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 craftwork 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.