleaned from the changes seen in pop-up making between their two pop-ups.

In addition, the Viewer Window and the ability to print multiple copies of a pop-up aided each of them. The girls exhibited great differences in styles and personality, but each was able to not only use the software effectively, but to produce more complex pop-ups at the end of testing than they did at the beginning.

Chapter 8

Conclusions, Contributions, and Future Work

This document has presented an overview of craft in general and of paper engineering in particular. In the process, a framework of craft learning and practice was developed. Guided by this framework, a software application, Popup Workshop, was designed to help children learn and practice the craft of pop-up making and its efficacy evaluated using the framework.

This final chapter revisits the thesis question, examines what answers can be drawn from the previous chapters, and identifies some of the core contributions of this research. Finally, some avenues of possible future work are explored.

8.1 Conclusions

The thesis question asked in Section 1.5 was:

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?

The first part of this question, whether such a program can be made, has been answered in the affirmative. Popup Workshop, was used by a number of children to produce the variety of pop-ups illustrated in Appendix F. These pop-ups employed both 90° and 180° elements in abstract and pictorial illustrations. Children from ages 6-12 were both interested and motivated in using the program, and they were able to use it with a minimum of assistance.

With respect to the second part of the question, Chapter 6 described the changes seen in the test users in the competencies of craft as defined by the supporting framework as they worked

with Popup Workshop. Knowledge, in the form of vocabulary changes seen was increased with all of the children learning at least a few terms for pop-up elements. Changes were also seen in the ability of children to select appropriate elements to produce the effect they wanted. Skill increased as well, with all of the children able to make several functioning pop-ups of various levels of difficulty and all gained skill in material and tool use. Change in appreciation was harder to determine, however all of the children appeared to be developing that competency in terms of being able to describe the work of others and to compare pop-ups. They also were able to draw upon the work of others in designing their own pop-ups.

8.2 Core Contributions

Several important contributions have emerged from this work. First, Popup Workshop presents new developments in software tools for paper engineering. Second, the development of a framework for craft learning and practice can aid in the design and evaluation of computational tools for crafts. Third, the user testing advances the design of assessments for computational craft-work and in observations of children's practice. Finally, the survey of related research in this area will provide a support on which future work in this area can build. This section examines these core contributions in more detail.

8.2.1 Popup Workshop

Popup Workshop represents a departure from other software previously produced for the use of paper engineers in terms of availability, child-friendliness, and method of pop-up animation.

First, this is the first general purpose program for pop-up design available to the public that can produce both 90° and 180° elements. As discussed in Section 4.2, there is only one other software application currently available, Pop-up Card Designer, and it is aimed specifically at the origamic architecture community. This means that it produces only 90° elements, and in fact only parallel 90° elements. Pop-up Card Designer is also available only for the Windows operating

system.

Popup Workshop has been available for free download on the Web since March 2005 as a Java application in a native Macintosh form and as a .jar file for use with Windows or Linux. Both the original 1.1 and subsequent 2.0 version are available [48]. In addition, the documentation for both versions is available for download. From March 2005 through September 2008 (approximately 3.5 years), the program was downloaded 2942 times. For each download, information was requested from the users and included their name, country, email address, and any comments they had. Because some users provided no information or downloaded the software multiple times, 1590 users from 73 countries were identified as unique.

Second, Popup Workshop is also the first software for paper engineering that has been created with children as the intended primary user community. Pop-up Card Designer can be used by children, but they are not its intended audience. In fact, no other software has been proposed in the literature for children's pop-up making.

Finally, there is the proof of the effectiveness of Popup Workshop's method for animating pop-up designs as 3-dimensional images. In previous research on this subject, mathematical formulas have been conceived for particular elements [34, 66]. Each of these mathematical methods is applicable to a single element type or a small group of elements, making addition of new elements difficult. However, Popup Workshop uses a constraint system to calculate the positions of element corners, a method that is easily adapted to any element type. Although such a system does not find the corners exactly, it has been shown to be accurate enough to produce functional software.

8.2.2 Craft Framework

It is a truism in programming that the application for which the software is destined must be understood in order to produce a usable system. This is no less true for craft software. Craft is a complex mix of materials, methods, and tools. In addition, there is a real need for ways in which to assess the usability of software for craft applications. This can be difficult, since craft is a

difficult area to assess to begin with and the addition of computation may change the practice of craft in many ways. For instance, adding another tool, in this case the computer, may make the craftsman's task easier in some ways and more difficult in others. The framework developed here for craft learning and practice can provide guidance for both computational design and assessment in many craft fields.

By partitioning craft practice into three competencies, knowledge, skill and appreciation, a craft may be examined for areas in which computation can be beneficial, areas in which computation should not be allowed to interfere with the craft practice, and how the design of the software should proceed. Section 4.3 of this work presents an example of how this process works for paper engineering. This use of the framework is a contribution to the field of metadesign, the design of software for design itself and can be applied to any metadesign project dealing with craft enhancement.

In addition, the assessment of children's practice of pop-up making in Chapter 6 was undertaken using this framework and it provided an effective method of teasing out evidence of genuine growth in the practice of the craft. Using the framework to design assessment methods allowed the user testing to focus on those parts of craft learning that were most important, and to isolate those portions for testing.

8.2.3 User Testing

User testing of Popup Workshop produced a great many pop-ups made by children in a range of ages from 6-12. While some examples of children's work in paper engineering have been published before [58], this is the first assemblage of children's work using a software system and the first to follow a set of children over time. As such, it represents a set of data which has not been previously reported.

8.2.4 Literature Survey

Two areas of literature dealing with pop-ups were surveyed for this study. First, in Section 4.2 previous research in the development of software for paper engineering was reviewed. This review covered the total of the work published previously in the field. Second, the most important literature on the use of pop-ups in the classroom was surveyed in Section 3.3.2, along with the more minor works and instructional materials of use to teachers that are listed in Appendix B.

Some review of the first category has been attempted in all of the published research on computer enhancement of pop-up making, but Section 4.2 provides the most complete such survey to date. Additionally, it does not appear that the literature about pop-ups in the classroom has previously been collected in one place. As a result, this collection of references provides a central resource for both the developer desiring to produce paper engineering software, and the teacher wanting to incorporate pop-ups in the classroom.

8.3 Future Work

There are many followup possibilities to this research. Two areas merit particular attention. First are changes to the software, and in particular to the method of animation of pop-up forms. Second are opportunities for further user studies and curricular applications of Popup Workshop.

8.3.1 Software Additions and Enhancements

It is probably the case that all software is seen by its creator as a work in progress. One can always list scores of possible feature additions, improvements, and of course bugs. Popup Workshop is no exception. For instance, adding color to the Viewer Window to echo that in the Editor Window was mentioned by several children in user tests as a possible change. Another possibility would be to allow double-sided printing of patterns so color could be computer applied to both sides of an element. More generally, the code as written is only a prototype and classes representing element types repeat a great deal of code; refactoring would be a useful exercise.

These types of changes are relatively mundane and common to most software. The most novel enhancement to Popup Workshop, and one that would benefit greatly from further refinement, is its method of animating pop-up designs.

Popup Workshop uses a constraint system to animate the pop-up's opening and closing in the Viewer Window. The current system proves the effectiveness of this approach but there are three improvements that could be made.

First, the constraint system generates two solutions for the location of an element. For 90° elements, one solution is "popped-out" away from the base plane and the other lies flat against the base plane. In the case of 180° elements, the solutions produce elements attached to both the front and back sides of the page. Currently the program finds the correct solution in most cases. Section 5.4.4 describes algorithmic modifications to address this issue that would be useful to explore.

Second, although the Viewer Window experiences minimal latency with the number of levels that children use (generally four levels or less) and on the computers used during testing, improvements in drawing speed would certainly make the software more useful on slower computers.

Third, it would be helpful to develop a language to describe elements in terms of anchored points, unanchored points, and the relationships between them. Such a development might make it very easy to add new elements, much more so than in the current software. If a new element could be added in a brief language description rather than by adding the code directly, both program readability and modification speed could be improved. This is a natural extension of the current constraint system.

8.3.2 Further User Studies and Curricular Applications

The current study focused on the support that Popup Workshop gives to children in learning and practicing the craft of paper engineering. There are many topics that were not covered in this study that might be usefully pursued.

First, children's pop-up making is a valuable platform for studying children's artistic expression and methods of design. Some of the topics that could be explored include the processes which children use to design pop-ups and the role of pop-up constraints in the design. Previous studies of children's artistic development often use drawing as the object of study. As Golomb, a researcher in the area of children's artistic development has written:

...to fully understand artistic development and the meaning of the early stages in drawing, we need to study performance in a related, though different medium that does not entail the same problems in the representation of dimensionality, but poses its own domain specific challenges and questions to be addressed [38, pp. 2–3]

There are several factors that make paper engineering a useful craft to create these challenges. With pop-ups, the medium is paper, which is robust and, moreover, paper objects that fold flat make it a convenient form to both study and store. As an example, Golomb comments on the difficulties of studying children's clay figures, which tend to fall apart and are difficult to store. The elements used to create pop-ups can be limited in number, and constrained in form, making them amenable to study children's design techniques. And pop-ups are unique in being both 2- and 3-dimensional, standing between flat art domains such as drawing and painting, and 3-dimensional domains like modeling in clay.

Second, a fruitful avenue of study in paper engineering could be focused on collaboration and group work. The current study investigates children working individually, with only occasional interaction between the two pairs of siblings in the study. What happens when children work together to create pop-ups? Because the software allows multiple copies of a pop-up to be easily made, groups of children could work together on pop-up books. What are the implications of this for storytelling, writing, and group cooperation?

Third, and related to group work in general, would be studies examining the use of this software in the classroom. Paper engineering is an area in which work has been done with traditional pop-up making techniques or by using pop-up books in literacy [89, 106, 58], mathematics [108, 122] and design technology and art [58]. Adding software, if it supports the craft, could be

useful in the classroom by providing an interactive tool for study in these and other areas. Many teachers have downloaded Popup Workshop. It would be interesting to contact them and find out what they are doing in the classroom, and to observe its use as a starting point for this research.

8.4 Final Remarks

This work began as a personal exploration of pop-up making, and as a way of focusing my interests in craft, art, computer programming, and teaching into a single subject. I had never made a pop-up before this voyage of exploration began, and my delight in doing so expanded into the delight of seeing the children in the user tests express themselves in many beautiful ways.

If this work encourages others to investigate children's design of pop-ups, methods of computational enhancement of pop-up making, or ways to bring pop-up making into the lives of more children, it will have served a larger purpose.

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Appendix A

Glossary

90° element – A pop-up element that displays best when the page is half-open. This type of element usually consists of cuts and folds with no extra pieces glued on.

180° element – A pop-up element that displays best when the page is fully open. This type of element usually consists of extra pieces glued to the page. Commercial pop-up books commonly use this type of element.

action book – See movable book.

anchored point – A point on a corner of an element's plane that attaches to a base plane of the element.

angled element – An element that has its folds or seams at an angle to its parent fold. For examples, see Figure 4.7.

angled step – An angled step is a 90° angled pop-up element consisting of two cuts, and two outer folds that are not parallel to the parent fold. See Figure 4.6.

attached plane – Extra, usually flat piece of paper placed on another element. See Figure 4.9.

base page – The page available to place pop-up or movable devices. The two sides of an opened book or piece of paper. See Figure 4.3.

base plane – The plane(s) on which a pop-up element sits. Most pop-up elements have two base planes, a right base plane, and a left base plane. See Figure 4.13.

battledore – A small book for children made of heavy cardboard, and used during the 18th and into the 19th centuries. They usually contained an alphabet and religious texts to teach reading.

beak – A beak is a 90° angled pop-up element consisting of one cut, and two outer folds that meet on the parent fold. See Figure 4.6.

boat – A 180° parallel pop-up element that uses connections on each side of the parent fold to bend paper into a boat shape or cylinder. See Figure 4.8.

Bookano – One of S. Louis Giraud's names for the first pop-ups that he produced. See also *living models*.

box – A 180° pop-up element shaped like a box. This element may also be made with a top, or a pointed top like a house, and can be made in angled or parallel forms. See Figure 4.7

carousel book – A book that may be opened and tied back on itself, with paper connections between the pages to produce a 3D effect. Also called a *star book* for the shape of the book when opened. See Figure 3.8

chapbook – A cheap book made from folded sheets of paper, and often illustrated with wood-block prints. Developed in the mid-17th century and produced through the 19th century, these were the equivalent of the mass-market paperback and were sold to adults and children by traveling peddlers.

coil – A 180° pop-up element consisting of a spiral cut out of paper, with one end glued to each side of the page. See Figure 4.8.

cut – A slit made in the paper to produce a pop-up element, particularly a 90° element.

device – A movable mechanism, that may be a single element, or a whole connected series of elements.

dissolving picture – See *transformation*.

Editor Window – The window in Popup Workshop on which the user draws, and that serves as the pattern that is later printed, cut, folded and glued to produce a pop-up. There may be multiple Editor Windows, one for the base page and one for each added piece. See Figure 5.1

element – Pop-ups consist of one or more elements, simple forms that themselves will open and close. For a taxonomy of elements, see Figure 4.5.

emblem book – A children's book in which artifacts, animals, plants, etc. stand for some moral quality. For instance, a book may be a symbol of education, or a bee of industriousness.

flap – An extra sheet or piece of paper cut and attached to a page, or a cut made in the page, so that it may be lifted to reveal what lies underneath. See Figure 3.4.

flap book – A movable book that consists of flaps that the reader can lift. A flap book has only flap devices. These are often books for small children.

fugitive sheet – A page that has been separated from its original book, or printed separately from a book.

gatefold – A page inserted in a book that is wider than the book, and is folded into the book to fit. Sometimes the page is folded as a panorama, and may be glued on the back to provide the effect of a small book attached to the edge of the page. See Figure 4.2.

gutter – The fold down the center of an open book or card. See Figure 4.3.

harlequinade – An early type of flap book, first published in about 1765, in which the page is divided into four flaps. Also called *turn-ups* or *metamorphoses*. See Figure 3.5.

hornbook – A wooden paddle, to which was pasted a page of text, usually an alphabet and some religious texts, covered with a thin sheet of horn, and used as a beginning children's reading book in the 17th and 18th centuries.

inverted element – A pop-up element that has reversed folds, valley folds where one would expect mountain folds and vice versa. This inversion often arises when the element is placed on a mountain fold or a seam which folds in the same direction as a mountain fold, instead of a valley fold. In the case of a v-fold, the inverted element occurs when the V is reversed.

level – When elements are placed on top of one another, they produce levels. The base page is said to be at level 0. See Figure 4.12

lift-up – Another name for a *scenic*.

living models One of S. Louis Giraud's names for the first pop-ups that he produced. See also *Bookano*.

metamorphose – The name for a *harlequinade* in the United States.

mix and match book – A book in which the pages are cut into flaps, allowing the reader to select a part of an illustration from each page.

mountain fold – A fold that folds out toward the viewer. See Figure 4.3.

moveable – A term for either a *moveable book* or a single element.

moveable book – A book that differs from the usual flat page format. This may take the form of attached devices that are moved by the reader or automatically move when the book is opened, or the actual form of the book may be different from the usual cover with pages.

moving arm – A pop-up element in which some part of the pop-up displays an animated motion.

See Figure 4.10.

novelty book – A name for any book that is of unusual format or design. This includes movable books, and may also include other books such as board books, cloth books, and books that convert into toys.

OA – A shorter term for *origamic architecture*.

origamic architecture – Pop-ups produced by cutting and folding a single piece of paper with no gluing. They are usually 90° pop-ups. See Figure 4.16.

packaging company – A company that produces books and sells them to publishers. Often used for pop-up production as they have specialized knowledge and facilities.

page – In this dissertation, the term "page" refers to what is usually termed a *double truck* in publishing, that is, facing left and right pages on each side of the gutter, taken as a unit.

panorama – A book that folds out into a long zig-zag form. See Figure 3.7.

paper doll book – A movable book in which the object is to dress a paper doll in various clothes. Paper doll books may consist of a doll and clothes to cut out, or the head of the doll may be placed in slots in the page, or be visible through a hole cut through all the pages.

paper engineer – The craftsman who designs pop-ups and other movable devices, particularly for professionally produced books and cards.

parallel element – A pop-up element in which the folds and seams are parallel to the parent fold. For examples, see Figure 4.7.

parent fold – The fold across which a pop-up element is placed, in order to produce motion. The parent fold may be the gutter. See Figure 4.13.

peep-show – An accordion-folded book (or device) that pulls out to provide depth and has a small viewing hole. Elements of a scene are arranged inside to provide a 3D view. See Figure 3.9.

plane – A face of an element. One flat side. Many elements have two planes, on the right and left sides. See Figure 4.13.

platform – An element that produces a flat surface on which an attached plane may sit to make a table-like device. See Figure 4.7.

pop-up – A device or element that opens automatically when the book is opened, and that produces a 3D object.

pop-up book – A movable book that contains at least one pop-up. It may also contain other movable devices.

pull-tab – A paper tab that when pulled or pushed produces motion in a device or element.

revolving picture – A circular form of *transformation*.

scenic – An early precursor of the pop-up, in which the 3D effect is produced by multiple levels, that may be raised by a pull-tab or ribbon. Also called a *lift-up*. See Figure 3.10.

seam – The line along which pieces are glued in pop-up elements.

slot book – A book that has slots in the pages into which paper pieces may be placed. For instance, paper dolls may be placed into scenes in a house shown on the pages.

star book – See *carousel book*.

step – A step is a 90° pop-up element consisting of two cuts, and two outer folds and a center fold that are parallel to the parent fold. See Figure 4.6.

tent – A tent is a 180° parallel pop-up element consisting of a tent-shaped piece that is glued onto the page at opposite sides. See Figure 4.6.

toilet book – A children's *emblem book* produced by Grimaldi in 1821. Flaps were used to convert toilet items such as mirrors and combs into illustrations of the virtues they represented. See Figure 3.6.

Tool Area – The area of the Editor Window in Popup Workshop with buttons to choose an action. It is divided into three smaller Tool Areas.

toy book – See *novelty book*.

transformation – A picture that transforms into another picture by means of sliding panels. See Figure 3.11.

tunnel book – See *peep-show*.

turn-up – See *harlequinade*.

unanchored point – A point in a pop-up element that is not part of one of the base planes of that element.

v-fold – A v-fold is a 180° angled pop-up element consisting of a piece that is glued onto the page at the two bottom sides, that are placed at an angle. See Figure 4.6.

valley fold – A fold that folds in, away from the viewer. See Figure 4.3.

Viewer Window – The window in Popup Workshop that contains a 3D representation of the current work.

volvelle – A device in a moveable book, consisting of a rotating wheel, that may point to, or uncover information, or serve as a calculating device. See Figure 3.1

wheel – See *volvelle*.

Appendix B

Resources for Pop-up Making Learners and Teachers

This list of resources is far from comprehensive, but includes the most useful found for the beginner in this field. Resources for the teacher have also been included, including those that discuss how to include professional pop-ups (or other movable books) into classroom activities, and those that list suggestions for professional pop-ups to include.

B.1 Instruction Books

This section lists a few of the most useful instruction books available for paper engineering. For books that include patterns to cut out and assemble, see Section B.2

- Duncan Birmingham, *Pop Up!: A Manual of Paper Mechanisms*, ISBN: 1-899618-09-0

This is the most useful instruction book available for learning the basic elements and their geometric constraints. (It was the most used book in the construction of Popup Workshop.) Marvelous detail on variations of v-folds is included, for instance. It also includes such devices as wheels and pull-tabs. The illustrations are simple line drawings.

- David A. Carter and James Diaz, *The Elements of Pop-Up: A Pop-Up Book for Aspiring Paper Engineers*, ISBN: 0-689822-24-3

This is a book for those who like their illustrations in 3D. Actual working models of elements and clear indications of constraints are provided, including pull-tabs, wheels,

and transformations. It doesn't contain the variations you can find in Birmingham above, but it is useful to see them actually work.

- Paul Jackson and Paul Forrester, *The Pop-Up Book : Step-By-Step Instructions for Creating over 100 Original Paper Projects*, ISBN: 0-805028-84-6

This book contains basic directions for both 90° and 180° elements. The best part of this book is the wealth of illustrations of variations on each element, the design section in which valentines are designed using each of the elements, and a gallery of various cards.

- Barbara Valenta, *Pop-O-Mania*, ISBN: 0-803719-47-7

A perfect book for the young (6-10) beginning paper engineer. Only a few elements are featured, beaks and steps and a few others. But the presence of actual working variations on these helps children see what they are doing.

- Masahiro Chatani, *Pop-up Origamic Architecture*, ISBN: 0-870406-56-6

Masahiro Chatani has a large number of books available dealing with Origamic Architecture. This book is simply one example, but a good one to start with, as it contains 0° , 90° , and 180° designs. Patterns are provided, along with photos of the results.

- Gwen Diehn, *Making Books that Fly, Fold, Wrap, Hide, Pop Up, Twist, and Turn*, ISBN: 1-579900-23-2

Aimed at grades 4-7, pop-ups are only a part of this book. It includes books in many forms that children can make for themselves. An ideal start on bookmaking for a young person, and this would be useful for teachers as well. Also available in paperback.

B.2 Kit Books

Books in this section are instructional books on paper engineering that contain patterns that can be cut out and assembled, or even pre-cut pieces. This allows beginners to get a start on

making pop-ups without making a design first. This is often a good way to begin.

- Mark Hiner, *Paper Engineering for Pop-Up Books and Cards*, ISBN: 0-906212-49-9

This book provides 10 devices to cut and assemble. They remain in the book for future reference. Included are wheels, pull-tabs and transformations as well as pop-ups. This is aimed at adults and is a good way to start making movable books.

- David A. Carter and James Diaz, *Let's Make It Pop-up*, ISBN: 0-689865-08-2

This books contains pre-cut pieces to assemble into pop-ups, and is recommended for ages 4-6. It's a good way to start young children, as no cutting is required. Some of the patterns can be found at Carter's web page (see Section B.2.2).

- Diego Uribe, *Fractal Cuts*, ISBN: 0-906212-88-X

This is an odd but wonderful book. It contains 10 90° cards to cut out and fold. All are based on self-similarity, and the book is a compendium of information on fractals, which is tied to the pop-ups. A book for high schoolers or adults, it would also be useful for a teacher who is using pop-up cards as fractal manipulatives.

- Carol Barton, *The Pocket Paper Engineer, Volume 1: Basic Forms*, ISBN: 0-962775-20-7

This book focuses on 90° elements and contains cards for the reader to make based on many variations of the basic elements. It's a bit expensive, but lovely, with pockets included to store the finished cards. Extra sets of cards are available separately. Future volumes are planned for 180° elements.

B.2.1 Web Sites

Using the links found on these sites, the interested reader can continue to explore. Web sites are of course ephemeral, but those chosen have been in existence for some time. Web sites particularly dealing with subjects of interest to teachers are reviewed in Section B.3.

B.2.2 Web Sites of Paper Engineers

Some of the paper engineers' sites contain instructional material or patterns, and are therefore very useful to the beginner.

- Robert Sabuda, <http://www.robertsabuda.com>

A wealth of articles, pictures, and pop-up making directions. One of the most useful sites on the web.

- David and Noelle Carter, <http://www.popupbooks.com/>

The "Surprise" and "Make It" links lead to patterns to print, cut and fold.

- Mark Hiner, <http://www.markhiner.co.uk>

This site contains no "how to" information, but has nice articles about the history and production of pop-ups.

- Masahiro Chatani, <http://www.japandesign.ne.jp/IAA/chatani>

This site is mostly in Japanese. Wonderful pictures of his origamic architecture designs.

- Carol Barton, <http://www.popularkinetics.com/>

Carol Barton's company, Popular Kinetics Press, produces books, and these are sold here. In addition, Carol teaches classes in pop-up making, and information on classes is on her website, as well as a blog on book arts.

B.2.3 Other Web Sites

Most of these sites contain photos, and sometimes videos or animations of pop-ups. In addition, there are many articles on the history and production of pop-ups. Many are aimed at collectors, but the beginning paper engineer can find inspiration in seeing the designs of the past.

- Pop-up Lady, <http://www.popuplady.com>

Contains a great variety of articles, links, and photos. Oriented toward collectors.

- Ann R. Montanaro, <http://www.rci.rutgers.edu/montanar>

The page has links to an exhibit of her collection, and to the Movable Book Society.

- Stichting Geschiedenis Kinderen Jeugdliteratuur,

<http://www.hetoudekinderboek.nl/>

This site is in Dutch. Has a wonderful collection of historical children's books, including photos of every page in each book—which is rare. "Beweegbare boeken" is the link for movable books.

- Movemania (Adriaan Heino), http://www.euronet.nl/users/aheino/public_html/

This site has a history of movable books with examples.

- Pop Goes the Page—University of Virginia Library,

<http://www.lib.virginia.edu/small/exhibits/popup/>

An exhibit of movable books, arranged by history. Most illustrations are of the covers, unfortunately, but there are some pop-up pages shown.

- Origamic Architecture, <http://members.aol.com/kselena/OA/oamainpg.html>

A large page on OA with many photos and a great deal of information on the hobby.

- The Wonderful World of Pop-up and Animated Books, <http://popupbooks.net/>

This is a gallery of a personal (and large) collection of movable books. The visitor can list books by author, illustrator, etc. or title. Many photos of the book pages are included.

- Hawcock Books, How It's Done, <http://www.hawcockbooks.co.uk/howitsdone.pdf>

A color illustrated document on how pop-ups are made. This would be a good tool to show children about the manufacturing process.

- The Great Menagerie—University of North Texas,
<http://www.library.unt.edu/rarebooks/exhibits/popup/main.htm>

A collection of pop-ups of the 19th and 20th centuries, with videos of the action for some.

B.3 Resources for Teachers

This seems like a good place to list the resources for teachers that have been located, in order to have them all in one place. Pop-ups (and other movable books) can be used in the classroom in two ways, making pop-ups and using commercial books, and these uses sometimes overlap. This section has been roughly divided according to which of those uses is most important in the resource.

B.3.1 Making Pop-up Books in the Classroom

This selection ranges from books which present a curriculum using pop-up making through small activities that include pop-up making. The following five resources are the most important and are more fully described in Section 3.3.2. The reader is directed there for more information.

- Patrick Shannon and Barbara G. Samuels. Developing an understanding of literacy through production of pop-up books. *Reading Horizons*, 25(3):213-221, Spring 1985.
- Paul Johnson, *Literacy Through the Book Arts*, ISBN: 0-435087-66-5
- Elaine Simmt and Brent Davis. Fractal cards: A space for exploration in geometry and discrete mathematics. *Mathematics Teacher*, 91:102-108, Feb 1998.
- Malcolm Swan, Barbara Binns and John Gillespie, *Numeracy Through Problem Solving*:

Be a Paper Engineer (Teacher's Guide), ISBN: 0-582034-90-6 (Note: available through <http://www.mathshell.com/>)

- Paul Johnson, *Pop-Up Paper Engineering: Cross-Curricular Activities in Design Engineering Technology, English and Art*, ISBN: 1-850009-09-0

The following articles may also be of interest to teachers wishing to incorporate pop-up making into classroom activities.

- Gerry Bohning and Ann Phillips and Sandra Bryant, *Literature on the Move: Making and Using Pop-up and Lift-flap Books.*, ISBN: 1-563080-70-2

The first section of this book describes how to make many simple pop-up elements. The second section describes how to use pop-up making in grades K-6 by making books on themes in several subjects.

- Rose Reissman, Pop-Up Portfolio Research (Teaching Ideas), *English Journal*, 85(1):74-76, Jan 1996.

A project making pop-up portfolios for a unit on newspapers and politics is described. The students collected clippings and made pop-ups that included their reactions to the happenings.

- Rose C. Reissman, Give the Gift of Family Literacy—Student-Designed Gift Books, *English Journal*, 82(6):74-76, Oct 1993.

Describes a project involving students making gift books for their families. Pop-up books are included, but only as a part of the project.

- Sherry Ball, Creating Pop-ups. *Book Links*, 12(6):25-27, Jun-Jul 2003.

A few suggestions on how to use pop-up making in the classroom and a list of books and web links to get started.

- David Cassell, Maths Resource: Pop-Up Polyhedra. *Language Arts*, 17(1):24-27, Jan 1988.

Discusses polyhedra that pop-up by means of a rubber band. Folding nets are included.

- Hans Walser, The Pop-up Cuboctahedron. *The College Mathematics Journal*, 22(2):89-92, Mar 2000.

This is a more difficult rubber band polyhedral pop-up, probably for at least high school level.

- Giancarlo Navarra and Sue Pope, POP-UP Workshop. <http://www.pedf.cuni.cz/kmdm/download/aktivita/eltmaps/Classroom/12%20PopUpDef.pdf>

A workshop for teachers exploring the mathematical possibilities of 90° pop-ups. Visualization is stressed.

- V. Mohan Ram, Pop-up Engineering and Geometric Concepts: Mathematics Workshop http://www.hiceducation.org/Edu_Proceedings/V.%20Mohan%20Ram.pdf

Another online workshop for teachers on the geometric properties of 90° pop-ups. Some attention is given to geometric constraints.

- National Museum of Women in the Arts: Art, Books, and Creativity <http://www.artbookscreativity.org/>

A website exploring the connection of visual arts and writing through the making of art books. A year-long curriculum is available. This is a relatively new site.

- Vanessa Evans Huse, Nancy Larson Buemel and Rhonda Harris Taylor, Making Connections: From Paper to Pop-up Books. *Teaching Children Mathematics*, 1(1):14-17, Sep 1994.

Discusses using paper to teach mathematics. A simple pop-up card is shown, and activities around it are mentioned.

B.3.2 Using Commercial Pop-up Books in the Classroom

- Richard F. Abrahamson and Robert Stewart, Movable Books—A New Golden Age. *Language Arts*, 59(4):342-347, Apr 1982.

A much-cited article discussing how to use pop-up books in the classroom, some particularly valuable books to use, and a bit about making pop-ups in the classroom.

- Gerry Bohning and Marguerite C. Radencich, Math Action Books for Young Readers, *Arithmetic Teacher*, 37(1):40-48, Sep 1989.

Ideas for using pop-up and pull-tab books in primary math classes. Suggestions and a list of possible books to use are included.

- Gerry Bohning and Marguerite C. Radencich, Concept Action Books: Invitation to Participate. *Early Childhood Education Journal*, 15(4):16-20, Jun 1988.

Ways of using action books (including lift-the-flap and pop-ups) with young children. There are a few simple activities around making flap books and a list of useful books as well.

- Lea M. McGee and Rosalind Charlesworth, Books with movables: More than just novelties. *Reading Teacher*, 37(9):853-859, 1984.

Using movable books to hook young readers. Includes a list of books to use.

- Marguerite C. Radencich and Gerry Bohning, Pop up, pull down, push in, slide out: Natural Science Action Books, *Childhood Education*, 64(3):157-161, Feb 1988.

Ideas for using pop-up and pull-tab books in science classes. Suggestions and a list of possible books to use are included.

- Vivienne Smith, Lifting the flaps on information: purpose and play in non-fiction texts. *Reading*, 37(3):116-122,, 2003.

The purpose and function of flaps in lift-the-flap non-fiction books and why some succeed and some do not.

- Ann R. Montanaro, *Pop-up and movable books: A bibliography*, ISBN: 0-810837-28-5 (2000 update)

The standard reference for librarians on pop-up books published.

- Rhonda Harris Taylor and Nancy Larson Bluemel, Pop-up Books: An Introductory Guide. *Collection Building*, 22(1):21-32, 2003.
- Nancy Larson Bluemel, Rhonda Harris Taylor *Pop-up Books: A Guide for Teachers and Librarians* ISBN: 1-591583-98-5

These two resources are primarily for librarians, but would be useful for teachers. They give basic information on resources on pop-up books.

Appendix C

Popup Workshop Documentation

Popup Workshop Version 2.0 Documentation

February 2007

Susan Hendrix, hendrixs@cs.colorado.edu

Craft Technology Group

<http://13d.cs.colorado.edu/ctg>

C.1 Introduction

Popup Workshop is a program to help you design simple pop-up books and cards, and print a pattern on your printer to cut and fold.

Although this software creates only a limited set of pop-up forms, we hope that using this application will start you on your way to learning about pop-up design. See the For Further Reading section to get more information on how to add to these pop-ups, or create your own designs using additional forms, or, if you are a teacher, how to incorporate pop-ups in your classes.

We hope to be updating the software to add more features, fix bugs, and to add new pop-up forms in the future.

C.2 System Requirements

Version 2.0 of Popup Workshop requires Java 1.5 or later, and Java3D.

If you have a Mac, this means that you must have OS X, and if you are running an earlier Java version, you may have to upgrade Java. (Java 1.5 is available via Software Update.)

We have provided a Windows Version 2.0. You may have to upgrade Java to version 1.5 if you do not have it currently. You may also have to obtain Java3D. This will depend on your version of Windows. See <http://www.sun.com/software/learnabout/java/>.

Note that development of this application has been on Mac. The Windows version has not been tested. It should function as the Mac version does, but it is possible that this is not the case. We would like to hear about any problems encountered that we may have missed.

A color printer is desirable, but is not required.

C.3 Downloading, Installing and Running Popup Workshop

We ask that you fill out a registration form to download Popup Workshop. There is no charge for the application. We appreciate your bug reports, ideas for additions and improvements, and pictures of your creations to put on our web page.

For Mac: Click on the download link on the website, and wait for the download to complete. The downloaded disk image should automatically open and mount. If it does not, double click the .dmg file that you downloaded to open and mount the disk image containing the Popup Workshop folder. Drag the Popup Workshop folder to your Applications folder. Double-click the Workshop icon to start Popup Workshop.

For Windows: Click on the download link, and choose "Save" to download the zip folder. Double-click the resulting folder to obtain the .jar file. (If the file is an .exe file, and not a .zip file, change the extension to .zip before double-clicking.) Double-click the .jar file to run Popup Workshop.

C.4 General Information

Popup Workshop starts up with two windows, the Popup Editor and the Popup Viewer. Figure C.1 shows the windows as they appear on opening the application.

Changes are made using the editor window. This is also the design that you will print and cut to make your pop-up.

The viewer allows you to see how the finished pop-up will look, to open it and close it using the slider beside the pop-up, and to rotate it and look at it from all sides by using the mouse. (Position the mouse on the 3D view of the pop-up, click and drag to move the view. Click the Reset button to return to the front, half-open view.)

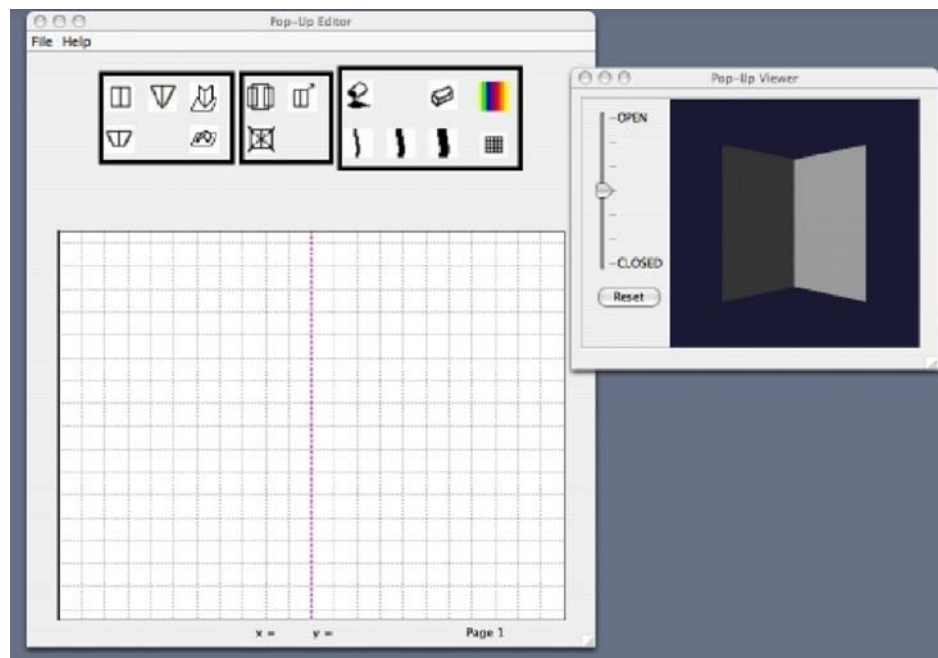


Figure C.1: Popup Workshop starting windows

Addition of some pop-up elements may cause additional windows to open. These elements consist of additional pages that are cut out and glued to a base. Therefore, they require multiple pages. Each page is shown on an editor window.

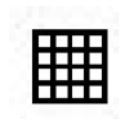
Notice that the pop-up starts with a single fold down the center. The pop-up is designed

to fit on a letter-sized sheet when printed.

Folds and cuts are designated as follows:

- Mountain folds fold toward you. They are drawn as blue dashed lines.
- Valley folds fold away from you. (The starting centerfold is a valley fold.) They are drawn as magenta dashed lines.
- Cuts are drawn as red solid lines.
- Seams are lines where two sheets meet when glued together. They are drawn as black, irregularly dashed lines.

The Editor starts with a grid of black dashed lines to help you line up your design. You can turn the grid off and on by clicking on the grid button, which looks like this:



Other actions are chosen with other buttons. The chosen button turns yellow to let you know which one it is.

There is a position indicator at the bottom of the Editor Window. This gives the x- and y-coordinates of the cursor when it is in the page area.

C.5 Adding Elements

Pop-ups, even very complicated ones, are made up of simpler forms or elements. In this version of Popup Workshop, we support 5 such elements. Three of them are made up of cuts and folds in the original page. There are 2 other elements that are made by applying forms cut from additional sheets of paper.

Lets talk about the 3 simpler elements first. All of these elements are placed on top of a fold. This can be the centerfold that you start with when you start the application, or a fold

created by another element. In this way, you can build up more complex designs. You can place elements on mountain folds or valley folds.

In each case, add an element by first selecting the button representing the type of element you wish to add. Then click and hold the mouse button near the fold on which you want to place the element. Drag the mouse to make the element the size you want.

The leftmost area of buttons is where you look to choose elements to add. The elements we support are:



Step: This element has two cuts (at the top and bottom) and two folds at the sides, along with a fold in the center. The folds are all parallel.



Beak: This element has only one cut, and three folds. It can be placed point up or point down.



Angled Step: This element is just a beak with the point cut off. It has two cuts and two folds like the step, but the sides are not parallel.

There are also the two applied elements. When you add one of these elements, you will see that it makes a new Editor Window, since it requires a separate piece to attach to the page. Each piece also comes with tabs, which are numbered to help you decide where they should be attached. These elements can be added to mountain or valley folds, and also to the seams of other applied elements.

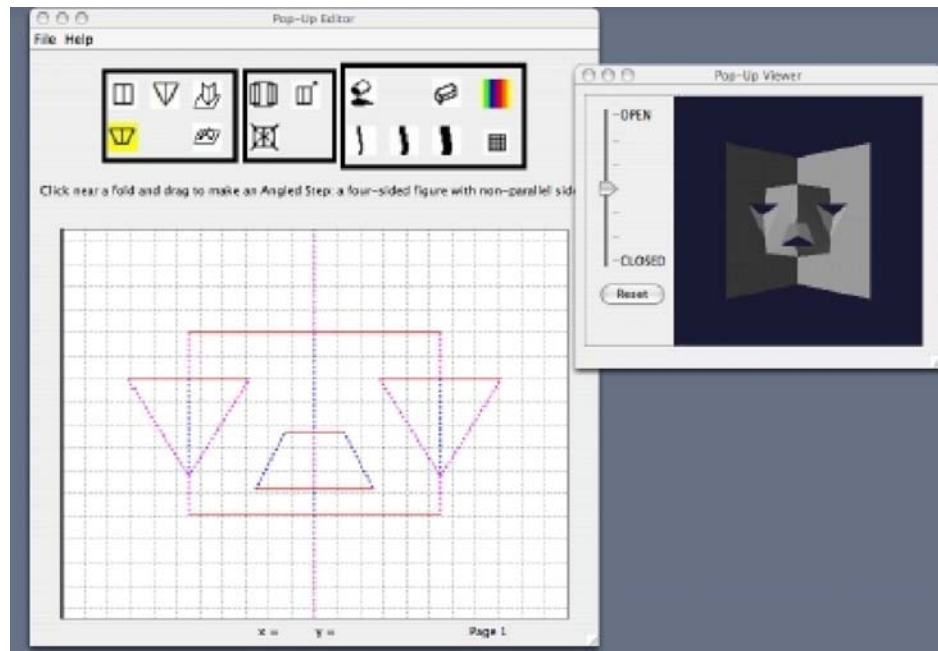


Figure C.2: PopUp Workshop with design in progress.

The applied elements we support are:



Tent: This element is somewhat like the Step, but it is a separate piece. It really does look like a tent, with the two opposite sides glued to the base.



V-fold: This element also has two tabs attached to the base, but they are along the same side of the piece. This makes it really stick up in the air. By changing the angles and lengths of sides, you can make it slant toward or away from you when the page is opened. This takes some experimenting.

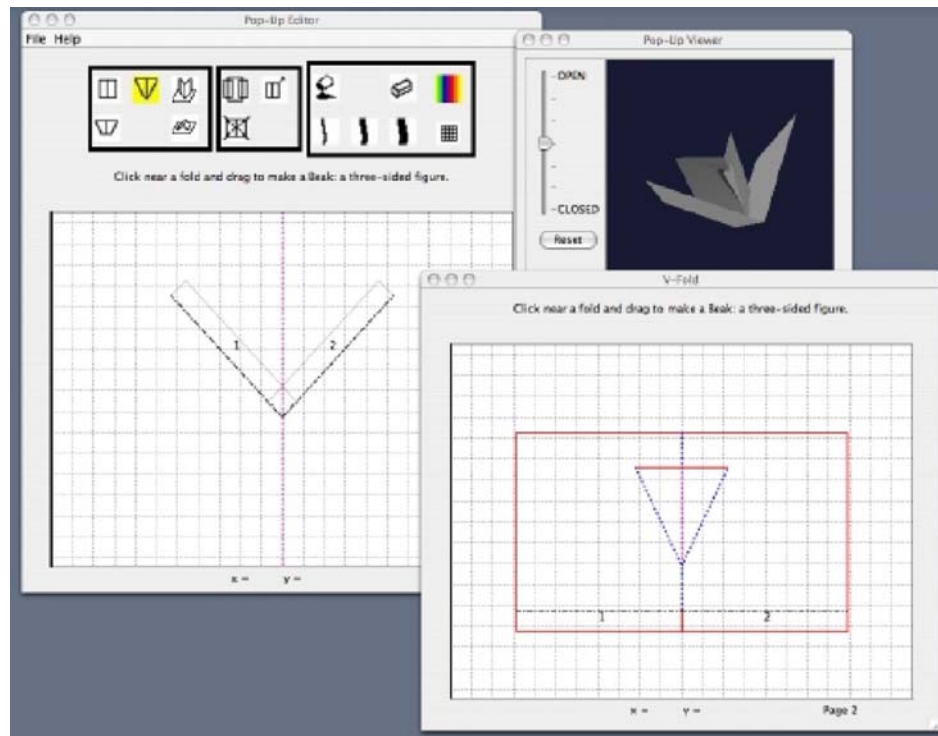


Figure C.3: Popup Workshop with design in progress that includes multiple pages.

C.6 Changing Elements

Once you have some elements added to your pop-up, you can change them. Select the change button, which looks like this:



You will notice that small green squares appear on points of your elements. Click with your mouse on the point you want to change, and drag the point. Notice that you may not be able to drag the point in some directions. The program only allows you to change elements in ways that will still allow them to fold correctly when you open and close the page. (Can you figure out what the rules are?)

If you have additional elements on a fold you are changing, they will move to remain on

the fold.

C.7 Deleting Elements

You can delete elements, too. Select the delete button in the center section of buttons, which looks like this:

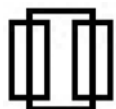


You will notice that small red squares appear on points of your elements. Click with your mouse on any point of the element you want to delete. It will disappear.

If you delete an element that has more elements on top of its folds, the ones on top will be deleted as well. If you delete an element that has additional pages for the attached pieces, the windows with those pages will go away.

C.8 Replicating Elements

Sometimes you want to have the same (or similar) elements on opposite sides of another element. You can make this easy by replicating. Select the replicate button, which looks like this:



You will notice that small blue squares appear on points of your elements. Click with your mouse on any point of the element you want to replicate. If it is on the outside fold of another element, a copy will be placed on the other outside fold. (Elements placed on folds of the replicated element will not be replicated.)

C.9 Decorating Elements

There are several decorating tools available. Bring up a color palette to select a color to use with the color button, which looks like this:



After you select a color, the color of the borders of the button areas will change to remind you of the color you are using.

You can fill an area of an element with color by using the fill button, which looks like this:



After selecting the fill button, click in each area you wish to fill with the current color. If you wish to erase fill color, select white in the color palette, and use another fill to erase the previous color.

You can draw lines with three pen tools (small, medium and large). The buttons look like this:



Use your mouse to draw after you pick the pen thickness you want.

To erase the drawing you have done, use the erase button, which looks like this:



You will notice that small red squares appear on the ends of the lines you have drawn. Click with your mouse on any red square to remove that line.

C.10 Saving and Printing Your Popup

When you have a pop-up that you want to print, use File → Print to bring up the system print dialog. (Do you have the grid turned off?)

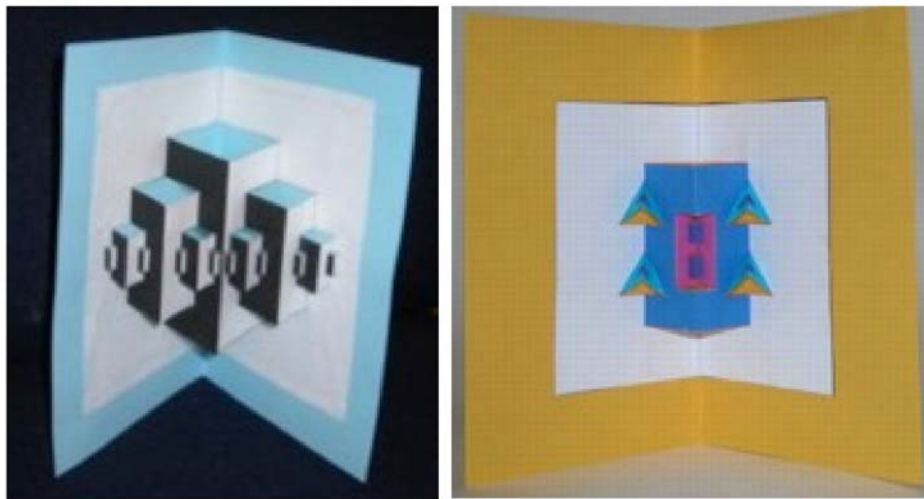


Figure C.4: Two pop-ups made with Popup Workshop

If you wish to have a .jpg file to decorate further in a program such as Adobe Illustrator or PhotoShop, or to resize in a graphics program for different sizes of paper, you can use the File → Export Image menu item. This will bring up a system dialog box so that you can name your file(s), and tell the system where to put it. (If you have multiple Editor windows, you will have multiple files to name and save.) You will want to put .jpg on the end of the file(s).

You can save your work in a form that will let you work on it later. Use File → Save or File → Save As to bring up a system dialog to give a filename and place to put it. You can open a saved pop-up with the File → Open menu item. Popup Workshop files are saved in a format called XML, which is a text format, and may be emailed, for example. Because of the need to save multiple page data, saves from earlier versions of Popup Workshop may not open in Version 2.0.

If you decide that you want to start over from scratch, choose the File → New menu item. You will be given a chance to save your work if you have not done so. You can also use File → Revert to Last Saved to get rid of any changes since you last used the Save option.

C.11 Finishing Your Popup

Print out your pop-up. Cut on the cut lines (the red solid ones) and fold on the dotted lines. It helps to go over the dotted lines with a ballpoint pen that is out of ink to make them fold more easily. You may want to make a few very simple designs to practice first. Avoid very small elements when you are first starting. You may want to use a craft knife to make the cuts instead of scissors.

For applied elements, cut out the piece and fold it. Match up the seams and numbers in order to put the piece in the place where it should go. Glue it with craft glue or school glue. Be sure and let it dry before you close the pop-up, or it might stick.

If you have printed your pop-up on standard printer paper, you may want to glue it to an outer card of construction paper, card stock, or cardboard. Figure C.4 shows a pop-up made with Popup Workshop, printed on standard paper on a black and white printer, and mounted on construction paper, and a similar pop-up, printed on a color printer. Card stock usually works better than standard printer paper if you use elements that are glued on.

Try decorating your pop-ups with foil, different colored papers, stickers, your own pictures, or pictures cut from magazines or newspapers. You can change the shape of almost any cut. You can add pictures on the sides of elements that stick up beyond the centerfold of the element and they will still fold. In fact, in many cases, you can cut away part of an element, or add to it, and still have a pop-up that will open and close properly. You may add other elements or pieces made by hand, like flaps to lift. Experiment!

Here are some more pop-ups made with PopupWorkshop. (Figure C.5.)

Add a story to a set of pop-ups and make a book by stapling or gluing the pages together. You can also put on other pop-up elements that you make yourself. Look at the For Further



Figure C.5: Other pop-ups made with Popup Workshop

Reading section for some places to learn more about making pop-ups and books, and how to make different pop-up elements.

C.12 Trouble Reporting

Please send any bugs you find, or things you think we should add to Popup Workshop, to Sue Hendrix, hendrixs@cs.colorado.edu. Let us know what you think!

C.13 For Further Reading

If you enjoy Popup Workshop, you will probably want to know more about making pop-ups. We recommend one website in particular, the home page of Robert Sabuda, who is a famous paper engineer. His site is at:

- <http://robertsabuda.com/>

Try the Explore Pop-ups section for some simple pop-ups you can make. If you want to know more about making your own books, check out this website:

- <http://library.thinkquest.org/J001156/makingbooks/makeown.htm>

Or you can get this book:

- Gwen Diehn, *Making Books that Fly, Fold, Wrap, Hide, Pop Up, Twist, and Turn*, Lark Books, New York, 1998.

There are some good books for young people on pop-up making. Try these:

- Duncan Birmingham, *Pop Up! : A Manual of Paper Mechanisms*, Tarquin Pubns, Norfolk, 2000.
- Barbara Valenta, *Pop-O-Mania: How to Create Your Own Pop-Ups*, Hamlyn, London, 1997.

If you are a teacher, and want to incorporate pop-ups in your classes, try these resources:

- Paul Johnson, *Pop-up Paper Engineering: Cross-Curricular Activities in Design Technology, English, and Art*
- Simmt, Elaine and Brent Davis. "Fractal Cards: A Space for Exploration in Geometry and Discrete Mathematics." *Mathematics Teacher*, 91 (February 1998):102-108.
- Diego Uribe, *Fractal Cuts*, Tarquin Publications, 1999.

And for more complex projects:

- David A. Carter, James Diaz, *The Elements of Pop-Up : A Pop-Up Book for Aspiring Paper Engineers*, Little Simon, New York, 1999.
- Masahiro Chatani, *Pop-up Greeting Cards*, Ondori/Japan Publications, Tokyo, 1986.
- Paul Jackson, Paul Forrester, *The Pop-Up Book : Step-By-Step Instructions for Creating over 100 Original Paper Projects*, Henry Holt and Co., New York, 1996.

C.14 Known Bugs in This Version

- (1) Saved popups from earlier versions of Popup Workshop may not open in version 2.0.
- (2) Vfold tab occasionally goes the wrong way.
- (3) The Viewer image looks bad sometimes. This can happen with a tent or v-fold—they will be on the wrong side of the sheet. Sometimes doesn't open up a structure properly that is on a tent or vfold.
- (4) The Windows version has not been tested

C.15 Changes in Version 2.0

- (1) Added 2 applied elements (V-folds and Tents). This allows multiple Editor windows and support for multiple pages.
- (2) Viewer changed to Java3D.
- (3) Added rotate ability to viewer, and a reset button.
- (4) When areas are cut out of the paper, the viewer now shows them as cut out.
- (5) Changed names of the elements to be more child-friendly (Step instead of Parallel Double Slit, for example).
- (6) Added help area on editor to suggest what action can be taken with currently selected button.
- (7) Added Java generics to code. This makes it more robust going forward, but requires Java 1.5 or greater.

C.16 Acknowledgements

The work described in this documentation has been supported in part by National Science Foundation grant REC0125363, and by a gift from Mitsubishi Electric Research Laboratories (MERL) in Cambridge, Massachusetts.

Appendix D

User Testing Materials, Books, and Tools

This appendix lists the tools, materials and books available to children taking part in the user tests.

D.1 Tools

Tools included mats, scissors, craft knives and creasing tools for cutting and creasing the paper, and art supplies for decoration.

- self-healing mats, small and large
- children's scissors
- extra-sharp point scissors
- craft knife and blade assortment
- empty pen for creasing paper
- embossing tool for creasing paper
- craft glue
- metal straightedge
- protractor

- compass
- scotch tape
- pens and pencils
- colored markers—small point and large
- crayolas
- colored pencils
- white-out
- plastic templates with circles and alphabet

D.2 Materials

Materials included paper of various sorts. The most commonly used paper was card stock, as this makes better working pop-ups than thinner printer paper. Some craft materials for decoration were provided as well.

- printer paper, 24#
- white card stock, 110#
- colored card stock, 110#
- scrapbooking paper in mixed colors and designs
- brightly colored feathers
- mixed sequins
- googly eyes
- assorted faceted glass gems

- yarn: yellow, red and blue
- string
- large pipe cleaners

D.3 Instruction Books

Books for children to find ideas on pop-up construction were included.

- *The Elements of Pop-Up: A Pop-Up Book for Aspiring Paper Engineers*, David A. Carter and James Diaz, ISBN: 0-689822-24-3
- *Making Books that Fly, Fold, Wrap, Hide, Pop Up, Twist, and Turn*, Gwen Diehn, ISBN: 1-579900-23-2
- *Paper Engineering for Pop-Up Books and Cards*, Mark Hiner, ISBN: 0-906212-49-9
- *Pop Up!: A Manual of Paper Mechanisms*, Duncan Birmingham, ISBN: 1-899618-09-0
- *Pop-O-Mania : How to Create Your Own Pop-Ups*, Barbara Valenta, ISBN: 0-803719-47-7

D.4 Pop-up Books

Pop-up books allowed children to both get ideas about things they might do, and develop appreciation for the work of others. An attempt was made to provide a wide range of pop-up books, from those for preschool children to more complex books.

- *Alice in Wonderland*, Lewis Carroll, Otto Seibold (illustrator), James R. Diaz (paper engineer), ISBN: 0-439411-84-X
- *Alice's Adventures in Wonderland*, Lewis Carroll, Robert Sabuda (illustrator and paper engineer), ISBN: 0-689847-43-2

- *America the Beautiful*, Robert Sabuda (illustrator and paper engineer), ISBN: 0-689847-44-0
- *Animal Poppoites*, Matthew Reinhart (illustrator and paper engineer), ISBN: 0-689844-23-9
- *Dinosaur Babies*, Jennifer A. Kirkpatrick, National Geographic Society, James R. Diaz (paper engineer), ISBN: 0-870448-41-6
- *Encyclopedia Prehistorica Dinosaurs: The Definitive Pop-Up*, Robert Sabuda and Matthew Reinhart (illustrators and paper engineers), ISBN: 0-673622-28-2
- *Flapdoodle Dinosaurs*, David A. Carter (illustrator and paper engineer), ISBN: 0-689846-43-6
- *Mommy*, Maurice Sendak, Arthur Yorinks, Matthew Reinhart (paper engineer), ISBN: 0-439880-50-5
- *One Red Dot*, David A. Carter (paper engineer), ISBN: 0-689877-69-2
- *Pizza!*, Jan Peřńkowski (paper engineer), ISBN: 0-744581-92-3
- *Pop-up Haunted House*, Christine Deverell, Richard Deverell and Chris King (illustrators), ISBN: 0-185081-48-3
- *Snappy Little Bugs*, Dug Steer and Claire Neilson, Derek Matthews (illustrator), ISBN: 1-571458-99-9
- *Snappy Little Dinosaurs*, Dugald Steer, Derek Matthews (illustrator), ISBN: 1-571459-02-2
- *Snappy Little Fairy Tales*, Beth Harwood, Derek Matthews (illustrator), ISBN: 1-592233-17-1

- *Snappy little Zoo*, Dugald Steer, Derek Matthews (illustrator), ISBN: 1-571459-21-9
- *The Very Bouncy Bear*, Jack Tickle, ISBN: 0-760772-93-2
- *The Very Busy Bee*, Jack Tickle, ISBN: 1-845061-63-2
- *The Very Dizzy Dinosaur*, Jack Tickle, ISBN: 1-845062-04-3
- *The Very Friendly Firefly*, Jack Tickle, ISBN: 1-845063-01-5
- *The Very Happy Hen*, Jack Tickle, ISBN: 1-854309-98-6
- *The Very Lazy Lion*, Jack Tickle, ISBN: 1-854309-17-X
- *Wizard of Oz*, L. Frank Baum, Robert Sabuda (illustrator and paper engineer), ISBN: 0-689817-51-7

Appendix E

User Testing Questionnaires

This appendix lists the questions asked of users in the first and last sessions, and in the email follow-up.

E.1 First Session Questions

An informal conversation held in the first session touched on the following subjects for each user:

- Age and grade in school
- Favorite and least favorite school subjects
- Activities participated in outside of school
- Computer skill and usage
- Interest and participation in crafts, especially paper crafts
- Previous experience in pop-up making, if any
- Pop-up books owned and read and their feelings about them
- Discussion of what they think a pop-up is

E.2 Final Session Questions

An informal conversation held in the final session touched on the following for each user:

- What each user liked and disliked about the program
- Suggested changes to the program
- Going over the program's interface and asking about the action of buttons. This occasionally took the form of asking them to instruct the researcher in the use of the software.
- Easiest and hardest part of making pop-ups
- If pop-ups were made without the software, asking them to compare the two methods
- Discussing each of the pop-ups they had made

E.3 Email Follow-up Questions

The following questions were sent via email to all of the users several months after testing was complete:

- What has happened to the pop-ups you made? For instance, did you give any away, put them in a book, lose them, display them, put them up in your room, throw them away?
- Which one is the one you like the best? How do you feel about it and why?
- Which one is the one you like the least? How do you feel about it and why?
- Have you made any more pop-ups since? If so, describe the neatest one.
- Have you read any pop-up books since? If so, which ones? Have you gotten any new ones?

- Have you downloaded and used the software since the sessions we had? If so, could you describe what you've done with it?
- These are questions I've asked before, but if you have any new or changed thoughts, I'd love to hear them. Since you've had more time to think about it, you might have some new ideas.
 - * What did you like about the program?
 - * What didn't you like about the program?
 - * What things do you think should be changed in the program?
 - * What was the easiest part of making pop-ups?
 - * What was the hardest part?
- Is there anything else you would like to say?

Appendix F

Pop-ups Created by User Test Subjects

Photos of all the pop-ups made in user testing are shown in this appendix, as well as a short summary of each user test session. These are chronologically by child and show the development of their pop-up making abilities. See Chapter 6 for descriptions of the methods and analysis of the results, as well as Appendix D for a complete list of books, tools and materials available to the children.

F.1 Daisy

Daisy was 12 when she started user testing, and had been in the 6th grade the previous year. She liked middle school and was fond of math and language arts (although she indicated she liked reading but not writing.) She did crafts, and was currently working on making a dollhouse—making the furniture out of wood. Daisy said she liked to draw, especially imaginary creatures. She was in summer camp, and doing a lot of outdoor activities. She used the computer occasionally at home for games.

During Daisy's first session, we talked about her and about pop-ups, and she looked at the three sample books and talked about them. She then started experimenting with the Popup Workshop. She used a lot of elements at random, and did not print a pop-up, but she got to see the action of all the controls. (Session 1 date: 7/03/06, 35 minutes)

In her second session, Daisy used non-applied structures to make an "alien" design. She used the craft knife to cut it out. It had a lot of small structures, and took some time to fold.

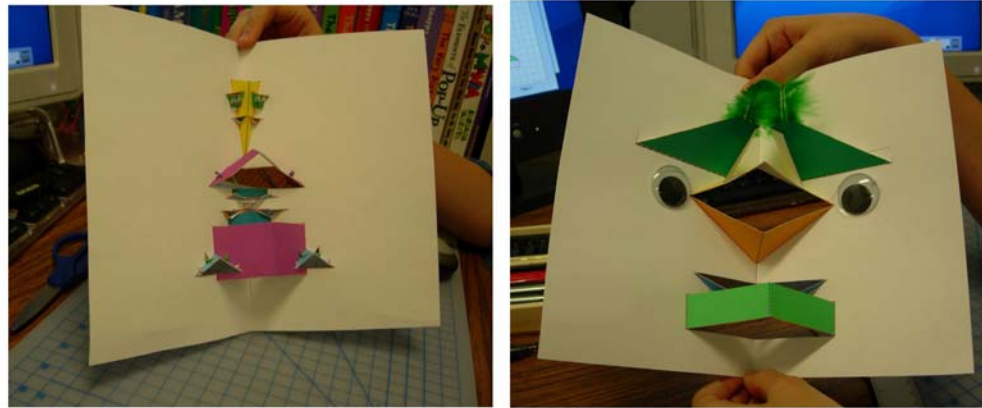


Figure F.1: Daisy session 2: Two abstract figures, an alien and a bird.

She added googly eyes to it. She then made a bird. This also included two v-folds, and she made larger structures that were easier to cut and fold. This was decorated with googly eyes and feathers. She then spent some time looking at several pop-up books, talking about how they were made. The two pop-ups created in this session are shown in Figure F.1. (Session 2 date: 7/11/06, 116 minutes)



Figure F.2: Daisy session 3: Two abstract figures.

In session 3, Daisy built 2 pop-ups, and a third which was not decorated until session 7. All three of these pop-ups arose from discussions of the features of the program, in particular the replication button, the difference between tents and steps, and the difference between putting

elements on the center fold of another element, and putting them on the outer folds. She also spent some time in looking at pop-up books after finishing her session at the computer. The researcher suggested that she might want to do an illustration of a story, and to think about that for the next session. The two completed pop-ups from this session are shown in Figure F.2 (although the first pop-up is also shown in Figure F.6 after yarn was added.) Daisy also completed cutting, folding, and gluing on the first pop-up shown in Figure F.6, but did not add decoration until session 7. (Session 3 date: 7/18/06, 113 minutes)

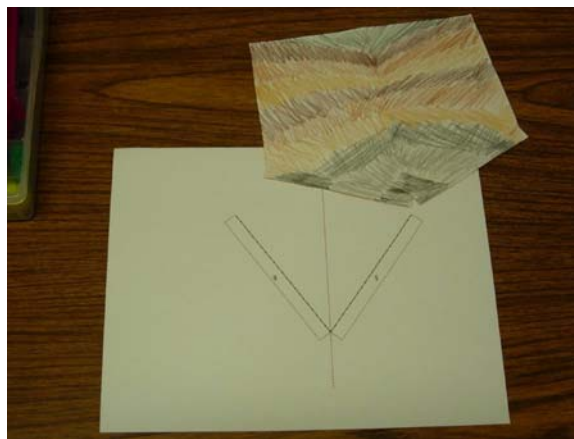


Figure F.3: Daisy session 4: Beginning the owl.

Since the suggestion had been made during the last session about illustrating a story, in session 4 Daisy came with a book that she was reading, *The Capture* [65]. The characters in the book are owls, and Daisy wanted to make an owl pop-up. She looked at several pop-up books with birds, and liked the toucan in *The Very Lazy Lion*. This became her model. This pop-up uses a v-fold for the bird's body. Daisy made a v-fold on the computer and experimented with getting the v-fold to slant the way she wanted it. She printed it, and discarded the base, choosing to use a larger base made of two sheets of scrapbooking paper. (Because she arranged the v-fold on the new base later to suit, the v-fold slanted more in the final owl.) She also drew and cut out a head, and colored the body. The body and original base are shown in Figure F.3. (Session 4 date: 8/02/06, 52 minutes)

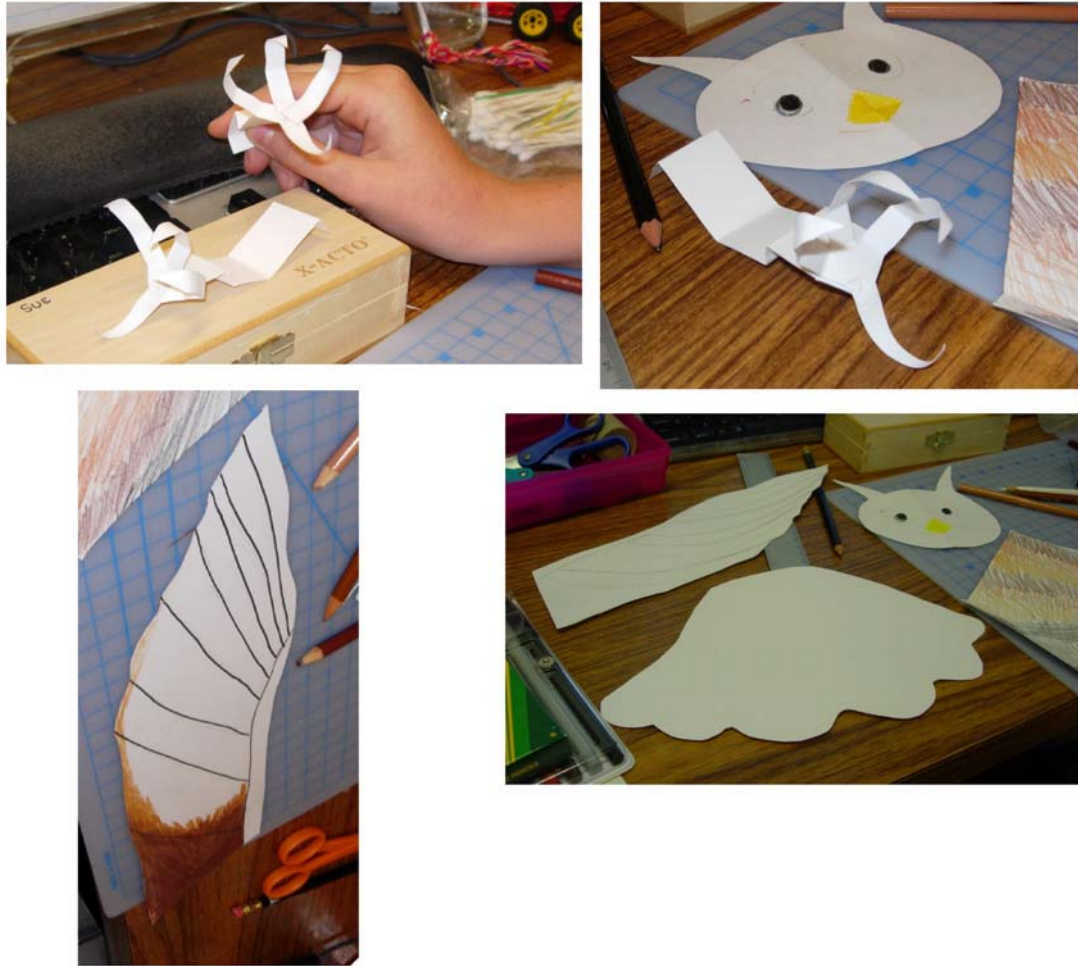


Figure F.4: Daisy session 5: Details of the owl's talons, wing being colored, and the head, wing and tail sections.

In session 5, Daisy added ears and a beak to the owl's head, and cut out pieces for the wings and tail. Most of the second half of the session was spent in making the legs and talons for the owl. These are not foldable, the resulting owl is more a paper sculpture than a pop-up, although without the feet it will fold. During most of this session, Daisy used pictures of owls on the web to refine her design. By the end of the session, all of the parts of the owl were cut out. Various pieces of the owl are shown in Figure F.4. (Session 5 date: 8/24/06, 104 minutes)

Most of session 6 was spent in coloring the owl which Daisy then assembled. The feet were attached with double-sided tape so that they could be detached and the owl folded when it



Figure F.5: Daisy session 6: Putting the owl together, and the finished owl, both sitting on the table, and as a viewer would see it, from below, when it is on her wall.

was moved. (This was a concern both for taking it home, and because Daisy's family was moving overseas the next week.) The finished owl is quite large—the background is two sheets of 12" x 12" scrapbooking paper glued together, so it is very nearly 2 feet in width. Daisy said that she wanted to put it on the wall of her bedroom. An early test to see how things fit, and the finished owl are shown in Figure F.5. The owl is also shown as it would appear from below after it is hung on her wall. (Session 6 date: 9/28/06, 91 minutes)

In her final session, Daisy started by further decorating two pop-ups built in session 3. She had wanted to put yarn on them at that time, and the yarn was now available. We talked about the program and looked at the sample books. Finally, Daisy made a quick abstract design on the



Figure F.6: Daisy session 7: An abstract face which was built in session 3, but not decorated until session 7, adding yarn to one pop-up produced in session 3 (shown without yarn in Figure F.2), and an abstract design.

computer. She started to do the cuts and folds, but decided that something needed to be changed. She changed it, reprinted, and finished the pop-up. (This was an advantage with the program.) The two popups built in session 3 and further decorated in this session, and a final abstract design are shown in Figure F.6. (Session 7 date: 9/29/06, 52 minutes)

F.2 Ursula

Ursula was 6 years old when she started the testing. She had completed kindergarten and was going to start first grade that fall. She had done a lot of paper construction before she started; she liked to build scenes out of paper and had made a large paper unicorn. Ursula was very quiet and shy.

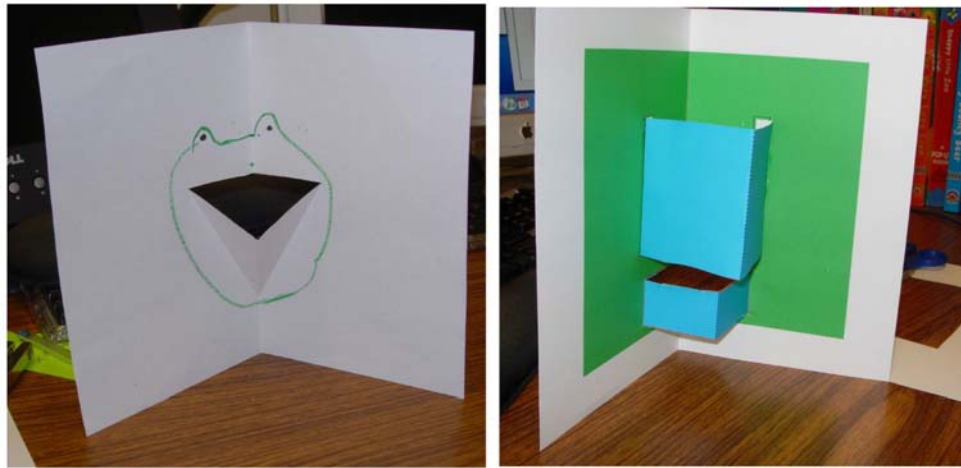


Figure F.7: Ursula session 1: A frog and blue boxes

In her first session, Ursula mentioned that a friend made a pop-up frog, but she did not know how to make one herself. Knowing that the beak can be, and often is, used to make a frog mouth, the researcher made the cut and folds for a beak by hand, showing her how it worked. Ursula drew the frog. She also mentioned that she wanted to make a book about a bunny. After the preliminary questions and looking at the sample pop-ups, the researcher started the program and asked if she would like to play around with it or get a demonstration. She wanted the demonstration, but most of all she wanted to make a pop-up. The researcher made several figures, changed them, erased them, showing her the program. At one point, 2 boxes (a tent and a step) were on the screen and Ursula wanted to print it. She colored the boxes using the program; it was printed and she and the researcher constructed the two boxes. She said that next time she wanted to make a bunny (although whether as part of the book or as a separate pop-up was not clear.) The

frog and boxes pop-ups are shown in Figure F.7. (Session 1 date: 7/7/06, 49 minutes)



Figure F.8: Ursula session 2: Bunny's picnic. Front and top views

In her second session, Ursula wanted to make a bunny, and had a story to go with the bunny book she wanted to make. (The bunny has a picnic with his friends; they go swimming, then go to the airport and fly to New Jersey, where they go to the beach.) She elected to play with the program some more to get ideas. She was shown change (on a v-fold), and delete. The researcher had her add some steps and beaks to the side of a step using replicate. She didn't want to color it, and had it printed. A v-fold was suggested for the bunny and she agreed. She drew a v-fold and she and the researcher changed it. She tried some drawn lines but didn't like them. She accidentally closed the program, and made the v-fold again. She made it bigger, printed it, then cut the bunny out of it. She had thought to make a separate body drawn on the paper, but she decided to draw the whole bunny on the v-fold. She colored it, put on googly eyes, then the researcher helped her glue it on to the base page, which she decorated to show the picnic blanket and a lake. She also started to do the cuts on the abstract boxes design before the session ended. The bunny is shown in Figure F.8. (Session 2 date: 7/14/06, 58 minutes)

Ursula's third session was a bit longer. She cut and folded the abstract white box popup printed in session 2 (the researcher helped with starting the smaller cuts and some of the folding.) She looked at *Snappy Little Fairy Tales*, and got an idea to make a bunny and his house. On the computer, she selected a v-fold for the house. After printing it, she made it into a castle instead, cutting crenellations on the top of the v-fold. She wanted to make a stand-up bunny, so the

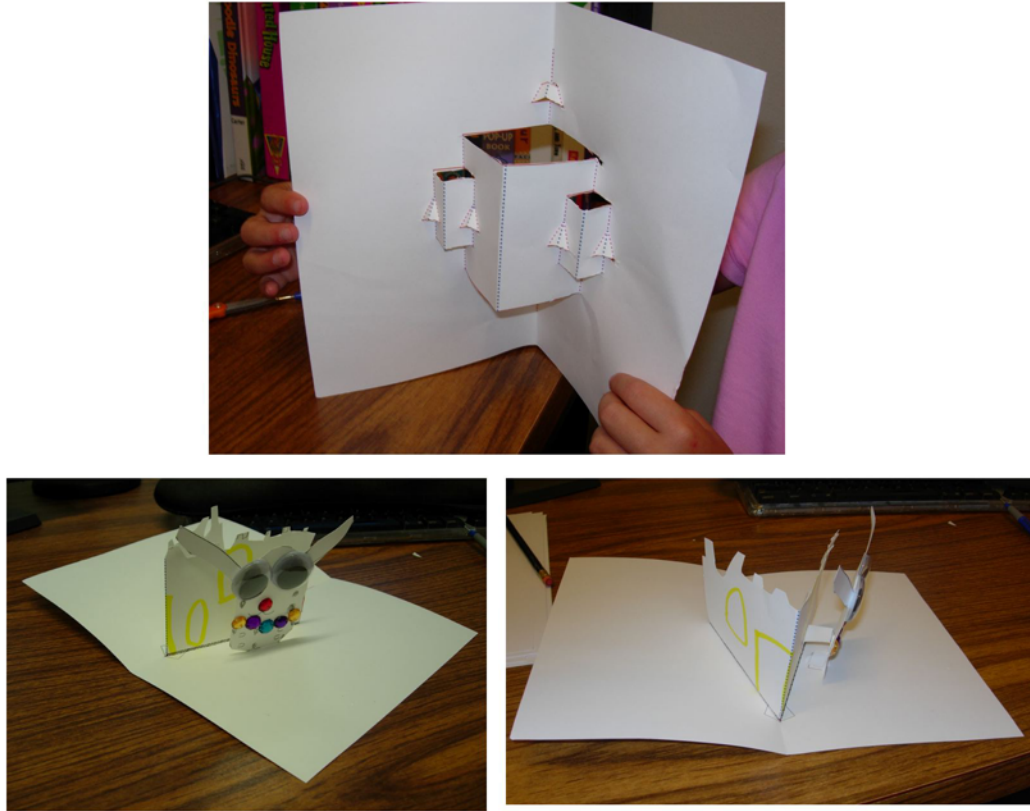


Figure F.9: Ursula session 3: Abstract design and the Bunny and his Castle (shown in two views to demonstrate the construction).

researcher suggested a tent to make it stand up (using the *Pop-o-mania* book as a guide.) A tent was put on the side of the v-fold, and the bunny attached to it. Since he lived in a castle, the bunny needed to be fancy, so Ursula selected some jewels and googly eyes to decorate him. The white abstract popup and the bunny and his castle are shown in Figure F.9. (Session 3 date: 7/21/06, 70 minutes)

Ursula decided in session 4 to make a turtle. She made a large v-fold on the computer. The turtle was drawn in on the v-fold—he was upside down, so she decided that he was a gymnast. She decorated him with a sequin for a nose, googly eyes, and feathers for him to fall into. Then the researcher asked her to design something using only the 3 simple (non-glued) structures and coloring with the computer (since she had been using mostly v-folds). The result is the house for

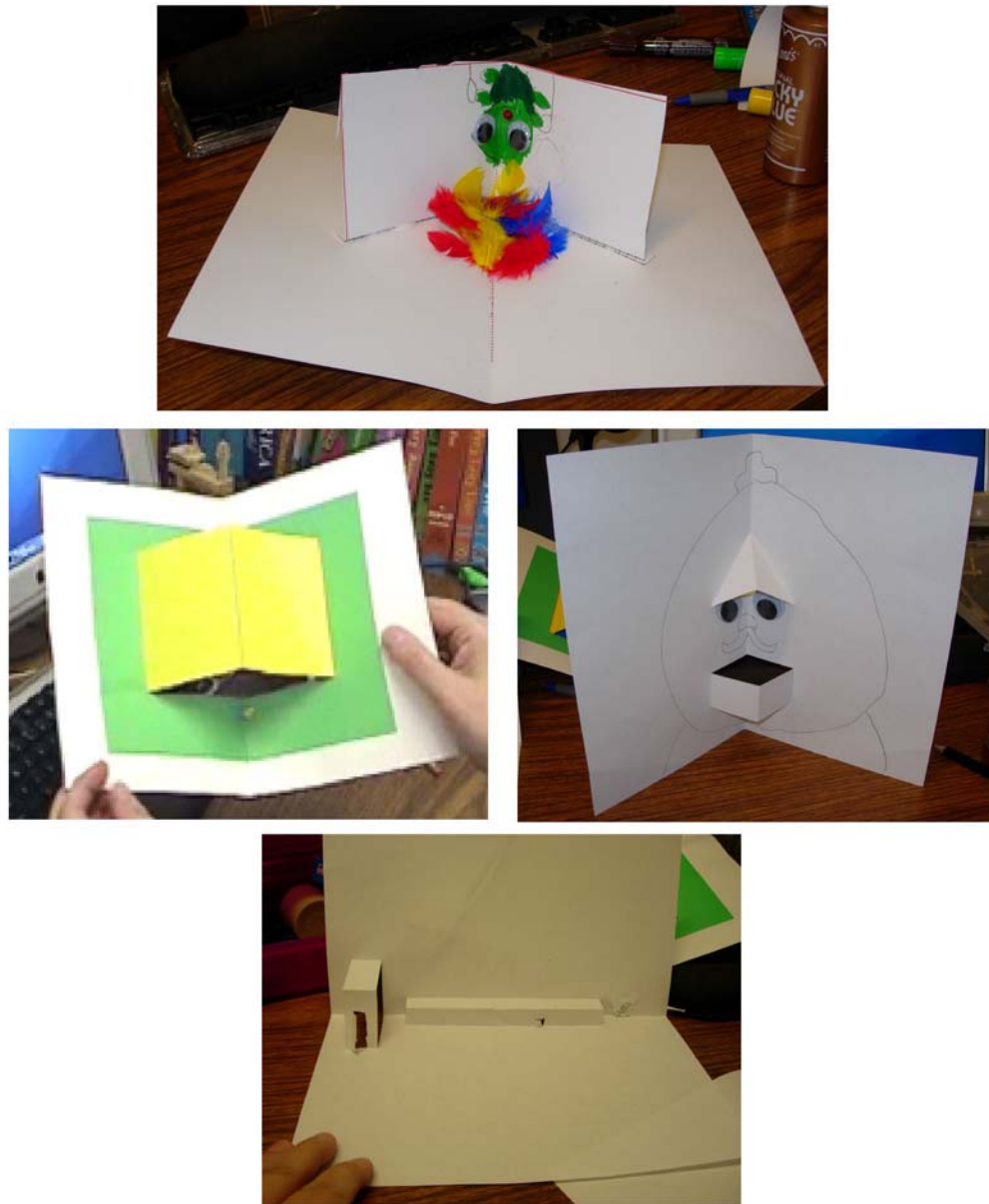


Figure F.10: Ursula session 4: Turtle Gymnast, houses for mommy and baby bunny, a white alien, and bunny and her houses.

mommy bunny and a small house for baby bunny. (The larger house is a step, and the smaller is an angled step, and she colored them yellow in the program.) The researcher showed her how to make the step elements by hand and she created the bunny and his house, and the white alien, which also used a beak. (These two pop-ups were made by hand, not with the program.) The four

pop-ups made in this session are shown in Figure F.10. (Session 4 date: 8/04/06, 47 minutes)

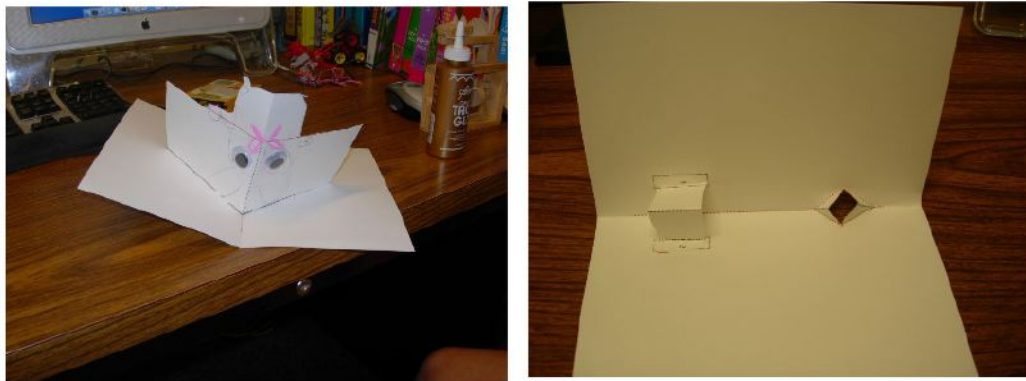


Figure F.11: Ursula session 5: Fat upside-down bunny gymnast, with a pink ribbon and the base for a pop-up completed in session 6, and shown in Figure F.12.

In session 5, Ursula wanted to make a bunny like her gymnast turtle (upside down), so she made a large v-fold. She asked to print the v-fold, and drew a bunny with a pink ribbon on it. She decided that since this is a fat bunny, that he can stick up above the original v-fold. She was much more confident in putting it together than she was with the turtle. We looked at some pop-up books and at *Elements of Pop-up* and *Pop-o-mania*. She liked the castle scene in *Pop-o-mania* and wanted to make something like it. After some discussion, she made two beaks together, and a tent to serve as the base for the scene. We printed it, and she cut, folded and glued it. This pop-up was completed in the next session. The gymnast bunny and the base for the castle are shown in Figure F.11. (Session 5 date: 8/18/06, 57 minutes)

Ursula was in her first week of first grade when she had session 6, and was a bit tired and off-task. She completed the castle scene, with bunny in his hole, and a castle with a swimming pool (with a turtle swimming in it), a balcony and a drawbridge. The rest of the session was spent in looking at pop-up books (*America the Beautiful*, *Pop-up Haunted House*, *The Wizard of Oz*, both versions of *Alice in Wonderland*, and *Animal Popposites*). The pop-up with the castle and the bunny in his hole are shown in Figure F.12. (Session 6 date: 8/25/06, 49 minutes)

Session 7 came after a more than 2-month hiatus. But Ursula remembered how to use the

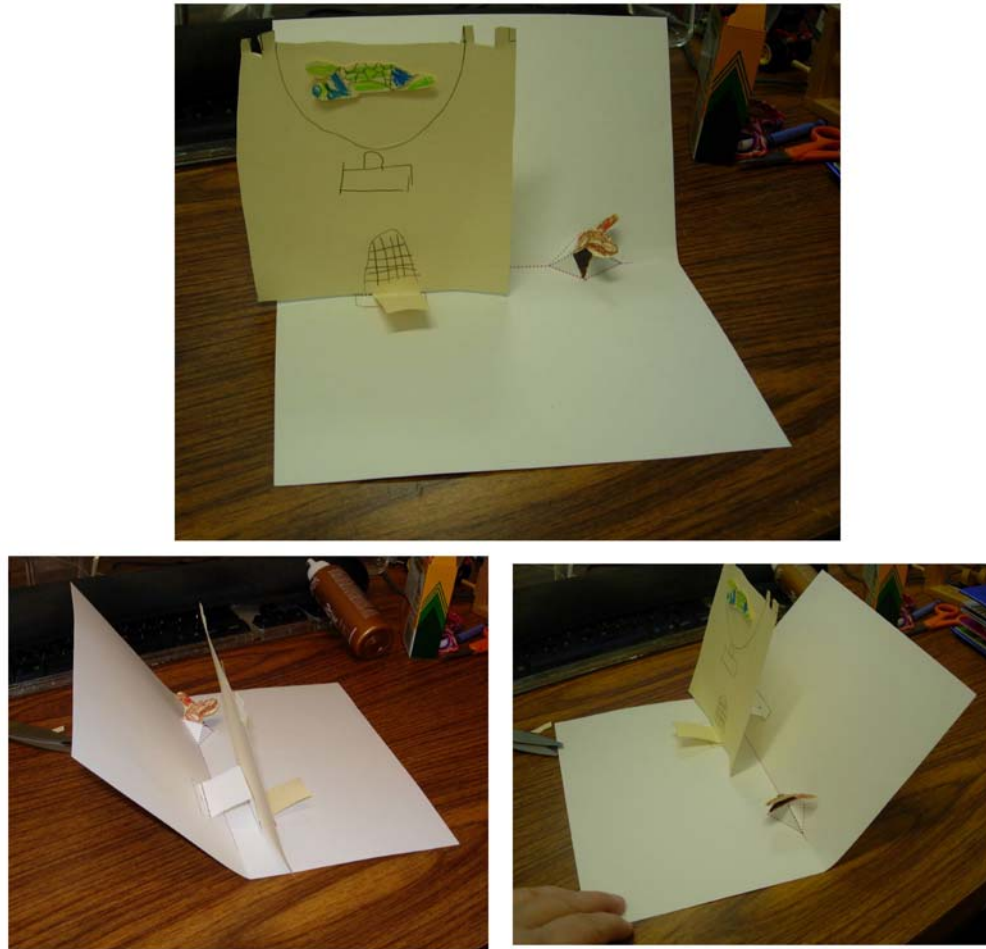


Figure F.12: Ursula session 6: The Castle of Bunny and Turtle. The pop-up uses the base constructed in session 5, and shown in Figure F.11

program and how to cut and fold a pop-up. She first made a quick abstract design which, because the beaks were small, was somewhat hard to fold. Also, the researcher used a knife to cut the very small triangle. She looked at *One Red Dot*. Then, because it was almost Veteran's Day and her class had been talking about the flag, she wanted to make an American Flag for her teacher. She picked the step for this herself. She tried to color it using the program, but since coloring is only lines or a fill of a whole segment this did not work well, and she took the color away and used markers after it was printed. We also looked at *Pop-o-mania* and *Encyclopedia Prehistorica Dinosaurs*. Her abstract design and the flag are shown in Figure F.13. (Session 7 date: 11/10/06,

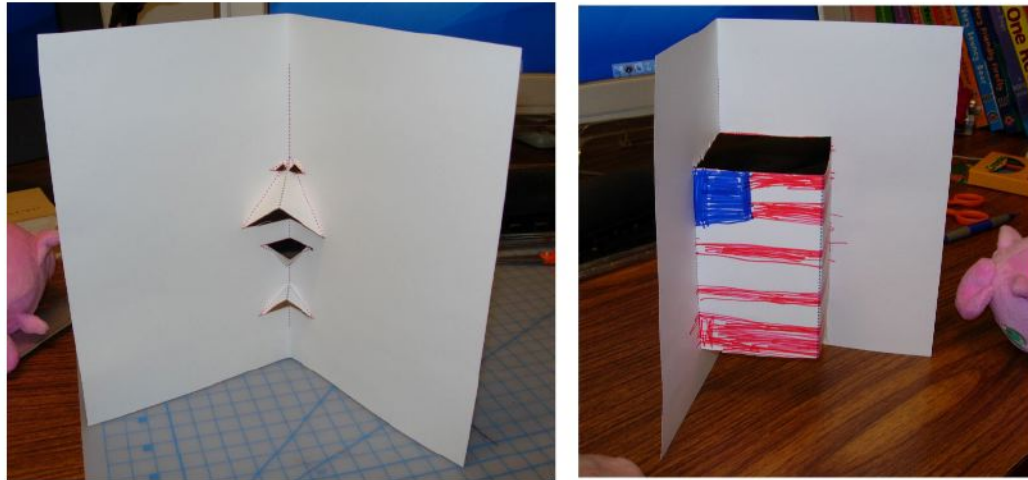


Figure F.13: Ursula session 7: An abstract design, and American Flag.

49 minutes)

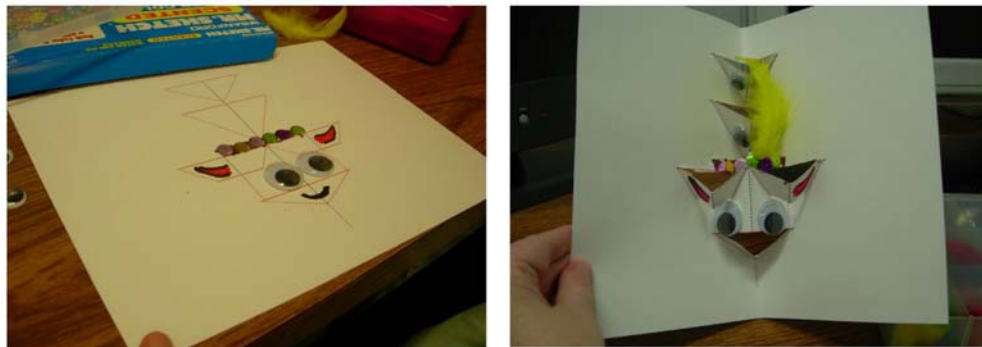


Figure F.14: Ursula session 8: Totem Pole.

Ursula made one pop-up in session 8, and we did the final testing. She played around on the computer. (The researcher suggested that she concentrate on non-applied elements.) Once again, she wanted to print very quickly without coloring. She decorated the result with googly eyes, sequins, markers and feathers. She did not name this pop-up during the session, but called it a totem pole when talking with her father. We did the tests, talked and looked at the sample books. Her totem pole, both in an early state and completed, is shown in Figure F.14. (Session 8 date: 11/17/06, 23 minutes)

F.3 Richard

Richard was 6 years old and about to start first grade when testing was begun. He liked to write and color in school. Richard had done some pop-up making on his own before starting sessions. (His sister is Daisy, who began before he did, and it is possible that seeing her pop-ups inspired him.) He enjoyed playing with paper and playing games on the computer. He was in a summer camp at the time. Since he and his sister were moving, he only participated in 5 sessions. Richard was very talkative—he tended to voice his thoughts, which made him a very good test subject.



Figure F.15: Richard session 1: Alien and His Ship, front and side views.

At Richard's first session he answered questions and looked at the sample pop-ups. Then, since he had been making his own pop-ups before, he was asked to make one in order to see what sort of pop-ups he had been doing. He cut out 3 steps, then attached an alien and his ship while he talked about his activities in and out of school. He looked at the 3 sample pop-up books. He added some decorations (sequins and feathers) to the alien and the ship, and colored the background. He described the alien as just landing as it started to rain. He started to play with the program but did not complete a pop-up before the session ended. The alien and ship pop-up made in this session is shown in Figure F.15. (Session 1 date: 8/02/06, 45 minutes)

In Richard's second session, he started by looking at the *Pop-o-mania* book. He had never

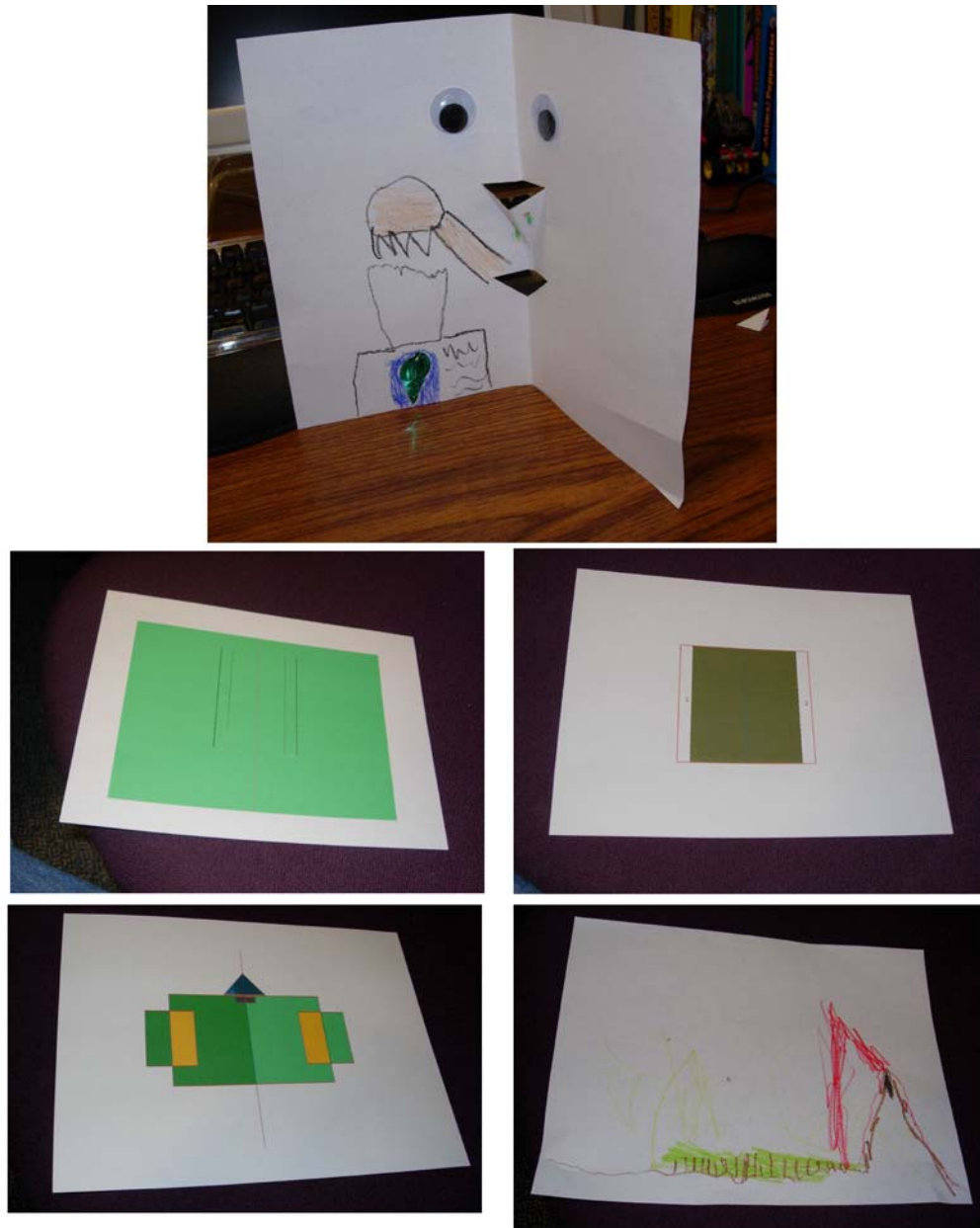


Figure F.16: Richard session 2: Man with a Cold, and incomplete pop-ups made in session 3. Two pieces which will become part of Volcano Camp, an abstract design, and a sketch of Volcano Camp. See Figure F.17 to see the finished pop-ups.

done a beak before, and looking at the book he took a piece of paper and tried to make his own. The first one he made on the paper was a cut-out triangle (the mouth for the person in the pop-up), but the second was a correctly made beak. These form the basis for the Man with a Cold

pop-up, which he decorated. We talked about beaks and steps, then moved to the computer, where he played with those and with angled steps. He made an abstract design in the process, colored it on the computer, and we printed it out, deciding to cut and fold it next time. (He wanted to make it as a present for his sister.) He then tried a tent on the computer. He had an idea about using it to make a volcano, and drew a sketch of a volcano and a forest. He colored the tent, and we printed it—to put together next time. The Man with a Cold, the two unfinished pop-ups, and the sketch of the volcano pop-up are shown in Figure F.16. (Session 2 date: 8/18/06, 51 minutes)

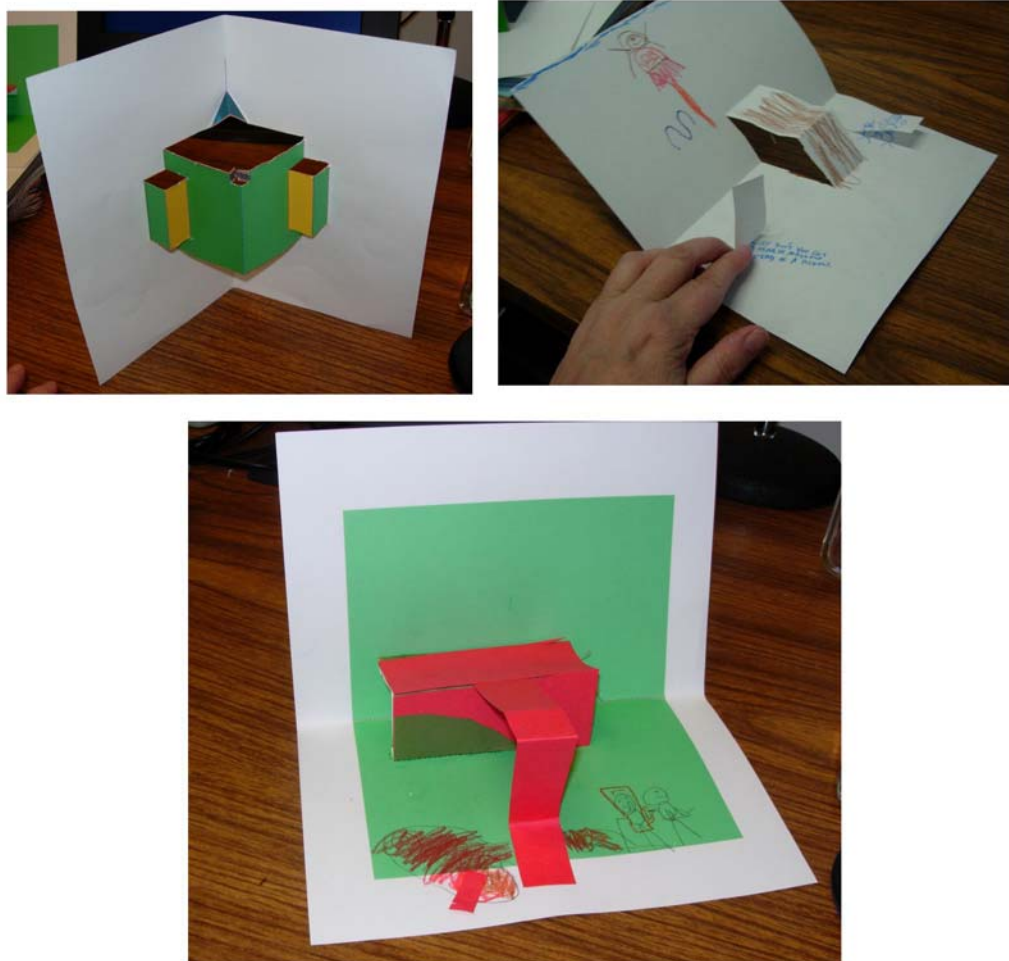


Figure F.17: Richard session 3: An abstract design, Alien and Ship with Flaps, and Volcano Camp. See Figure F.16 to see the original printed sheets and sketch of the Volcano Camp.

In session 3, Richard cut out, folded and attached the tent for the volcano camp pop-up. Then he cut and folded the abstract while it dried. He added red paper for the lava on the volcano (which he cut freehand—it bent where the natural folding occurred when it was closed.) He drew 2 campers, one of which is trying to alert the other one (who is oblivious) about the volcano, and their tent, which is surrounded by lava. When the volcano camp pop-up was complete, he took another piece of paper to make a final pop-up. He made a step by hand, and colored it and drew on the paper to make a mountain and an alien ship. He also added two flaps. He asked the researcher to write "Why don't you get a marshmallow instead of a pillow" under one flap, and drew a picture under the other. Figure F.17 shows the finished abstract, Volcano Camp, and Alien and his Ship pop-ups. (Session 3 date: 9/22/06, 51 minutes)

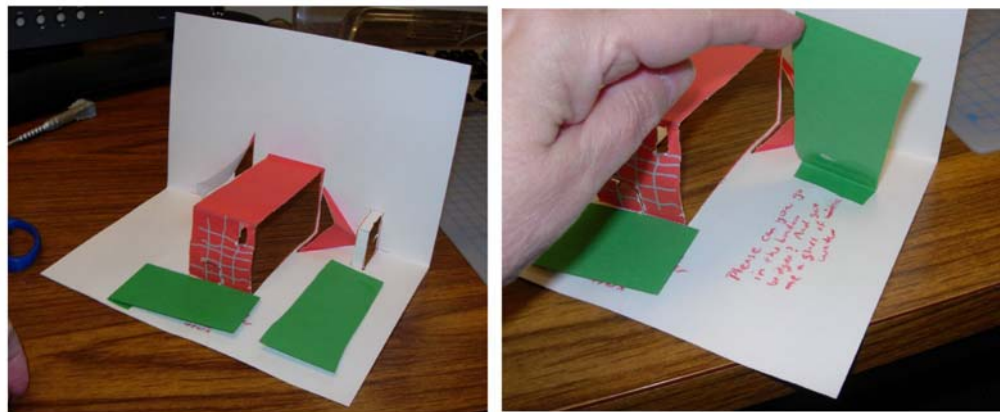


Figure F.18: Richard session 4: A city with flaps. 4 non-applied structures and two flaps.

In session 4 (10/5/06), Richard looked at several pop-up books, one of which was *America the Beautiful*, which has a lot of buildings in it. In playing with the computer, he wanted to make a city. He made several non-applied structures, one of which was a step. He used change to make it longer on one side, and used the line drawing tool to make a brick design on one face. This became his city. After it was cut and folded, he added flaps. He asked the researcher to write under the flaps for him. Figure F.18 shows the finished city pop-up. (Session 4 date: 10/05/06, 63 minutes)

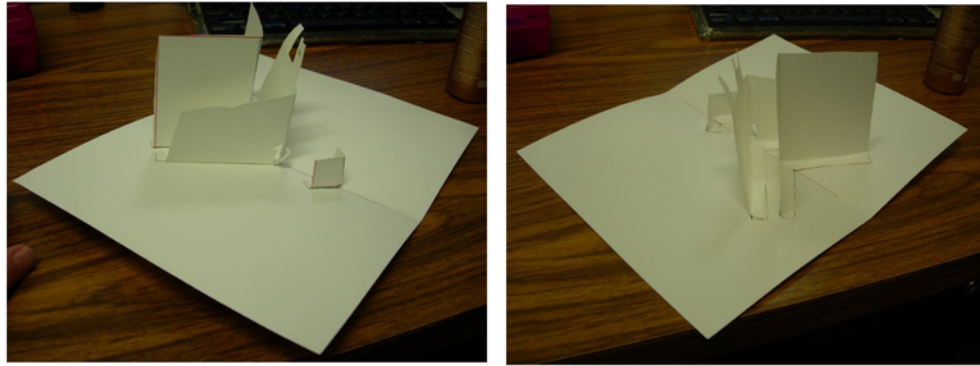


Figure F.19: Richard session 5: Base for castle, mountain (in the back), and soldiers.

Richard's session 5 was his last. He looked at the sample pop-up books. He had made no v-folds up to this time, and he really liked one pop-up in the *Raggedy Ann* book that was a castle, mountain and soldiers made from multiple v-folds. When he had finished looking at the books, we looked at the program, and he made a similar pop-up with 3 v-folds—to make a mountain, castle, and soldiers. He finished getting the v-folds on the base page, and took it home to decorate later. This unfinished pop-up is shown in Figure F.19. (Session 5 date: 10/06/06, 64 minutes)

F.4 Peggy

Peggy was 11 years old when she started testing and turned 12 during the test period. She was in 6th grade. She enjoyed pop-ups and had some at home. Her favorite activities were reading, shopping with her Mom, and playing games on the computer and drawing with SketchUp. She said that she enjoyed all her school subjects, although later in the testing she expressed some frustration with her math class. She had made a few simple pop-ups with her twin sister (Emily, see Section F.5) but only during the holidays. She did crafts with her sister sometimes, but said that Emily was the crafty one.

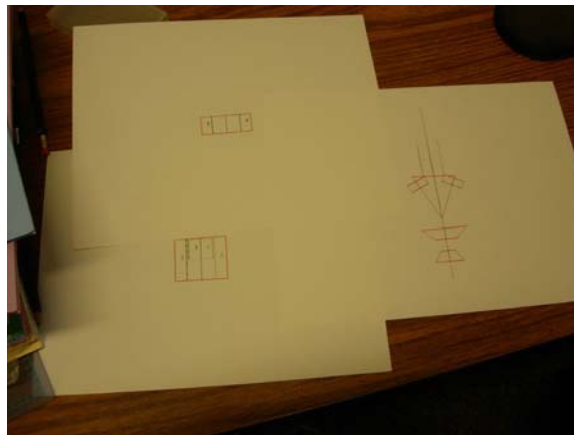


Figure F.20: Peggy session 1: The beginning of an abstract face.

After answering preliminary questions, and looking at the sample pop-up books, Peggy started looking at the program in her first session. We explored the tools. She put a tent over another tent, and this became part of her first pop-up, which she built upside down. (What was originally viewed as a beard became a hat in the finished pop-up.) She used the Viewer extensively, and at one point when the figure was rotated in the Viewer, started to view the pop-up in the Editor as being upside down. She colored the pattern at the start, but decided to print it as a white pop-up. We talked about materials and she looked at Sabuda's *Alice in Wonderland* before the session finished. The unfinished pop-up is shown in Figure F.20. (Session 1 date: 11/05/06, 49 minutes)

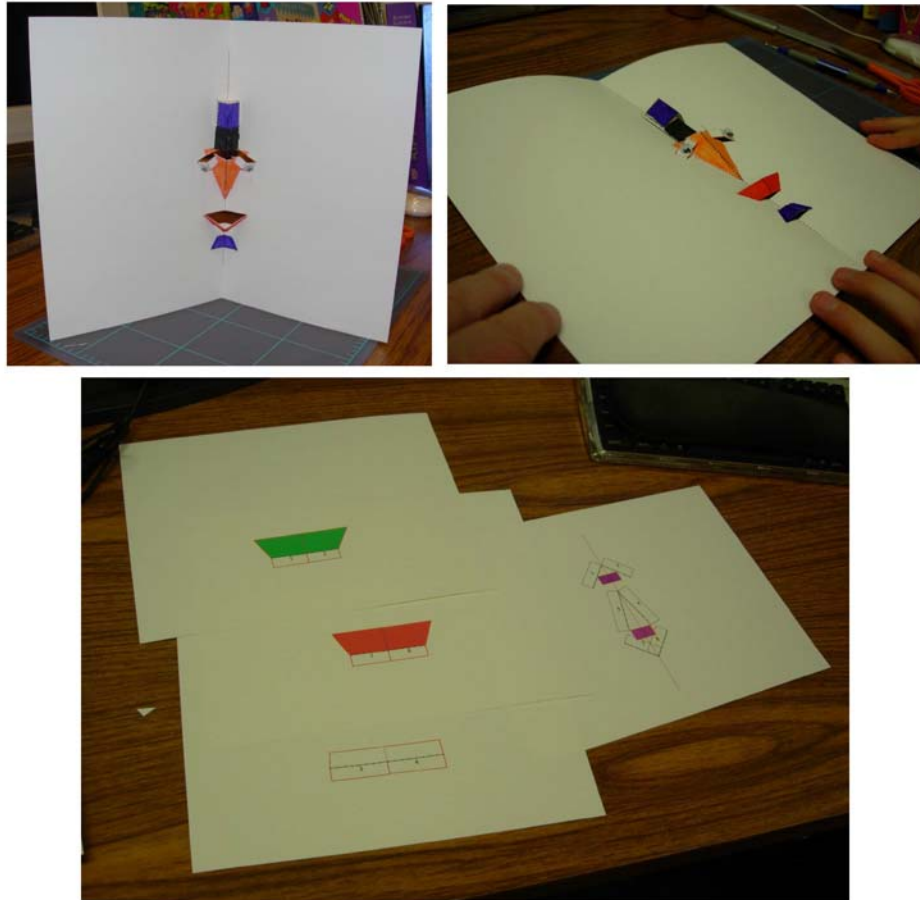


Figure F.21: Peggy session 2: The abstract face complete, two views. The beginning pieces of the table and chairs.

In session 2, Peggy cut, folded and glued the pop-up from session 1. This was decorated with googly eyes and markers. Back at the computer, Peggy made a v-fold, which was one element she had not yet tried. We took some time to look at the books on making pop-ups. She went back to the computer and played with the v-fold, seeing it as a chair. We discussed ways of making a seat, and she opted for a step. She then thought a table would be a good addition. We discussed table shapes for a while (there are several ways to make such a structure), and she decided on a v-fold with a flat piece (folded in the center) on top of it. She quickly made a chair for the other side of the table and colored the table and chairs. She had to leave, so the researcher printed and saved the design after she was gone. The finished pop-up started in session 1, and the unfinished

table and chairs are shown in Figure F.21. (Session 2 date: 11/12/06, 51 minutes)

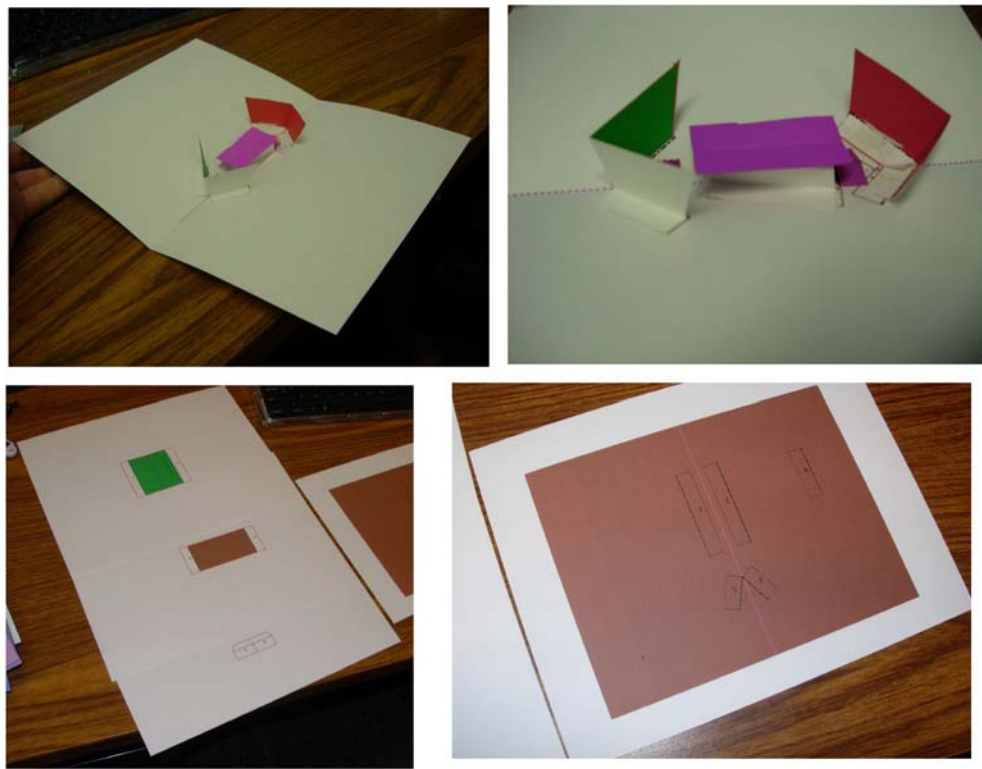


Figure F.22: Peggy session 3: The table and chairs, and pieces for the campground.

Peggy assembled the table and chairs in session 3, adding a table top cut from purple paper and using white-out to remove the numbers on the tabs that showed. She played with tents on the computer which suggested the idea of a campground, and she ended up putting a tent on the side of the tent to support other structures. She also wanted a campfire, and added a v-fold to do a campfire in the same way as she had done the table previously. The campground was printed and ready for assembly at the end of the session. The finished table and chairs started in session 1, and the unfinished campground are shown in Figure F.22. (Session 3 date: 11/19/06, 55 minutes)

In session 4, Peggy wanted two trees and a person for her campground, and drew and colored them, coloring on both sides. She spent some time on constructing the tent extension for the trees and person, the main problem being to brace the pieces so they would stand up when opened (and not flop.) The campfire is similar to the table, with a folded piece on top of the

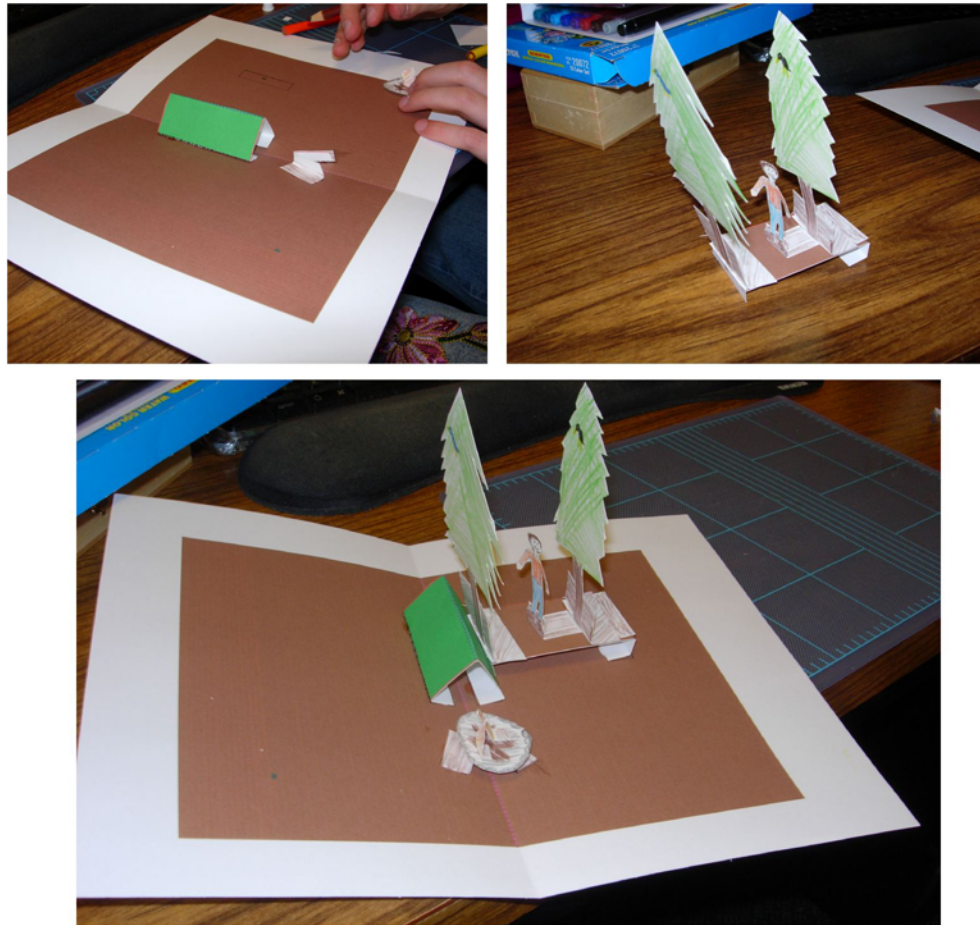


Figure F.23: Peggy session 4: The campground being constructed, and the finished campground.

v-fold, however she attached the flames separately. The campground, both under construction and completed, is shown in Figure F.23. (Session 4 date: 11/26/06, 61 minutes)

In starting her next pop-up in session 5, Peggy wanted to make something with a wheel. We looked at several wheels, and she settled on something like one example in the *Elements of Pop-up*, with changing colors under the base page. She thought of that as the sun. She wanted to make a cloud to cover the sun, and experimented with an asymmetric v-fold. Her model for this was a flapping arm in *Pizza!*. She added a tree trunk. By the end of the session, she had the pop-up printed, and the tree trunk cut and folded. (Session 5 date: 12/03/06, 54 minutes)

In session 6, Peggy cut and folded the v-fold for the cloud. At this point, the original

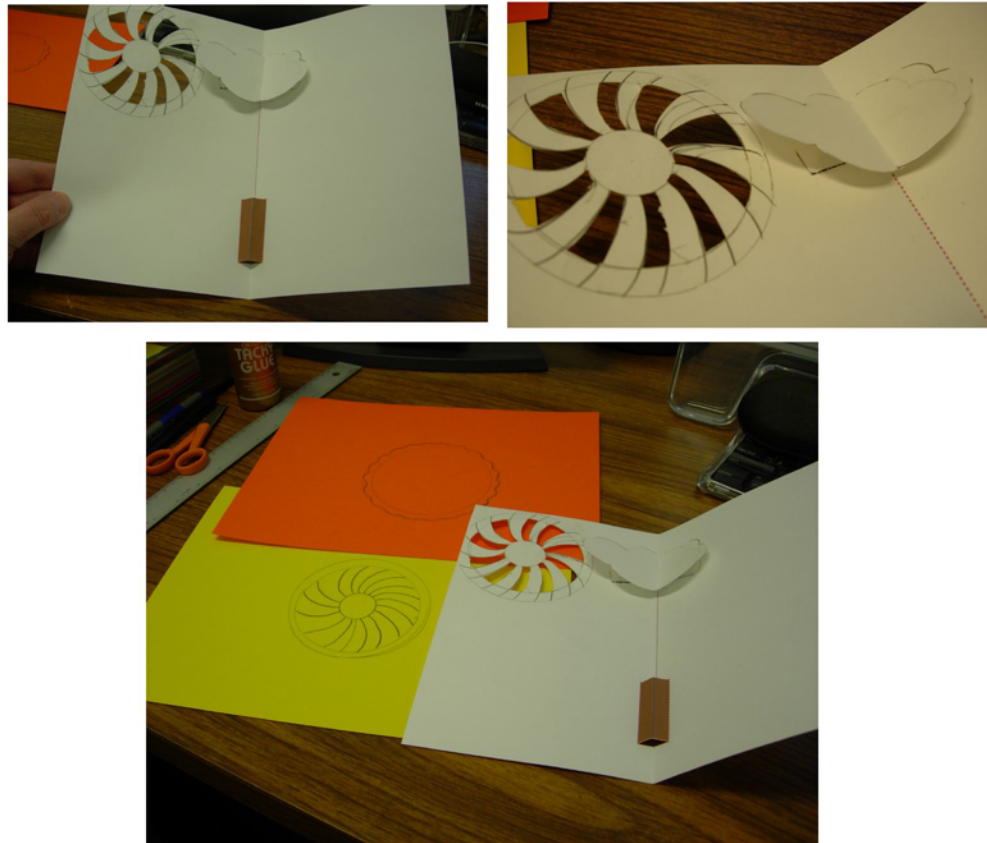


Figure F.24: Peggy session 6: The sun, tree and cloud, under construction.

idea for the flapping arm of the v-fold being the cloud was forgotten, and the cloud became a "table" like her previous campfire. As it turned out, the cloud did not cover the sun, but the table construction allowed it to "float" above the rest of the base page, which was a good effect. Peggy then turned to the sun. She made the parts of the sun wheel—yellow and orange—and cut out the holes on the base page so that the sun would show through. She was still uncertain how to attach the wheel. The tree, cloud and sun scene at the end of the session is shown in Figure F.24. Note the parts of the sun-wheel and the floating cloud effect. (Session 6 date: 1/07/07, 50 minutes)

At the start of session 7, the attachment of the wheel was resolved. The researcher had discovered how to construct a paper brad, and showed Peggy the books describing it. This construction was used in *Elements of Pop-up*, and Peggy had tried to see how it was done, but it was hard to understand in the finished state of the book. Birmingham's *Pop-up* and Hiner's *Paper*



Figure F.25: Peggy session 7: The sun, tree and cloud, finished. Close-ups of the sun, and the slider on the tree.

Engineering for Pop-Up Books and Cards provided clearer directions. The final design was taken from Birmingham. After the wheel was finished, decoration was added in the center of the sun (a glass jewel) and to the cloud, and the top of the tree was drawn. Peggy also added a slider mechanism to move part of the tree. (This does not show up well in the photos.) The finished tree, cloud and sun scene is shown in Figure F.25. (Session 7 date: 1/28/07, 62 minutes)

Peggy's last session was spent looking at the sample pop-up books and talking about the program. No pop-ups were made. (Session 8 date: 2/04/07, 35 minutes)

F.5 Emily

Emily was 11 when she started the user testing, and turned 12 during testing. (She was the fraternal twin of Peggy, above.) She liked Art and Language Arts in school, and at one point in the testing said that she would like to be a writer. She didn't like math. Emily did a lot of crafts; she was currently weaving, sewing stuffed animals, and taking oil painting lessons. She used the computer a lot at home (StarCraft, SketchUp) but not as much as her sister did. Peggy owned a couple of pop-ups and liked them because they were 3D. She had made some simple pop-ups, and was familiar with the beak, but not the step.



Figure F.26: Emily session 1: Printed face, not yet cut and folded.

In her first session, Emily answered questions and looked at the sample pop-up books. She then started with the program. She found color selection first, and used the viewer quickly. In trying most of the buttons, she built up Freddy Squarehead and printed it. The hair, mouth, eyes and ears were done with the line drawing tool. We discussed where it would be folded and cut, but this was not done until the next session. The uncut and unfolded Freddy Squarehead is shown in Figure F.26. (Session 1 date: 11/05/06, 41 minutes)

In her second session, Emily cut and folded Freddy, then wrote the text on him. (Note that she cut out around the hair on the top of the step that makes up his head.) She wanted to make a cat next. After some discussion and looking at pop-ups, she decided on a step (similar



Figure F.27: Emily session 2: Freddy Squarehead and Cinnamon the Cat.

to Freddy.) She wanted the nose to fold out, so she put two beaks inside each other. (The first would fold in, and the second would fold out.) The ears and facial features were done using the line drawing tool. (The ears, eyes and body were colored with markers later.) In cutting out the cat, she changed the top cut to be around the ears and rounded the bottom of the head, using yellow paper to fill in the brown color from the step. Emily found that doing two beaks inside one another was very difficult to fold, and left the nose indented. The finished Freddy Squarehead and Cinnamon the Cat are shown in Figure F.27. (Session 2 date: 11/12/06, 62 minutes)

Emily made the mouse with a beak, but otherwise the construction was much like that for the two previous characters—with the basic shape changed along the cut line. A tent was added for the paws. This time, a flap was added, with a piece of cheese underneath. Emily wanted to make a bird. This time, an angled step was the body, and she changed the top cut for the head once more, with a v-fold for a beak. The finished Mr. Mousy and the printed pieces for the bird are shown in Figure F.28. (Session 3 date: 11/19/06, 21 minutes)

In session 4, Emily cut out the bird, once again cutting the top line to make the head part of the main element. She covered the head of the bird with blue paper. Since the head was cut out as an extension of the body then covered with blue paper, the part of the base page that makes up the head had a mountain, rather than a valley fold. Emily was concerned that folding the head the other way would make the beak not attach properly, but found that it worked well. We discussed

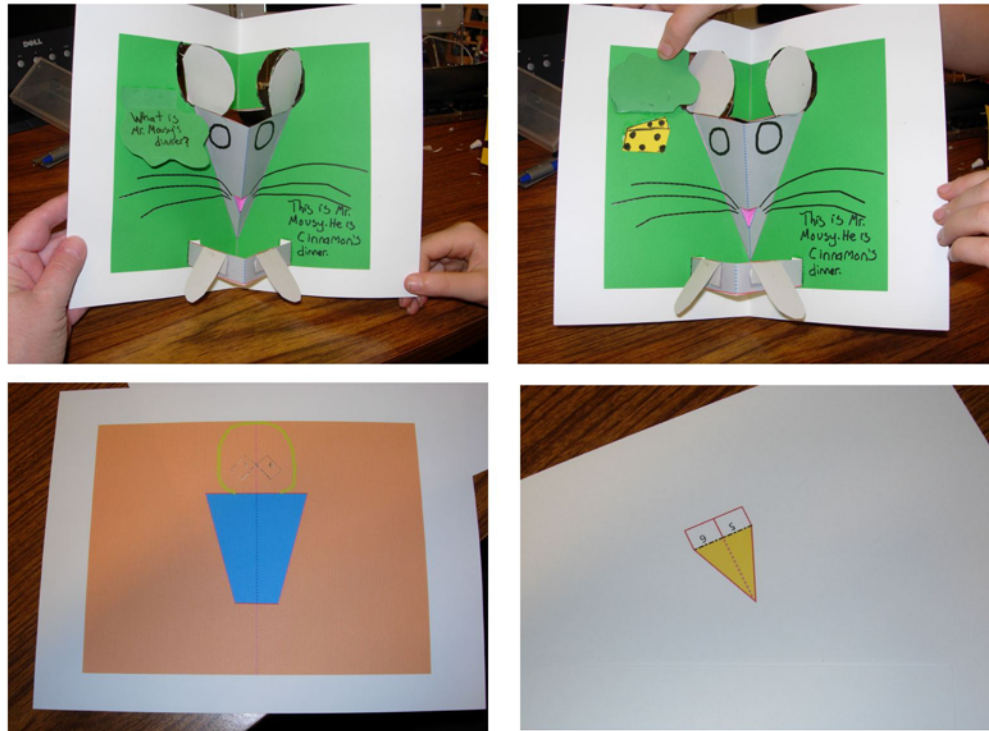


Figure F.28: Emily session 3: Mr. Mousy, showing the action of the flap, and the beginning pieces for a bird.



Figure F.29: Emily session 4: Mr. Tweedy Mo, showing the action of the flap.

how to attach the wings, and she decided on simply putting them on the side of the body. This worked just fine. She also added a flap showing the bird's dinner. In this session, Emily also made the giraffe, shown in session 5, except for the neck, text, and flap. The finished bird is shown in

Figure F.29. (Session 4 date: 11/26/06, 60 minutes)



Figure F.30: Emily session 5: Howard the Giraffe, showing the action of the flap.

Emily finished the giraffe in session 5, adding the neck and head, the flap and the text. In this figure, she did not make the head or legs part of the body, but attached them separately. She also started to make a cow. She suggested "something above the paper." We looked at some pop-up books, and discussed various ways of doing this, and she decided on two v-folds, one for the head and one for the body. (This is similar to the "table" that her sister used in several pop-ups.) She also got the head for the cow drawn and colored, but not attached. (She used a "South Park" cow we found on the web as a model.) The finished giraffe is shown in Figure F.30. (Session 5 date: 12/03/06, 61 minutes)

During the 6th session, Emily finished the cow, and started on a moose. (She said that she wanted a moose and an elephant for the next pop-ups, then all the characters going down a slide for the last, so her overall plan for the book was complete by this point.) The finished cow floats above the surface of the page, with the head and the body moving separately. The flap shows the cow tap-dancing on the giraffe. Emily got the step for the moose completed and printed. The finished cow, along with close-ups of the flap, are shown in Figure F.31. (Session 6 date: 1/07/06, 65 minutes)

In session 7, Emily finished the body of the moose pop-up, altering the step to suggest the

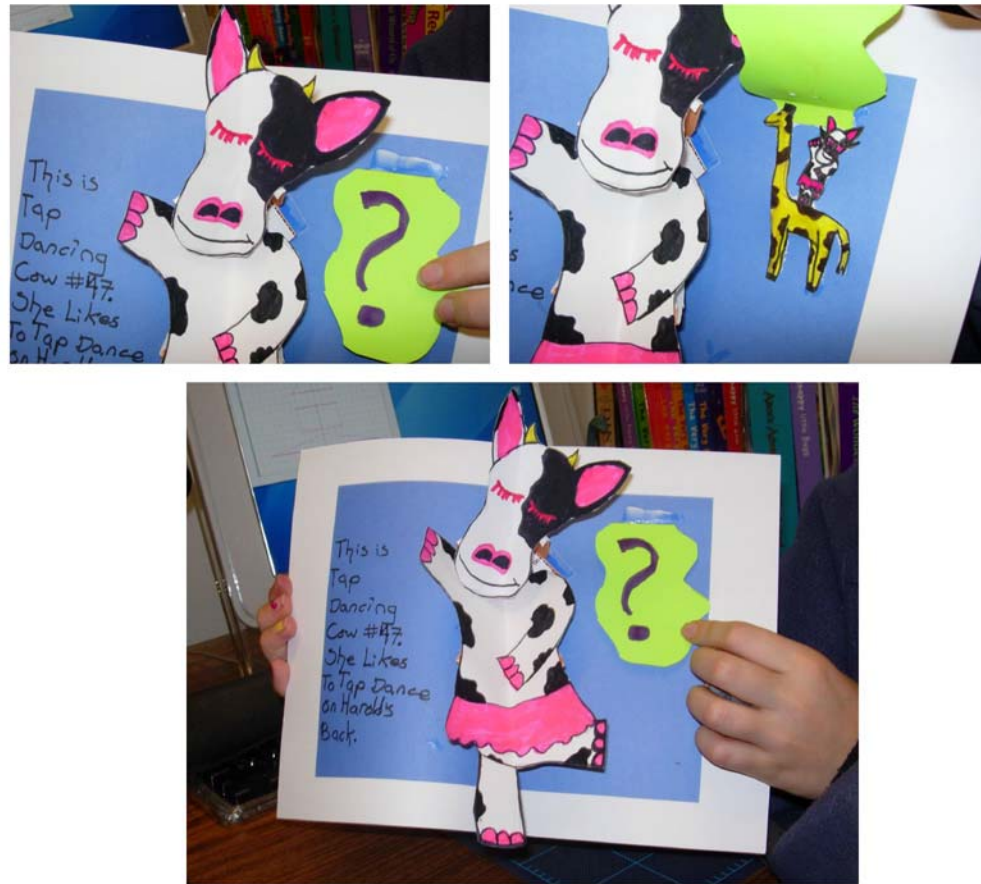


Figure F.31: Emily session 6: Tap-dancing Cow No. 47, showing the action of the flap.

shape of the moose's head, and adding antlers on the top of the head. She wanted to do a pull-tab mechanism on this pop-up and drew a picture of it—a smiley face that changes and sticks out its tongue. The sketch did not include a mechanism, and she decided to do a prototype. By the end of the session, she had a rough prototype. There were two problems that she had found with it that were as yet unsolved. First, the tongue needed to reliably come through the slot to stick out. Second, There was no way for the tab to stop at the right points. The moose without the tab and the prototype of the pull-tab are shown in Figure F.32. (Session 7 date: 1/28/07, 53 minutes)

Emily solved the tongue problem in session 8 by attaching a length of paper which remained through the slot and guided the tongue through. She added the smiley face to the moose pop-up and constructed the slider. She also solved the stopping problem (at least for pulling it

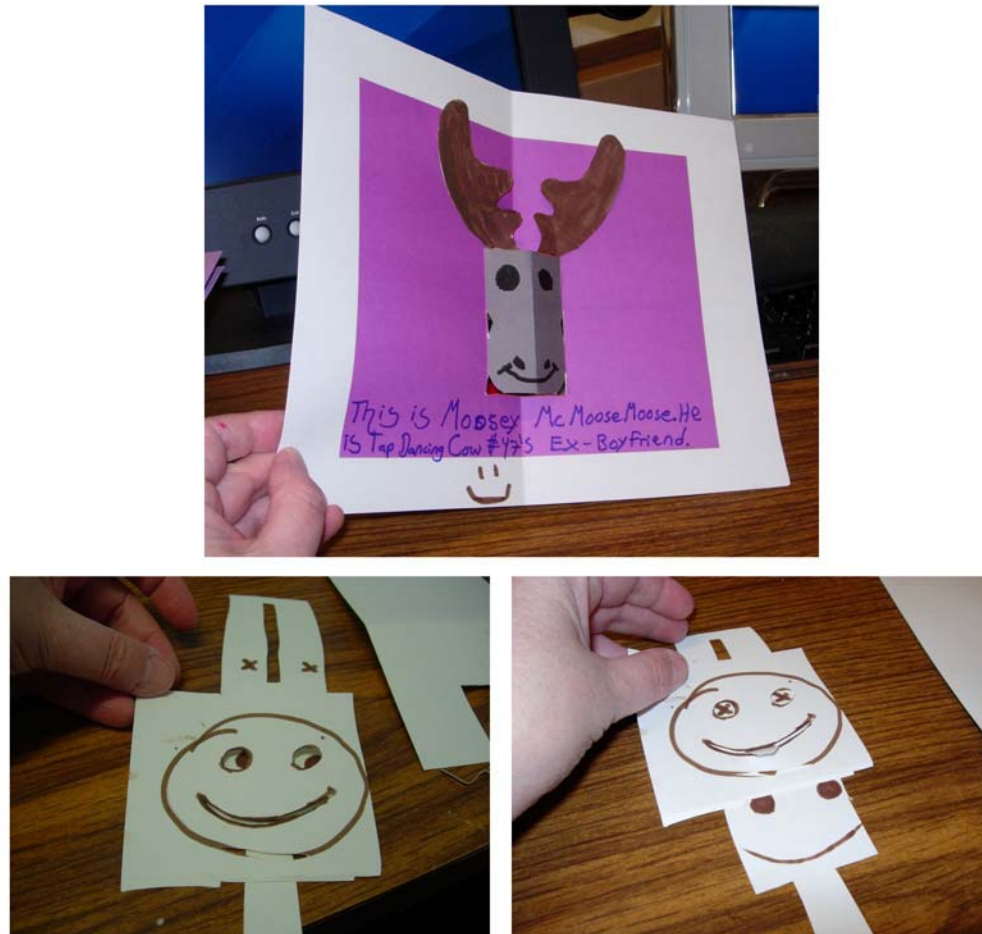


Figure F.32: Emily session 7: Moosey Mc Moose Moose. The moose pop-up and the prototype of the pull-tab mechanism.

down) by narrowing the slider for the slit at the point where she wanted it to stop. At the end of this session the pull-tab mechanism was mostly complete. The moose and the finished (but not yet attached and working) pull-tab mechanism are shown in Figure F.33. (Session 8 date: 2/04/07, 59 minutes)

Emily started session 9 by putting a stop on the pull tab so that it could not go too far up. At this point, she discovered that pulling the tab worked, but that the tab bent and could not be pushed back. She experimented with putting a back on the mechanism, but this did not help. At last, she put another tab on the top, so that one pulled the tab for motion in either direction.



Figure F.33: Emily session 8: More work on Moosey McMooseMoose. The final pull-tab mechanism and face to be added to the picture.

This worked well. During drying times, Emily started on the elephant. She made a beak for the face, and a v-fold for the trunk. The printer was out of ink, so it was printed later from the jpeg produced by "Export" (one time that making a jpeg was very useful.) The finished moose and close-ups of the pull-tab operation, along with the uncut pieces for the elephant, are shown in Figure F.34. (Session 9 date: 2/18/07, 120 minutes)

In session 10, Emily cut and folded the beak for the elephant's face. She then attached the trunk and bent it. (The v-fold still folds when bent.) Since we had printed several extra trunk pieces when we were having printer problems, she glued two trunk pieces together back-to-back so that both sides looked the same. Then Emily made tusks and attached them. (They also still fold correctly.) She decorated the background and wrote the text. She used a piece of gray paper to surround the other pieces and make the rest of the head. She wanted to attach a v-fold for the ears, with one anchoring point on the base (beside the head) and the other on the inside of the face (beak). She was uncertain that this would work, so she made a prototype and decided that it would. She attached the ears, and they folded well. She allowed the centerline to appear where it wanted to when folded. (The ears were not done with the computer.) In this session she also made a base page with just green color—no pop-up elements, which she would use for her



Figure F.34: Emily session 9: Moosey Mc Moose Moose complete, with details of the tab operation. The pieces for the elephant (designed during Session 9, but printed later in the week).

last pop-up. The steps in making Bart the Elephant are shown in Figure F.35. (Session 10 date: 2/25/07, 113 minutes)

In session 11, Emily wanted to put v-folds on the ears to make little pockets for the other characters to live in. She cut them freehand with the knife; it took several tries to get them just the right size. She attached these, and folded the elephant. She looked at photos of each of her pop-ups while she drew pictures of the characters to put on the ears. Then she attached them—to



Figure F.35: Emily session 10: Steps in making Bart the Elephant. Clockwise from upper left: 1) The trunk is attached. 2) Decoration and tusks are added. 3) The head is fitted around the face. 4) The ears are added (v-folds attached to side of head, and on the inside of the face).

the ears and to each other. We finished by looking at some spirals in various books, as she wanted to make a spiral for her final pop-up. Bart the Elephant, without and with his ear friends, is shown in Figure F.36. (Session 11 date: 3/04/07, 95 minutes)

In session 10, Emily had made a base page for her final pop-up. Now in session 12, she finished it. Since the pop-up contained a spiral, not a type of element that the computer makes, she only did the background in the program. She made the spiral by drawing around a CD box, then cut it, and positioned it on the paper. She made the ladder, the nasty fellow with the teeth, and the sign for the Slide of Ignorance with the knife and colored paper. (The sign letters are cut



Figure F.36: Emily session 11: Bart the Elephant is finished. Top left shows the v-fold pockets added to the ears. Then the characters are added to the ears. They are glued to the ears and to each other, not the base, which keeps the pop-up foldable.

freehand with the knife.) She drew the characters, making bodies for them and putting them in sliding positions, and gluing them to the slide. Finally the warning sign was made, and the pop-up was finished. The Slide of Ignorance pop-up is shown in Figure F.37. (Session 12 date: 3/11/07, 110 minutes)

Emily's final session was spent in looking at the sample pop-up books and talking about the program. In the course of explaining the program to the researcher, Emily made a surprisingly

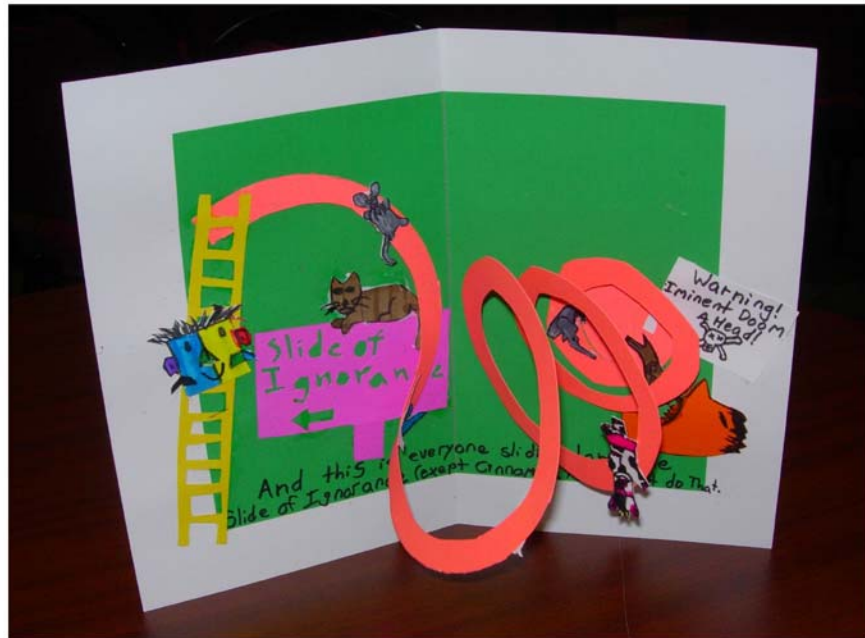


Figure F.37: Emily session 12: All of the characters sliding down the Slide of Ignorance, with a close-up.

asymmetric pop-up. She printed it and took it home to cut and fold. (Her parents had given her a craft knife of her own.) The jpeg which Emily printed to fold at home is shown in Figure F.38.

(Session 13 date: 3/24/07, 45 minutes)

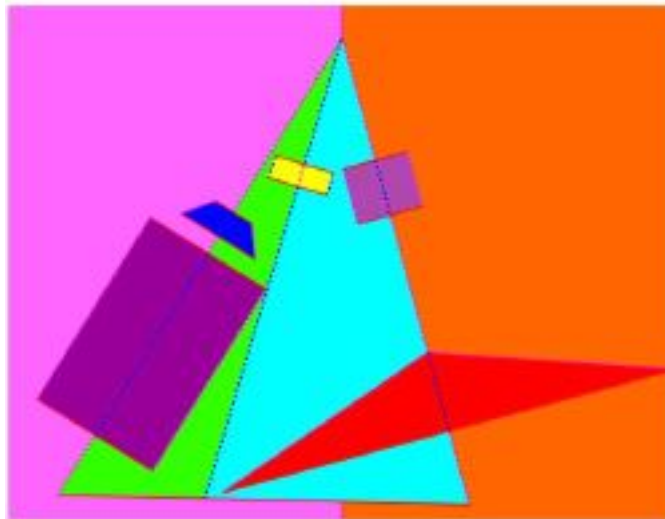


Figure F.38: Emily session 13: An abstract design, made while talking to the researcher. It was printed, and Emily took it home to cut and fold.

Appendix G

Test Subject Pop-up Analysis

Two sets of tables for each user are included here. The first table focuses on the elements produced for each pop-up with the software. Totals for each of the five types of elements are given for each pop-up, along with the highest level of the top element. If additional levels are added by adding other elements (including attached planes) by hand, the highest level in the completed pop-up is given in parentheses. An attached plane on an element is considered to add a level. The pop-ups are identified by name and also by reference to the photos in Appendix F.

The second set of tables concentrates on decoration and symmetry. It includes details of how the pop-up was decorated, both the use of art materials and added materials such as sequins and googly eyes. In addition, where the student got the ideas for the pop-up (if known) and any added elements (including attached planes) or alterations of the computer-generated elements are listed. Finally, these tables indicate the symmetry of the pop-up as follows:

S Original design symmetric, and symmetric when complete

A Original design asymmetric

St Original design symmetric, but turned on its side when complete, making it asymmetric

Sd Original design symmetric, but added decoration or elements later makes it asymmetric

Original design means the design elements as made in software, or cut by hand if no software is used. Sd and St are of course not mutually exclusive.

Pop-up (and Figure reference)	Beaks	Steps	Angled Steps	V-folds	Tents	Top level
Alien (F.1 left)	17	5	3			3
Bird (F.1 right)	2	1	1	2		2
Abstract face with yarn 1 (F.6 top left)	2	2	2		3	2
Abstract face with yarn 2 (F.6 top right)	5	4	1			3
Abstract (F.2 right)	2	5	4			3
Owl (F.5)				1		1(2)
Blue and white abstract (F.6 bottom)	3	12	4			4

Table G.1: Daisy: Software-Produced Elements. Elements or other additions added by hand are not included.

Pop-up (and Figure reference)	Beaks	Steps	Angled Steps	V-folds	Tents	Top level
Frog (F.7 left)						0(1)
Blue Boxes (F.7 right)		1			1	1
Bunny's Picnic (F.8)				1		1
White abstract (F.9 top)	4	3	1			3
Bunny and Castle (F.9 bottom)				1	1	2(3)
Turtle Gymnast (F.10 top)				1		1
Mommy and Baby Bunny Houses (F.10 middle left)		1	1			1
Bunny and Her Houses (F.10 bottom)						0(1)
White Alien (F.10 middle right)						0(1)
Bunny Gymnast (F.11 left)				1		1
Bunny and Turtle's Castle (F.12)	2				1	1(3)
White abstract (F.13 left)	5					2
Flag (F.13 right)		1				1
Totem Pole (F.14)	3	1	2			2

Table G.2: Ursula: Software-Produced Elements. Elements or other additions added by hand are not included.

Pop-up (and Figure reference)	Beaks	Steps	Angled Steps	V-folds	Tents	Top level
Alien and His Ship (F.15)						0(2)
Man with a Cold (F.16 top)						0(1)
Green and Yellow abstract (F.17 top left)	1	4				2
Alien and Ship (F.17 top right)						0(1)
Volcano Camp (F.17 bottom)					1	1(2)
City (F.18)	1	2	1			1
Unfinished Mountain Scene (F.19)				3		1

Table G.3: Richard: Software-Produced Elements. Elements or other additions added by hand are not included.

Pop-up (and Figure reference)	Beaks	Steps	Angled Steps	V-folds	Tents	Top level
Abstract Face (F.21 top)	1	2	2		2	2
Table and Chairs (F.22 top)		2		3		1(2)
Campground (F.23)				1	2	2(3)
Sun and Tree (F.25)		1		1		1(2)

Table G.4: Peggy: Software-Produced Elements. Elements or other additions added by hand are not included.

Pop-up (and Figure reference)	Beaks	Steps	Angled Steps	V-folds	Tents	Top level
Freddy Squarehead (F.27 left)	1	1	2			2
Cinnamon the Cat (F.27 right)	2	1				3(2)
Mr. Mousy (F.28 top)	1				1	1(2)
Tweedy Mo (F.29)			1	1		2
Howard the Giraffe (F.30)		1				1(2)
Tap-dancing Cow #47 (F.31)				2		1(2)
Moosy McMooseMoose (F.34 top)		1				1(2)
Bart the Elephant (F.36)	1			1		1(4)
Slide of Ignorance (F.37)						0(2)
Unfinished abstract (F.38)	2	3	1			2

Table G.5: Emily: Software-Produced Elements. Elements or other additions added by hand are not included.

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Alien (F.1 left)		Computer coloring, googly eyes	S	Playing with software
Bird (F.1 right)		Computer coloring, googly eyes, feather	S	Playing with software
Abstract face with yarn 1 (F.6 top left)		Computer coloring, googly eyes, yarn	S	Playing with software
Abstract face with yarn 2 (F.6 top right)		Computer coloring, googly eyes, yarn	S	Playing with software
Abstract (F.2 right)		Computer coloring	S	Playing with software
Owl (F.5)	Head, tail, wings, talons	Colored pencil	S	Idea of owl from book she was reading. Looked at several pop-up books for ideas on execution. Looked at owls on web.
Blue and white abstract (F.6 bottom)		Computer coloring	S	Playing with software

Table G.6: Decorative Features of Pop-ups Produced by Daisy.

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Frog (F.7 left)	All by hand: 1 beak	Computer coloring	S	A friend had made a frog and she wanted to know how to do it.
Blue Boxes (F.7 right)		Computer coloring	S	Playing with software
Bunny's Picnic (F.8)	Cut the v-fold to bunny shape	Crayon	Sd	Idea for bunny's picnic was her own, v-fold suggested by researcher as she was playing with software.
White abstract (F.9 top)			S	Playing with software
Bunny and Castle (F.9 bottom)	Cut top of v-fold for castle and attached plane for bunny.	crayon, eyes and jewels	A	Pop-up book for basic idea of castle. Wanted a separate bunny and researcher helped with implementation.

Table G.7: Decorative Features of Pop-ups Produced by Ursula (Sessions 1-3).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Turtle Gymnast (F.10 top)		markers, eyes, sequin and feathers	S	Playing on computer, but also influenced by Bunny and Castle pop-up.
Mommy and Baby Bunny Houses (F.10 middle left)		computer coloring	S	Playing with software. Researcher suggested using the 90° elements for a design. She later named it.
Bunny and Her Houses (F.10 bottom)	All done by hand: 2 steps, doors cut, extra bunny glued on	pencil	Sd, St	Learning to make steps by hand. This was the result
White Alien (F.10 middle right)	All done by hand: 1 step, 1 beak	googly eyes	S	Practicing making steps and beaks by hand.

Table G.8: Decorative Features of Pop-ups Produced by Ursula (Session 4).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Bunny Gymnast (F.11 left)	cut out top of v-fold to make bunny	googly eyes and crayon drawing	S	Wants to do something same as turtle gymnast, but with a bunny.
Bunny and Turtle's Castle (F.12)	attached castle with draw-bridge and turtle added to it, and bunny in hole	crayon and pencil	Sd,St	Inspired by castle in Pop-o-Mania book.
White abstract (F.13 left)			S	Playing with software.
Flag (F.13 right)		crayon coloring	Sd	Veteran's Day was near, she wanted to do something for her teacher, and they had been learning about the flag.
Totem Pole (F.14)		feathers, eyes, sequins, marker	S	Playing with software

Table G.9: Decorative Features of Pop-ups Produced by Ursula (Sessions 5-8).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Alien and His Ship (F.15)	All made by hand: 3 steps with attached planes	crayon coloring, sequins and feather	Sd, St	Researcher had heard that he had made pop-ups. Asked him to make one.
Man with a Cold (F.16 top)	All made by hand: cut out diamond shape (failed beak) and beak	gooly eyes, crayon drawing	Sd	Looking at Pop-o-mania book. Saw the beak. Took paper to try it. First one was the cut-out triangle, then did the second beak correctly.
Green and Yellow abstract (F.17 top left)		computer coloring	S	Playing with software. Made for his sister (he had seen abstracts she made.)
Alien and Ship (F.17 top right)	All made by hand: 1 step and 2 flaps	Crayon. Lettering done by researcher at his direction.	A	Wanted to do something quick. He made the step asymmetric and investigated where the fold ended up when page was folded.

Table G.10: Decorative Features of Pop-ups Produced by Richard (Sessions 1-3).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Volcano Camp (F.17 bottom)	1 free-form element for lava	computer coloring, red paper and crayon	St, Sd	Had idea from shape of tent element for mountain, then volcano. Sketched it out first.
City (F.18)	2 flaps, doors and windows cut in step	Computer coloring and lines, colored paper and crayon, Lettering done by researcher at his direction.	A	Idea of city from Sabuda book, America. Playing with software for final form.
Unfinished Mountain Scene (F.19)	Top of one v-fold cut to make castle	not done when sessions over	Sd	Idea from Raggedy Ann book, mountain, castle and soldiers

Table G.11: Decorative Features of Pop-ups Produced by Richard (Sessions 3-5).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Abstract Face (F.21 top)		Marker, googly eyes	S	Playing with software. Noticed face during that and refined it.
Table and Chairs (F.22 top)	Tabletop on one v-fold	Computer coloring, colored paper for tabletop	S	The shape of the v-fold when playing with the computer suggested a chair back to her.
Campground (F.23)	Trees and man on tent attached to a tent and the top of the fireplace and flames on one of the v-folds	Crayons	A	Shape of the tent suggested a campground. Reused table idea for campfire. Experimented by hand for man and trees.
Sun and Tree (F.25)	Sun wheel and slider, cloud on top of v-fold	Colored paper, markers, sequins, jewel	Sd	Elements of Pop-ups wheel attracted her. Pop-up book was inspiration for cloud, although it was changed in execution. Slider was from Pop-o-mania.

Table G.12: Decorative Features of Pop-ups Produced by Peggy.

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Freddy Squarehead (F.27 left)	Extended the top of the step to include hair	Computer coloring and lines	S	Playing with software
Cinnamon the Cat (F.27 right)	Extended the top of the step for ears, and rounded the bottom for chin. The double beak became single at the end. Double nose made 3 levels, but only folded 2.	markers and colored paper, computer coloring and lines	Sd	Likes cats and wanted a cat for Freddie. Playing with software for form
Mr. Mousy (F.28 top)	1 flap, paws on the tent, extended the step to make the ears	Computer coloring, lines, markers, colored paper	Sd	Decided on mouse for the cat to have for dinner. Her approach is to build up a story. Form is developed through playing with software.
Tweedy Mo (F.29)	Wings, 1 flap, extended angled step for head	Colored paper, markers, computer coloring	Sd	Continued the sad story of cat's food. Once again playing with software. Looks at pop-up books for ideas on wings.

Table G.13: Decorative Features of Pop-ups Produced by Emily (Sessions 1-4).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Howard the Giraffe (F.30)	legs, and neck with head, 1 flap	Colored paper, computer coloring, markers	Sd	Thinking about animals in general.
Tap-dancing Cow #47 (F.31)	Head and body attached to v-folds, 1 flap	Markers, colored paper, computer coloring for background	Sd	Idea for cow to continue animals. Wants something "above the paper" Uses a pop-up book and discussions about what her sister did to plan v-folds.
Moosy McMooseMoose (F.34 top)	pull-tab antlers mechanism,	Computer coloring, lines, colored paper and markers	Sd	Idea of moose goes along with animal theme. For the pull-tab, looks at Elements of Pop-ups, Hiner, but largely result of prototyping, trial and error.

Table G.14: Decorative Features of Pop-ups Produced by Emily (Sessions 5-9).

Pop-up (and Figure reference)	Non-computer elements and alterations of computer elements	Decoration	Symmetry	Idea from
Bart the Elephant (F.36)	Extra piece around beak for head, 2 v-folds for ears, tusks. Characters attached to ears, Folded the v-fold for trunk	Computer coloring, markers, colored paper.	Sd	Wanted to present all the characters along with the last one. Looks at both Birmingham and pop-up book for ideas on execution. Some prototyping on ears.
Slide of Ignorance (F.37)	All by hand: Spiral, cut-out pieces for signs, ladder, characters, and head	Computer coloring (for base page) Colored paper, markers	A	Has basic idea going in, a final wrap-up of all the characters and wants to do a coil. (Seen in pop-up books)
Unfinished abstract (F.38)		Computer coloring	A	Playing with software

Table G.15: Decorative Features of Pop-ups Produced by Emily (Sessions 10-13).