An Empirical Study of Aesthetic Computing

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December 15, 2003

Abstract

Aesthetic Computing is an area that has been developing over the past three years, supported by workshops, classes and an upcoming edited volume. In this area, the goal is to study the application of artistic practice and theory to computing. The Aesthetic Computing class is run every Spring, and contains both art and computer science students. The students look at issues in representation, and make projects to illustrate new representations of artifacts in mathematics and computing. Natural questions arise such as *Does aesthetic computing provide any benefit?*. To help answer this question, the student needs to be presented with a body of knowledge that represents the "aesthetic computing technique", and then the student applies this knowledge to create the artifacts. We present recent empirical studies from two classes, Aesthetic Computing and Computer Simulation, where aesthetic "methods/techniques" were employed. From the studies, we determined that while aesthetic computing techniques had their negative results, aside from the appeal of being able to customize formal structures, the most positive result was found in a perceived enhancement of *communication* of technical topics by the students to others.

1 Introduction

We present survey and focus group results on a class, called *Aesthetic Computing*, that has been taught in the Computer and Information Sciences and Engineering Department at the University of Florida for the past three years. The purpose of Aesthetic Computing is to apply aesthetics, loosely associated with art theory and practice, to elements of computing. Figure 1 illustrates the scope of Aesthetic Computing. This scope is defined by the elements of computing (theory, artifacts, or practice) being modified by art theory and practice. An *hour glass* metaphor is used to suggest a flow from top to bottom. For example, one might take a mathematical structure or computer program (i.e., artifacts), represent these structures with the aid of an artistic genre, and the result would then fall

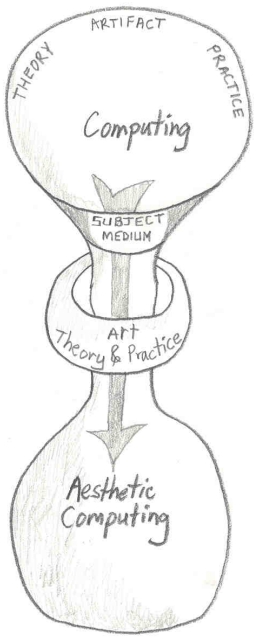


Figure 1: The area of aesthetic computing captured in the form of an hourglass.

within the aesthetic computing category. Some recent work by Fishwick in building customized notations[11] suggests this approach. On the other hand, one might be an artist whose activity is brought to bear on a practice within computing, such as scientific visualization. This sort of work is presented by Prophet in []. The theory of computing is located primarily within mathematics, and so by applying certain rules or heuristics, meant as guides for aesthetic appreciation and interpretation, we yield a better understanding of the concept of beauty in mathematics [9, 17]. Artwork in the Processing Language [1] treats programs as either the subject or the medium for artistic practice.

Our approach is to first indicate a history for the area of aesthetic computing, and then describe the course in more detail with examples of student projects. This is followed by a detailed empirical analysis of the course in terms of what students thought about the topic, and whether the topic was seen as useful, engaging, or beneficial. Both positive and negative attributes of aesthetic computing are discussed.

2 History and Context

Aesthetic Computing, within our University context, was brought about by a number of events. The first event was the formation of the Digital Arts and Sciences [13, 2] programs at the University of Florida. These programs yield degrees in two Colleges (Engineering and Fine Arts) and over two student populations (Undergraduate and Graduate). Approximately 32 students enter the program each year, with half being from Computer Science and the other half from Art. The idea of the DAS programs originated through discussions in the University administration two years prior to the start of the programs, and in May 2003, we graduated our first class of DAS Seniors. DAS encourages a blending of subject material from each area, and a small number of hybrid courses have emerged to take advantage of this evolving confluence of subjects. In 2000, one author (Fishwick) started a class in Aesthetic Computing with the idea of exploring the application of aesthetics to computing. This application is, in many ways, the converse of the more traditional application of digital media algorithms (i.e., from computing) to art. In 2001, the authors obtained a grant from the National Science Foundation to enrich the area and provide funds mainly for supporting the class in terms of software that could be used for building the appropriate projects.

As of this writing, Aesthetic Computing has grown beyond the original 2000 class experiment, to encompass the following:

- A web page: [3]
- A yearly class taught every Spring semester: [4]
- A news group: [5]
- Software support: [6]
- Several papers: [11, 16]
- An international workshop: [7]
- An edited book in progress: [14]
- A manifesto: [12]

The workshop involved a meeting in Dagstuhl, Germany (Dagstuhl) during the middle of July 2002. We held a week-long workshop, organized by Roger Malina, Christa Sommerer, and one author (Fishwick). The workshop, which was co-sponsored by Dagstuhl and Leonardo [8], was attended by over thirty representatives of the following disciplines: art, design, computer science and mathematics. The purpose of the workshop was to attempt to carve out an area, or at least to see whether this was possible, based on the notion

that aesthetics and art could play a role in computing disciplines. A manifesto was created on the last day of the workshop as a preliminary definition for the area, and was recently published in Leonardo [12].

3 The Aesthetic Computing Course

The Aesthetic Computing course has changed somewhat since the original one in 2000, but the key aspects have remained constant. There is a combination of instructor lecture, student talks, invited lectures, and student projects. The lecture involves a coverage of language, semiotics, analogy and metaphor, in addition to methods meant to enhance creativity. Students give talks on papers that have been published in areas that highlight these topics. Invited lecturers come from outside of Computer Science. The student projects are divided into two types: virtual and physical. Virtual projects are delivered in both 2D and 3D movies or interactive media. Physical projects are made from materials found in craft, hardware, and on-campus stores. Despite the general formulation of Aesthetic Computing in Figure 1, the course has focused on the *representation* of artifacts found in mathematics and computer science.

The following discussion is excerpt from [14], and is based on example structures built by the author and students in the class. Let's begin with a formal definition of a Finite State Machine (FSM) M [10]). These machines have states that are connected to each other through transitions that are made active when an input to the machine is of a particular value. Here is a formal definition for M:

$M =< Q, I, O, \delta, \lambda >$
$Q = \{S1, S2, S3\}$
$\delta : Q \times I \rightarrow Q$
$\delta(S1, 0) = S1; \delta(S2, 0) = S2; \delta(S3, 0) = S3$
$\delta(S1, 1) = S2; \delta(S2, 1) = S3; \delta(S3, 1) = S2$
$I = \{0, 1\}$
$\lambda : Q \rightarrow O$

Even though this text might seem to be the formal specification for M, it is actually one of many ways to look at the underlying formalism which would is encoded in XML. The above text is one type of presentation among many. In general, all presentations require additional natural language semantics if we are to make sense of them. Q is the state set for M; I the input set, O the output set, the transition function from one state to another, and the output function. Figure 2 illustrates our second presentation for the FSM. It has iconic properties so that when the machine is in state S2, the presentation of a circle for S2 encodes the concept of a boundary, and that which is inside it.

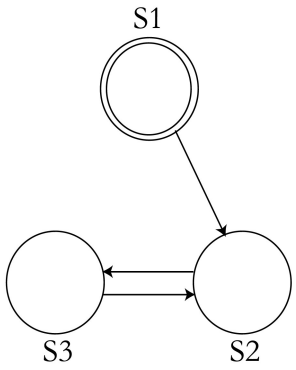
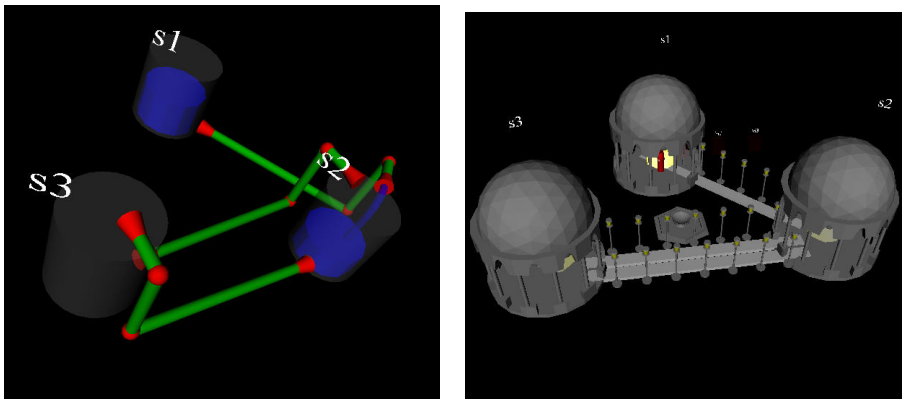


Figure 2: The pipeline behavioral model and the behavioral FSM states defining the phase of the water.

That is, the graphical depiction of S2 is consistent with the underlying metaphors of set theory, whereas the purely textual presentation does not capture these metaphors. Moreover, Figure 2 is incomplete on a non-interactive medium, such as paper, since the additional information (i.e., such as the input values needed to effect a change of state) encoded in the text representation is equally present during interaction with the figure. Similarly, the arrows capture the notion of transitioning from one state to another, since anyone who has seen an arrow fly knows that it is aimed toward a target. The metaphors of the figure dramatically improve the semantics of the machine, and so one is led to wonder whether employing presentations with alternative aesthetics might further improve the impact of the metaphor. The underlying assumption is that material aspects of levels of representation are based largely on what is available for a society, and what is affordable and materially efficient. Consider Figure 3 as a representation that has only recently become possible through computer graphics, and the ability to employ 3D components. The metaphor of the circle as a boundary has been replaced by a set of tanks (on the left), and small gazebo-like structures (on the right). The arrow in Figure 2 is now shown as either a pipe filled with water (left), or a red-clothed woman walking from one state to another along a lamp-lit walkway (right). There are a host of philosophical issues that come into play here. Isn't there a need to enforce visual minimalism within this sort of structure? What are the cultural barriers imposed that might prevent the adoption of models like Figure 3 being made possible for science and engineering? With respect to the issue of minimalism, we should note that is quite possible to preserve abstraction without requiring visual minimalism. Within the context of the art community, this can be seen when comparing and contrasting the genres of Abstract Expressionism and Surrealism. Both of



(a) FSM with a fluid metaphor.

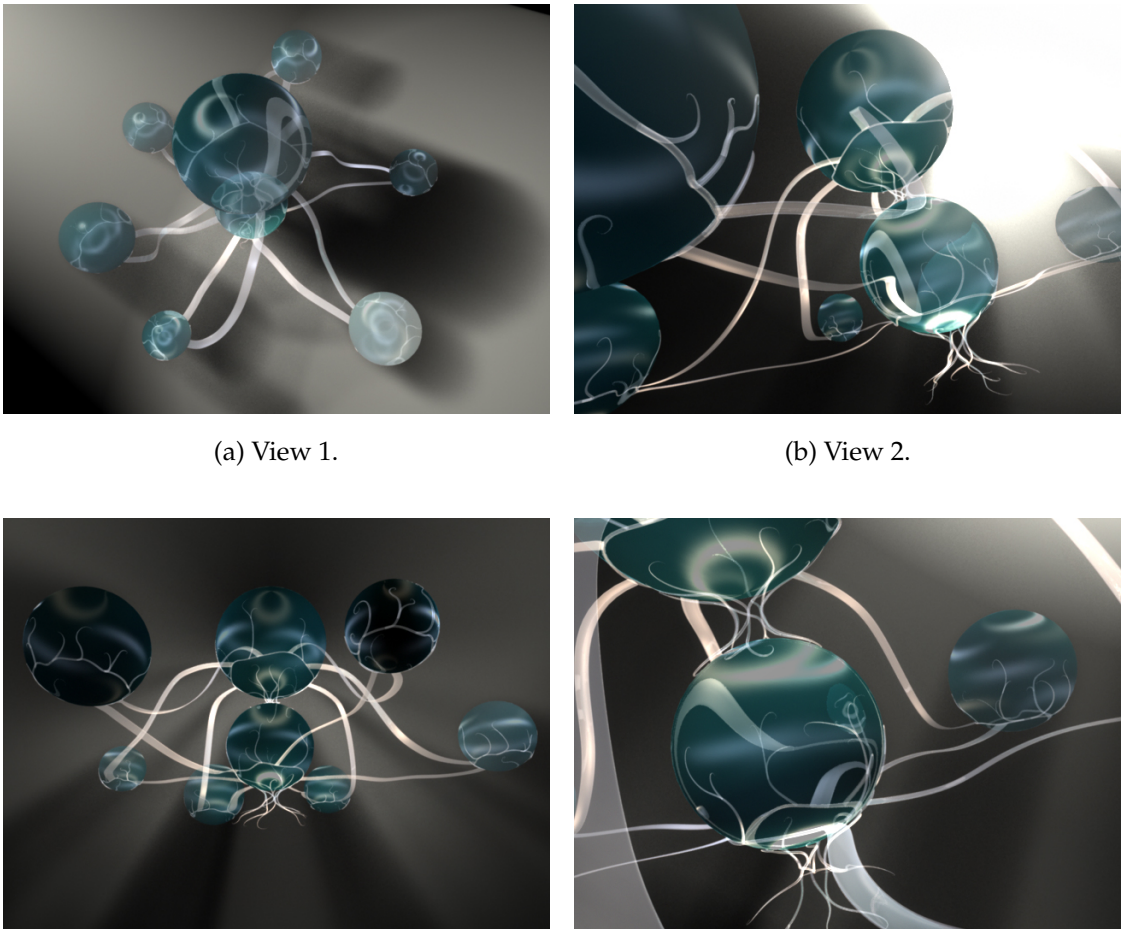
(b) FSM with an agent metaphor.

Figure 3: Two alternate presentations of the FSM in Figure 2.

these genres contain a wide variety of works that employ symbolism, iconography, and the richness of semiotics even though the visual presentations are strikingly different.

Deriving the idea of an abstract state in an FSM, for example, need not imply that the state be presented visually in a minimalist fashion. The key objective is to strengthen the metaphor underlying what it means to be a state, and the corresponding elements of boundary that go along with it. The second question about cultural barriers may be at the heart of the aesthetic computing challenge. Computer scientists have been educated with minimalist figures and text, and so it may come as a shock to realize that our representations for formal objects are not as constrained as we may have originally thought. Until the era of computer graphics and fast computers, we had little need to inquire about, what initially appeared to be, exotic ways to encode formal knowledge. However, it is not only a challenge for computer scientists, but also for artists, since artists should be encouraged to consider the computer, and computing practices, as subject material in addition to raw material. This suggestion on formal structures as raw or subject material may strike some artists as a modernist era agenda; however, there the computer, and its mathematical foundations, creates significantly higher complexity as a tool, or as a subject, than paint, palette knife, or chisel ever could. The following two examples were created in the author's Aesthetic Computing class (AC2) at the University of Florida. The class includes both artists and computer scientists, who work individually and on group projects to represent mathematical models found in mathematics, program and data structures, and

computer simulation. Figure 4 is based on a virtual model created by an artist (Joella Walz) and represents a functional feedback data flow network, whose purpose is to physically model sound when the model is executed. One type of modeled instrument, with the appropriate parameter settings, is of a Tibetan Prayer Bowl, which gives off a resonant bell sound.



(a) View 1.

(b) View 2.

(c) View 3.

(d) View 4.

Figure 4: An organic representation of a banded waveguide physical network modelfor synthesizing sound.

Figure 5 shows the equivalent 2D diagram (Essl 2002) for the structure shown in Figure 4. The first thing one notices is that the diagram has more complete information present, since it is specifically made for print media, whereas the structure in Figure 4 requires a highly interactive environment so that one can easily determine which nodes

are the delays, the band pass filters, and the primary interaction node. For Figure 4 to be as useful as Figure 5, barring issues of aesthetics and customization, the necessary interaction environment must be in place, with the ability to easily determine node roles and connections.

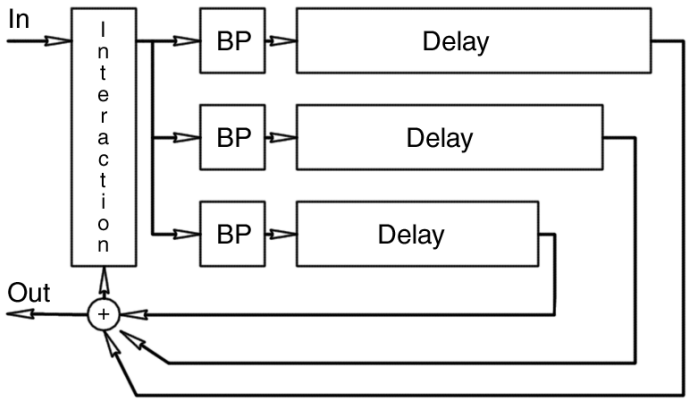


Figure 5: Diagrammatic representation of the banded waveguide model.

Figure 6 was created by a computer scientist (John Campbell) shows a physical model of the Taylor series, found in most calculus books. The Taylor series is an infinite sum resulting in a polynomial approximation to function F(x):

$f(x) = \sum_{n=0}^{\infty} \frac{f'^{(n)}(a)}{n!}(x-a)^n$

(a) View 1.

(b) View 2.

Figure 6: Two views of the Taylor Series physical model constructed from plexiglass, wood and metal.

4 Augmenting Models with Narrative

Jane– put your work here, with some anecdotes and quotes as you see appropriate.

5 Focus Group Results and Analysis

Jane– use transcription

6 Survey Results and Analysis

The aesthetic computing method has been used in two different classes at the University of Florida: Modeling and Simulation (Fall 2001, with 33 students), and Aesthetic Computing (Spring 2002 with 18 students). We surveyed each class in order to answer the following basic questions. Is the aesthetic computing method an effective tool for teaching, learning, and solving problems? In particular, is it a good method for students to:

1. learn topics in mathematics and computer science?
2. communicate topics in mathematics and computer science to others?
3. solve problems in mathematics and computer science?

Different surveys were used for each class, and each will be summarized separately. Unless otherwise stated, all questions are based on a standard Likert scale (1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, and 5 = strongly disagree).

7 Fall 2001

The Fall 2001 Modeling and Simulation class had 33 students. The course topic is defined as follows:

> Introduction to concepts in continuous and discrete simulation. Emphasis on fundamental concepts and methodology, using practical examples from a wide variety of disciplines.

In the survey, we defined the terms *aesthetic methods* and *standard methods* as follows.

> The term "aesthetic computing" refers to the technique you have used in your VRML homeworks and in your Final Project, where you use 3D objects as metaphors for more traditional symbols and icons. For example, to use a tank of water to represent a state in an FSM represents the technique of aesthetic computing, as differentiated from standard notations of a circle or a variable like "q".

The survey included the questions listed in the following table to determine if the aesthetic method was useful in learning, communication, and problem solving. The table also lists the mean and standard deviation (σ) of the results. Students said that aesthetic methods and standard methods were both useful in learning modeling and simulation, with a slight bias towards aesthetic methods. Both methods were equally useful

in problem-solving. They were more strongly in favor of using aesthetic methods over standard methods to communicate their knowledge of modeling and simulation to others. We also asked a few general questions. From them, we can see that students enjoyed using the aesthetic method, and would like to use it in other areas.

Fall 2001 survey questions	mean	σ
Learning:		
I have an adequate knowledge of modeling and simulation.	2.2	0.93
Aesthetic methods contributed to my knowledge of modeling and simulation.	2.2	0.92
Standard methods contributed to my knowledge of modeling and simulation.	2.4	0.70
Communication:		
I can explain topics in modeling and simulation to others.	2.0	0.81
Aesthetic methods contributed to my ability to explain topics in modeling and simulation to others.	2.1	0.96
Standard methods contributed to my ability to explain topics in modeling and simulation to others.	2.5	0.83
Problem-solving:		
I am able to solve problems in modeling and simulation.	2.0	0.75
Aesthetic methods contributed to my ability to solve problems in modeling and simulation.	2.3	0.75
Standard methods contributed to my ability to solve problems in modeling and simulation.	2.2	0.75
General questions:		
I prefer the aesthetic approach to the conventional approach of model building.	2.2	0.88
I would like using aesthetic methods in other domains of study such as program and data structures.	2.2	1.02
The use of aesthetic methods was more engaging than standard methods.	1.8	0.71

Several open-ended questions were asked. Here, we summarize the responses to three of them. Each table lists the question, followed by a list of responses and the number of students making that response.

In what ways can aesthetic methods be used to illustrate, teach, learn, or communicate other areas in computer science?	
3	data structures / algorithms / OO-programming
4	OS / networks
1	database
2	digital logic / computer architecture
4	discrete math / numerical analysis
1	graphic user interface
0	artificial intelligence
2	useful in any area
14	one or more of the 8 specific areas listed above
7	better understanding of difficult concepts
2	more interesting
7	easier to visualize / illustrate
11	one or more of the 3 general responses listed above
16	don't know / no response
0	negative response

Almost half the students (14 out of 33) said the aesthetic method would be useful in some specific area of mathematics and computer science. A third of the students gave general responses, stating that the method led to better understanding of difficult concepts, was more interesting than the standard method, or made it easier to visualize or illustrate topics in computer science. A sample response (one of the more detailed ones) is given below:

> *The video shown on networking would do wonders for kids in a networking class. Along these lines, if similar videos were made to show them how an OS worked or how a database worked, people would have a much better understanding of the topics. I showed my Dad the TCP/IP video and he had two reactions: (1) He enjoyed watching it because it was entertaining and very well done. (2) He felt that he had a better understanding of how TCP/IP worked even without having previous knowledge of TCP/IP.*

List the pros of aesthetic methods in modeling and simulation	
8	interesting / fun / appealing
17	better understanding / easy to visualize
6	teaching / learning / communicating
1	many applications
7	more expressive / more information / creative
11	no pros / no response

The most common response what that it gave better understanding of modeling and simulation, a response stated by half the class. A sample response is given below.

Aesthetic: Physical worlds are represented visually thus, it enables users to understand the problems easier. Since there is not much memorization during the learning process, what is learned remained longer. For instance, when I saw one of the videos (infonet), I felt that I wish I had seen data structures and computer organization courses with visual tools rather than via books and with standard techniques.

List the cons of aesthetic methods in modeling and simulation	
11	difficult / costly / lots of time / complex / hard to do
5	novel / not established / strange / won't fit on paper / unusual mode
1	culturally-specific / hard to please everyone
9	confusing if not done well / loses meaning / noise / not good for details
1	not applicable to all areas
12	no cons / no response

About a third of the class said that the method was difficult or takes a long time to learn and implement. The second most common response is the possible confusion of visual artifacts with the underlying model. For example:

Sometimes, if not done well, can cause further confusion. Usually takes a long time to make.

Sometimes you may get to off-track and lose the main meaning of a model in the visual complexity [of the] *representations.*

8 Spring 2002

Eighteen students were given a survey in Spring 2002 Aesthetic Computing course. The survey defined aesthetic computing and standard methods as follows:

Definition of "Aesthetic Computing": The term aesthetic computing refers to the technique of applying artistic and aesthetic styles to the presentation of formal structures of mathematics and computing.

Definition of "standard methods": refers to the more traditional typographic and diagramatic modes for presentation of formal structures of mathematics and computing.

The survey results are shown in the following table.

Spring 2002 survey questions	mean	σ
Aesthetic computing:		
I have an adequate knowledge of aesthetic computing.	1.9	0.76
I am able to use/do/apply aesthetic computing.	1.6	0.62
I am able to communicate topics in aesthetic computing to others.	1.9	0.76
Standard methods of computing:		
I have an adequate knowledge of standard methods of computing.	1.6	0.92
I am able to use/do/apply standard methods of computing.	1.7	0.75
I am able to communicate topics in standard methods of computing to others.	1.9	0.68
Aesthetic methods vs. Standard methods		
I have an adequate knowledge of formal structures of mathematics and computing.	1.7	0.83
Please rank how each of the following contributed to your knowledge of formal structures of mathematics and computing. (1 = high, 2 = substantial, 3 = some, 4 = little, 5 = none)		
aesthetic computing	3.2	1.04
standard method of computing	2.2	0.99
I am able to use/do/apply formal structures of mathematics and computing.	1.8	0.55
Please rank how each of the following contributed to your ability to use/do/apply formal structures of mathematics and computing. (1 = high, ..., 5 = none)		
aesthetic computing	3.1	0.94
standard method of computing	2.1	0.90
I am able to communicate topics in formal structures of mathematics and computing.	2.1	0.80
Please rank how each of the following contributed to your ability to communicate topics in formal structures of mathematics and computing. (1 = high, ..., 5 = none)		
aesthetic computing	2.6	0.92
standard method of computing	2.5	0.71
General questions:		
Aesthetic methods will prove useful in enabling team members with disparate areas of expertise to better communicate with one another.	1.5	0.51
Aesthetic methods will prove useful in helping team members in industry to work together more closely on multidisciplinary projects (such as simulation or game design).	1.7	0.56

Most students said that aesthetic methods made some contribution to their knowledge and ability in mathematics and computing, but the contribution of standard methods was stronger in these areas. However, half of the class (9 students) said that aesthetic computing substantially contributed to their ability to communicate topics in mathematics and computing. In the two general questions, most students strongly agreed or agreed that aesthetic methods will prove useful in communication and problem solving in multidisciplinary teams.

These results are similar to the Fall 2001 survey results. Aesthetic computing methods have some impact in learning and solving problems, but their greatest impact is on the ability of students to communicate their knowledge of mathematics and computer science to others.

Several open-ended questions were asked. Here, we summarize the responses to two of them.

In what ways can aesthetic methods be used to illustrate, teach, learn, or communicate other areas in computer science?	
9	data structures / algorithms / OO-programming
1	OS / networks
1	database
2	digital logic / computer architecture
0	discrete math / numerical analysis
0	graphic user interface
1	artificial intelligence
6	useful in any area
12	one or more of the 8 specific areas listed above
5	better understanding of difficult concepts
0	more interesting
6	easier to visualize / illustrate
8	one or more of the 3 general responses listed above
2	don't know / no response
2	negative response

The response to this question is very similar to the response to the same question by the Fall 2001 class on modeling and simulation. About two-thirds of the students listed a specific topic in which it would be useful, and about half gave general responses. Here is a sample response that emphasizes the communication aspects of the aesthetic method:

> *The aesthetic methods strength lies in the ability to communicate concepts to parties that have disparate backgrounds or no prior knowledge of the concept being explained. This means that aesthetic methods would be excellent for instructing novices or communicating concepts across disciplines or with foreign students.*

The next question elaborates on this issue, to determine how well the method can explain topics to the general public. A gallery was held, containing physical models along the lines of Fig. 6. Students were asked to create a physical sculpture, or piece, that represented a structure found in mathemats or computing. The gallery was held in the Reitz Union colonnade, which represents an elevated, enclosed walkway between the theatre and the main level of the Reitz Union. The location is frequented by faculty, students, staff, and the general public.

Based on your gallery experience, did you discover members of the public were able to understand the abstract concepts behind your structure?	
14	yes
1	mostly
2	partly
0	no
1	no response
2	visually interesting / intriguing
1	approachable
5	verbal discussion / text required

Nearly all students found that the general public was able to understand the basic concepts behind their gallery display. About a third of them (5 students) said that either a discussion, or the accompanying text, was required to understand it. It is likely that the students answered this question based on discussions with people who came up to their display and engaged them in conversation about it. Thus, it is possible that most of the general public would require more than just a viewing of the abstract aesthetic work to understand the underlying mathematical model, and that they would require some verbal discussion, or text, in addition to the model. The intent of the aesthetic method is not to replace a verbal explanation, but to augment it with a visually pleasing and intuitive metaphor.

9 Toward Distance Learning

The experience of the class to date has been one where students work on projects and talks in a seminar, rather than lecture, setting. To take the education to the next step where the class could be taught and enjoyed by participants outside of the University of Florida, it would be necessary to use collaborative software and tools. For the student talks, it would be possible to use collaboration software allowing slides to be shown on all client computers. The other possiblity is to publish pre-recorded videos of presentations and then allow students to comment on each others talks.

The most difficult item to translate into distance learning would be the *galley experience*, which tends to be very hands-on and interactive. One possibility is to use a multi-user VRML environment supporting shared events. Shared events make it so that events triggered on one client are broadcast by the server to all other clients, thus making interaction possible. Each client would be associated with an avatar, which would move around a virtual gallery space in the same way that a player traverses a level within multi-player games for game consoles and PCs. We plan to explore this in the Spring 2004 class.

10 Conclusions

The most fundamental aspect of Aesthetic Computing as an area, or sub-field, or even as a "strategy", is centered on the need to communicate across multiple fields from computer science to the liberal and fine arts. Leonardo [8] recognized this, and has been an active supporter of the area in terms of workshops and publication in its journal. Applying art theory and practice to computing stresses the converse of the more usual application of digital technology to the arts. Thus, it certainly seems logical to explore the "other side of the coin."

Apart from the general interdisciplinary goals, our studies on students in the Simulation and Aesthetic Computing classes demonstrated the following two results:

- Students enjoyed the technique, providing incentive for employing it.
- Students found that the technique improved their communication of technical concepts to others.

We are encouraged by these results, but also recognize that more empirical work needs to be performed especially for cognitive tasks. For example, one wonders whether the aesthetic computing approach improves memory, comprehension, or general problem solving? Some of these questions must be answered within the appropriate contexts, such as K-12 education since the questions are not relevant to university-level students who have already learned the core *traditional* notations prior to having been introduced to aesthetic computing. The university students can voice a preference for the method, but they are not capable of yielding more cognitively meaningful results based on their educational levels.

The technique as described in [15, 11, 16] is not meant to replace traditional notations and structures that are commonly found in mathematics and computing. If anything, they are meant to augment these, adding additional *perspectives*. While we cannot make any claims on increased learning, we have found that students enjoy interdisciplinary work, with the chance to blend both right and left-brain approaches in exploring novel notations for mathematics and computing.

Acknowledgments

The authors would like to thank the grant from the National Science Foundation (EIA-0119532) for sponsoring this work, and the students of all Aesthetic Computing classes for their voluntary help in focus group sessions and in completing the surveys. Paul Fishwick would like to thank his graduate students in the RUBE Project (Minho Park,

Jinho Lee, and Hyunju Shim) and a grant from the Air Force Research Laboratory (F30602-01-1-05920119532).

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