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Higgins Armory Virtual Swords Exhibit

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HIGGINS ARMORY VIRTUAL SWORD EXHIBIT

An Interactive Qualifying Project

submitted to the Faculty of

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in partial fulfillment of the requirement for the

Degree of Bachelor of Science

by

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1. Augmented Reality
2. Virtual Swords Exhibit
3. Virtual Armory

Professor Jeffrey L. Forgeng, Major Advisor

Abstract

This project created an experimental online interactive for the purpose of creating virtual experiences for patrons of the Higgins Armory Museum of Worcester, Massachusetts. The interactive delivers web-based augmented reality experience by leveraging the ubiquity of web cameras to bring select artifacts from the Armory's collection into households and classrooms across the world. The project team also compiled a research paper on the general history of swords. The backgrounds of the artifacts presented in the interactive are explored in depth.

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I. Introduction

The Higgins Armory Museum is a nonprofit educational institution located in Worcester Massachusetts. The museum houses one of the largest collections of weapons and armor in the United States. The collection contains primarily weapons and armor of European origin, as well as African, Indian, Japanese, and Islamic artifacts. In addition to the traditional display of arms and armor, the museum also hosts demonstrations and performances. Recently, the museum has also begun to display virtual exhibits as well.

In keeping with the theme of the Virtual Armory title, this project seeks to develop a virtual representation of artifacts in the physical Armory. Using computer techniques such as data matrix scanning and augmented reality, the goal of the project is to create a new digital experience for the Armory while retaining the tradition, history, and educational value of the all the artifacts currently in the Museum collection.

The idea behind the application was to allow patrons of the Higgins Armory Museum to be able to interact with artifacts in a new and interesting way. Artifacts are mounted on walls or inside display cases to protect them from damage and theft and to prevent injury to patrons. This can prevent patrons from fully viewing each artifact from all angles and interacting with the artifacts physically.

Allowing patrons to interact physically with the artifacts is not feasible. However, a virtual experience would allow the patron to see more of the artifact without the possibility of damage to either the patron or the artifact.

The application developed for this project allows patrons to hold, view, and manipulate 3D representations of swords from the Higgins Armory Collection. This is achieved through the use of a technology known as Augmented Reality. Unlike Virtual Reality, which replaces the users real world space with an entirely artificial one, Augmented Reality uses the real world space as a base and adds virtual elements to enhance it. These virtual elements are usually 3D models created with a computer modeling program. In Augmented Reality applications, the real world space the user exists in is captured in some way, usually through the use of a camera. The captured data is then redisplayed to the user, usually on a monitor, television set, or a head mounted display like video goggles. The space is then analyzed, and the digital component is layered on top of the projected image of the real world. This gives viewers the impression that the virtual objects are occupying the same real world space that they are.

To use the application, a data matrix known as a marker must be printed out. These markers are images that have been previously read in by a computer program and associated with a specific artifact at the Higgins Armory Museum. A web based application was developed which reads in the marker through a standard web camera. Once the marker image has been identified, the application finds the associated artifact. For each artifact associated with a marker image, a 3D model was created. The application then displays the real world as seen by the camera, then layers the 3D artifact model on top. For this project, all artifacts chosen were swords. The swords are placed in the window in such a way that it appears that the user is holding the sword. By moving the marker image, the user can move and rotate the sword, thus giving the impression that the user is interacting with the artifact. Additional information in the form of graphics and text provide educational content as well.

Above is an example of what a user can expect to see when using the application. The user and the space the user is occupying is captured by a web camera. When the user holds up a marker image, a virtual sword is added to the captured video. This window makes up one section of the project website.

In order to display the virtual component of the application, the 3D models, and to make creating a flash application for the web, the team decided to use a programming library known as FLARToolkit. FLARToolkit began as ARTookit, an augmented reality library written in C++, at the University of Washington. In an effort to increase the portability of ARToolkit, it was ported to Java and rechristened NYARToolkit. However, even NYARToolkit was not suited for internet applications. A group of Japanese developers, spearheaded by Tomohiko Koyama, ported NYARToolkit to

Actionscript 3.0, bringing the augmented reality toolkit to anyone with a Flash-enabled internet browser. However, FLARToolkit is simply a framework that provides the necessary interface between a graphics engine and the sensing equipment it utilizes. For our application we chose to use Papervision3D, a popular open-source 3D rendering engine compatible with Flash. FLARToolkit provided helper classes that made it easier to integrate Papervision3D into our application. The combination of FLARToolkit and Papervision3D allowed the team to create a Flash application which can connect to a users web camera, analyze each frame of the recorded video, identify marker images, and display and move 3D models appropriately.

The application itself was written in HTML in order to allow the team to put the final project up on the web. Patrons of Higgins Armory Museum will be able to have the virtual experience from home. The initial page only contains instructions on how to use the application, links to the marker images that can be printed out, and a link to the actual application.

The actual application displays a predefined set of information and a flash window. Once the user has allowed the flash to start, it immediately begins analyzing data captured through the users web camera. The user can then hold up a marker. Once this marker has been seen by the application and identified, the flash makes a call to a JavaScript function embedded in the page. This call includes the artifact accession number. Each artifact has its own xml file, which was generated from data contained in the Higgins Armory Database. Each xml file is named using the artifact's accession number. The file contains the object template data, which includes the name, date created, the location the artifact originated from, materials the artifact was made out of, the weight, and the artifact's location in the museum. Images and short facts known as blurbs are also stored in the xml. An xml file was created for all of the artifacts in the Higgins Armory Database, in order to speed up the process of adding more artifacts to the application at a later date.

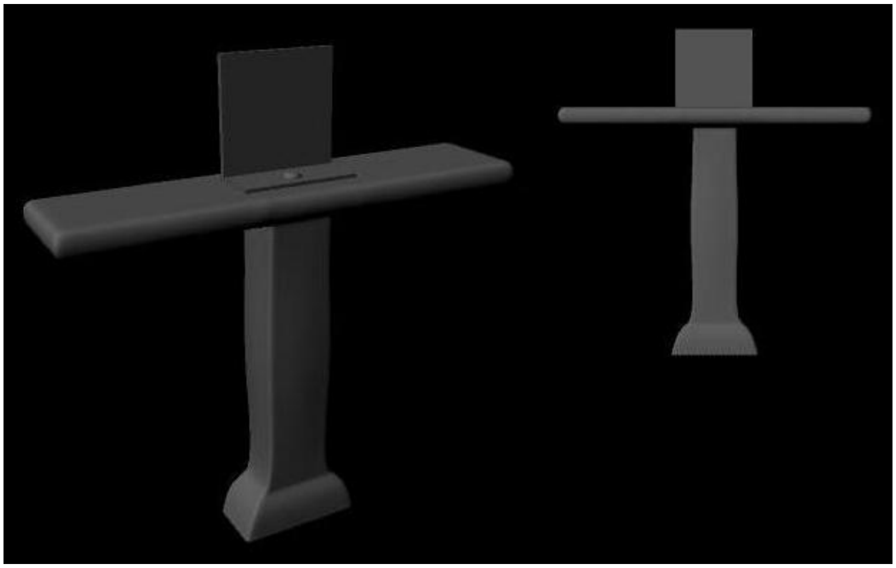
The JavaScript reads in the xml file and uses that data to update the webpage accordingly. The object template is displayed in the upper left hand corner. The blurbs are shown to the user three at a time and are replaced with new blurbs every twenty seconds. The upper right corner has the flash window, which updates itself without the JavaScript. The bottom right corner contains the two images.

If at any point the user holds up a new marker to the web camera, the flash will remove the old artifact from the screen and display the new one. A new JavaScript call will then be made to update the page with information relating to the new artifact. Each model used by the application was created using Autodesk Maya. Photos of each modeled artifact were taken at Higgins Armory Museum and used as reference. This process allowed the team to create models that had appropriate scales. The team tried to keep each model within 1,500 polygons in order to keep the frame rate of the flash window within a reasonable range. All models were triangulated, made up if only triangle polygons, so they would be compatible with the programming library used to display them. The models that exceeded the 1,500 polygon limit were "decimated", a process which removes unnecessary polygons, using Pixologix ZBrush's Decimation

Master plug-in. All models were also converted to the Collada format, .dae, to further provide compatibility with the programming library used.

Past projects with Higgins Armory Museum have included a significant research component. The team agreed to perform background research on swords and metallurgy from around the world, as we had already decided upon swords as our application's focus. Each team member selected four areas to research, resulting in twelve areas total. These places are Africa, Eastern Asia, Southeast Asia, Islamic Weapons, Rome, Greece, Viking Weapons, Medieval Weapons, Europe, America, and Renaissance Weapons. Swords were chosen from these areas to use in the application. Each sword has associated facts which were written based on the research done by the team.

During C term, the team prepared a live demo in order to gauge interest and find potential issues with the interface. The demo was held at Worcester Polytechnic Institute Gordon Library. The team brought a laptop with a web camera and an internet connection to run the application. The marker images were affixed to mocked up sword hilts made by Bob Henning. When a user held a sword hilt up to the camera so the marker image could be seen, the virtual sword would be overlaid on top of the sword hilt, which the team hoped would make the user feel as if they were interacting with the real artifact.



Above is a 3D model of what the team wanted the mock up sword hilt to look like. Bob Henning used this design to create a two wood and plexiglass hilts for the team to use in the library demo.

Students visiting the library could use the application and optionally fill out a survey about their experiences. The team members watching over the laptop made additional notes about behavior of the participants and how they used the application. By exposing a preliminary version of the application to the WPI student body, the team was able to gain valuable insight into some potential features and problems. Most surveyed students greatly enjoyed the flash portion of the application, which allowed them to hold and manipulate a 3D sword. However, the remaining portions of the application went largely unnoticed by participants. The team made further changes to the interface based on the received feedback.

At the end of the project, the team had created a working prototype of a virtual sword exhibit with multiple sword models. The application was successfully hosted online. A large number of files were generated to make future extension by other teams faster and simpler, since they require little to no technical knowledge to edit and then add to the application.

II. Augmented Reality (Elizabeth Labelle)

Augmented Reality is a type of Virtual Environment. It is most commonly compared to Virtual Reality, the most common of Virtual Environments. Augmented Reality is the technology of taking the real world perceptions of a user, including visual, audio, haptic (touch), olfactory (smell), and gustatory (taste) perception, and adding a virtual component on top of them. In this way, Augmented Reality enhances the world that is already there, rather than making an attempt to replace it.

Virtual Reality, by contrast, seeks to eliminate the real world perceptions of the user. Virtual Reality then seeks to create an entirely new virtual world to replace the real world. The virtual world can again include any or all of the five senses.

A typical set up for an Augmented Reality application involving only the user's sense of sight is as follows. First the real world component must be recorded in some manner. There are two main ways of doing this. The first is more literal, which involves using a camera or video recorder to take images or video of the world occupied by the user. This video is then redisplayed to the user in some way, usually on a monitor or television screen. The second involves giving the user a device which would only display the virtual components. In many cases, this is a set of glasses which allow the user to see through them to see the world. Virtual components can be added to the glasses. By looking through the lenses, the person would see both the real world (which they would be seeing anyway) plus any virtual elements projected on the glasses.

Next, the world is analyzed. How this is done, and what the analysis is looking for, differs from application to application. Once the world has been analyzed, the

Augmented Reality application decides what virtual elements to add to the scene and where to add them. In the case where the world is projected onto a monitor or television screen, the output video is edited to superimpose or composite the virtual images into the scene. In the case where the user is wearing a set of glasses, for instance, the virtual elements are simply displayed in the glasses. The space not taken up by the virtual elements are still transparent, allowing the user to continue to see the real world.

We chose Augmented Reality for our project because Virtual Reality would have required the team to recreate too many factors that were already available in the real world. The team would have had to digitally model and project in some way a representation of a room, the user, the digital swords that are the focus of the project, as well as any additional objects we would have wanted to exist in our application. Since a web camera can record video of a person in whichever room they happen to be standing in, the team would only need to model the virtual swords, a much faster and simpler process. The swords could then be added to the already present world.

The Augmented Reality in this application involves taking input in the form of video from a standard web camera. This video becomes the basis for our output. Even when not adding virtual components, the real world component will always be visible. This video is redisplayed to the user in the form of a flash application. A window on screen shows a video of whatever the web camera records. Through the use of Data Matrixes, simple black and white images that can be seen by a web camera, the application is able to track movement within the recorded video.

The ability to record and track movement in the world becomes an important one. The current position of the Data Matrix, which includes height, width, depth, and rotation away from the camera, is used to position a three dimensional model in the scene. The application assumes that the Data Matrix is being held by a person in their hand, and attempts to display the model in such a way that the person appears to be holding it. Additionally, since the video is constantly changing as the web camera records the video, the any change in position of the Data Matrix can be registered by the application and used to reposition the virtual model.

In this way, Augmented Reality takes the real world space of the person, which includes the room they are standing in, the person themselves, and the presumed position of the person's hand via the Data Matrix, and layers the sword on top. This layering will hopefully have the effect of making the person feel as if the sword is occupying the same space as them.

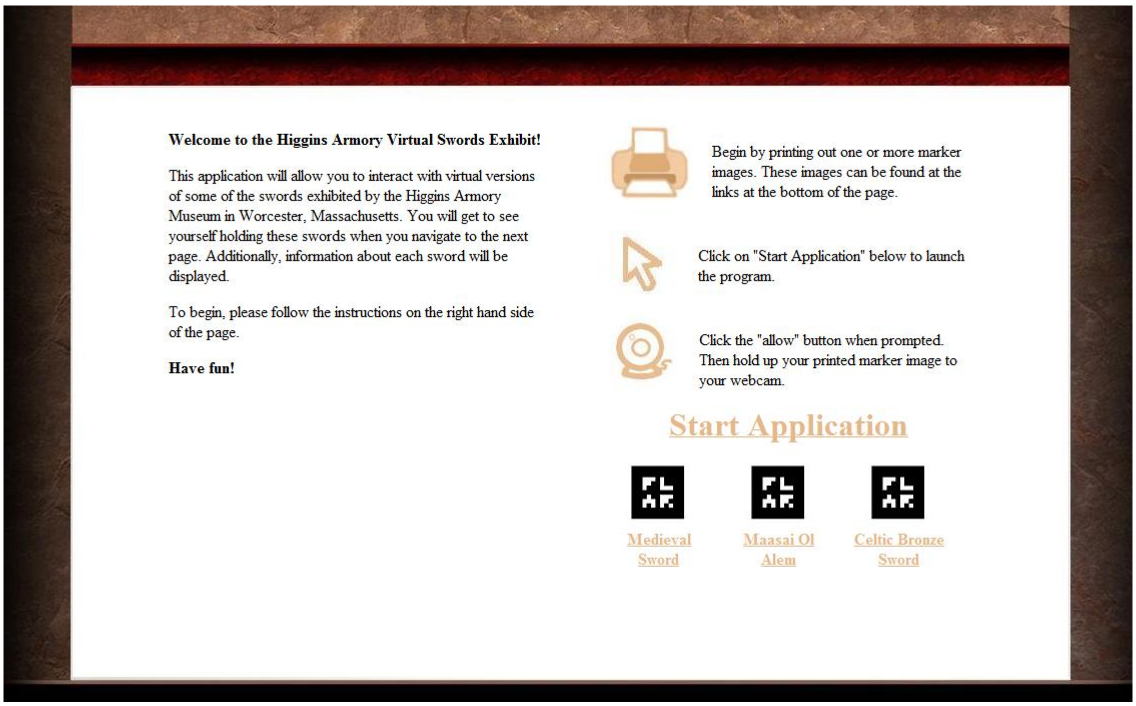
III. Application

1. Application Overview (Patrick Dignan)

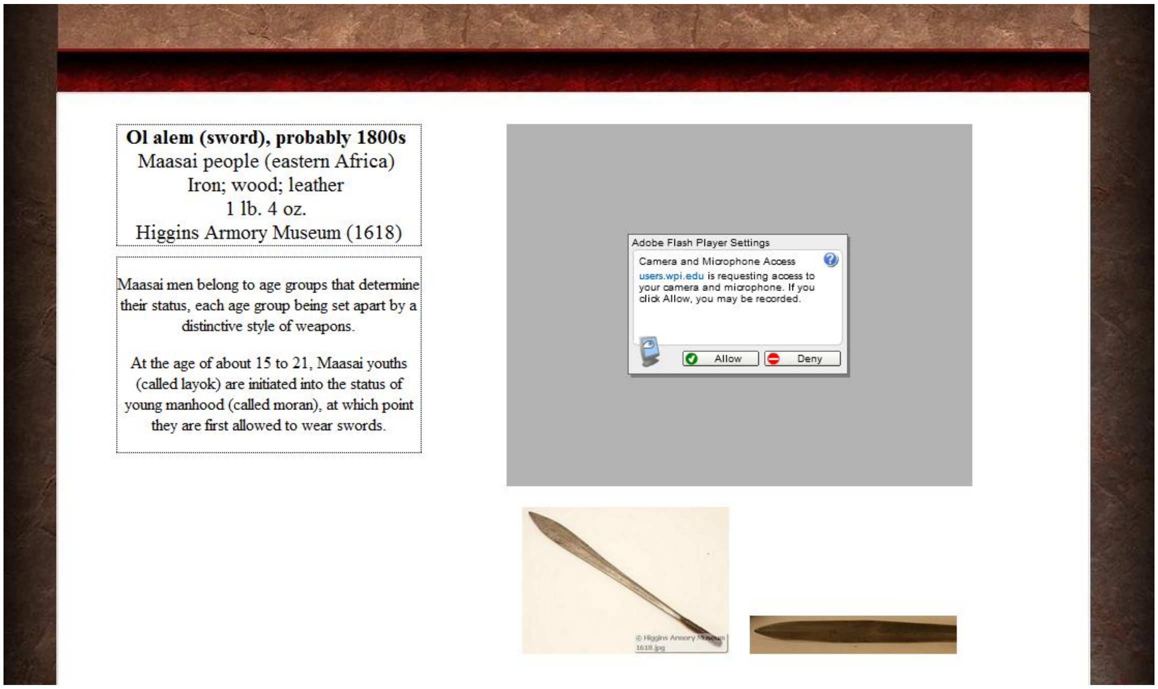
The project's overall goal was to create an easy to use, fun, and interesting experience that would bring the museum to life in ways that simply looking at arms and armor in a glass display case never could. Museum artifacts on display can not be physically interacted with by museum patrons due to safety concerns for both the patron and the artifacts themselves. Part of the team's initial research phase involved being able to interact with some of the artifacts located at the museum. The team enjoyed being able to interact with the artifacts in a more personal manner, and decided to target the project toward attempting to give museum patrons a similar experience.

The interactive is intended to create an educational experience that draws visitors in and while helping them learn in fun ways. The interactive takes advantage of a new technology known as Augmented Reality. In this project, Augmented Reality is used to show the visitor holding a full sword on the computer screen, when really all they are holding is a mock hilt or a piece of paper.

In order to accomplish this, a web site was developed using HTML, CSS, JavaScript, Flash, and XML. The web site has two web pages, one introducing the visitor to the application and one containing the application itself. The application is how our interactive is purveyed to the visitor. The visitor is introduced to the application with a brief instruction page that explains what needs to be done for the application to work properly. In order for the application to work as intended, a web camera is needed, such as is often built into new laptop computers. In addition, the Adobe Flash software is needed, and the software needs to be of at least version 10. The Flash software is almost always already installed on a visitor's computer, as it is required for many popular web sites, such as YouTube.



Above is the introductory page the user is first directed towards. This page contains a brief introduction to the exhibit, as well as instructions for how to find and print marker images. It also lets the user know that they will need a web camera and that they must hold up their marker images to the camera. A link then directs users toward the main application.



Above is a screenshot of the main application when the user first visits the page. The upper right corner contains the object label, which provides a description of the artifact. Below that are blurbs, short educational facts, which cycle every 20 seconds. The flash window is currently asking for the user's permission to access the web camera. Below the flash are two images of the selected artifact.

Augmented Reality, in the manner that the team's application implements it, requires a two dimensional image known as a Data Matrix or marker image to know both when to respond to actions and how to respond to them. For the purposes of the application, small black and white images were used as markers. When the web camera "sees" this marker, the application knows to produce an associated three dimensional model. These models were created using a computer modeling program, such as those used in the movie and video game industries.

The introductory website has links to other web pages containing pictures that can be printed out and used as markers for the application. So the basic flow of how a visitor to the web page would use the interactive begins with them reading the instructions. Next, the visitor would know from the instructions to click one of the several links at the bottom of the page linking to images of markers. The visitor must then print out at least one of these marker images. Next, the visitor would return to the introductory page, and click on the link to the main application page. The main application page loads with an initial set of information, currently about a sword called the Maasai sword. Then the visitor should position the marker in front of the camera at a distance between 1 foot and 8 feet. A sword will then appear on the screen based on where the visitor positions the marker. The visitor can then move the "sword" around on the screen by moving the marker around physically.

2. Application Content

2.1 Flash Application (Elizabeth Labelle)

The flash application is the Augmented Reality portion of the interactive. This is the section of the site which allows users to see themselves holding a virtual sword. This is accomplished through the combination of a number of different technologies.

The first of these technologies is a Data Matrix, which is more commonly known as a marker image. These images are simple, 2 dimensional, black and white pictures which can be printed out by a user of the interactive. Eventually, the goal of the project is to get the web camera to register a marker image whenever it sees one. In order to do this, each marker image must be scanned by a program to create a pattern file.

Above is an example of a typical Data Matrix, or marker image, as used by our application. It is easy to see how the image is broken down into blocks of black and white colors. The white border around the image was added by the team to make it easier for the camera to recognize the pattern.

A pattern file is a computer representation of an individual marker image. The image is scanned by a computer program and broken up into a two dimensional grid of pieces, where each block in the grid is a solid color. This grid forms the pattern file. The flash application takes each frame of the video and searches it for these blocks of color. When it finds these blocks, it compares the layout to the pattern files loaded into the application. If the layout of blocks in the video matches the layout of blocks in the pattern file, then the program can confidently say that it sees the marker image and display a sword. The number of blocks the program must see before it confirms a match can be adjusted. By allowing only 50% of the blocks to be correctly identified before having the program confirm a match, the amount of jitter in the application is reduced. This is because it is very unlikely that every section of the marker image will be correctly shown to the screen due to the lighting and angle of the scene.

The pattern files are loaded into the application code, which gives the program a reference to use. However, being able to recognize which sword to display does not give the program the ability to do the actual display. For that, FLARToolkit was utilized. FLARToolkit, which stands for Flash Augmented Reality Toolkit, utilizes a rendering library called Papervision3D to display the models as an overlay on top of a flash window.

Before the program can display the model, it must first know where to place it, and how big to make it. This is achieved by trying to figure out the orientation of the marker image, which is the tilt of the marker image in the x ,y, and z planes as well as its distance from the camera. FLARToolkit figures out the tilt of the marker image based on the corners of the image. By comparing the location of each corner, and remembering that the marker image is almost always a square, it is possible to approximate its tilt in relation to its normal upright form. The distance away from the screen is gotten by comparing the size of the image in the video frame to the size of the marker image, which is saved in the pattern file.

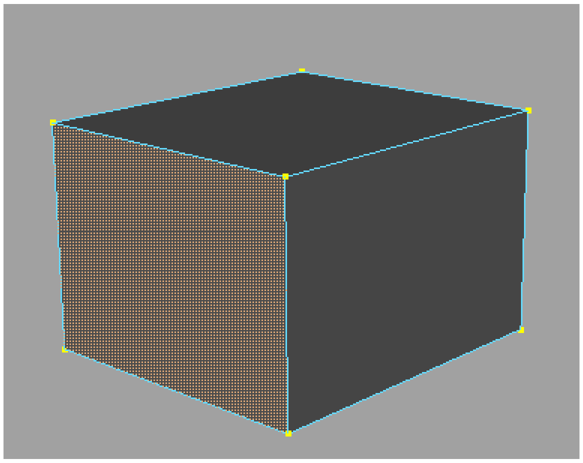
Once the size and orientation of the marker image is confirmed, the program takes the 3D model loaded in the code and performs a scale and rotation operation on it to match that of the marker image. The model is then overlaid directly on top of the marker image on screen. Optimally, the sword model would cover the marker image completely, giving the user the impression that they are only holding the sword, and not the marker image.

FLARToolkit provides all of the standard features of a flash application in addition to the Augmented Reality and 3D model rendering capabilities. This allowed us to only have to deal with one programming environment while developing the application.

2.2 3D Models (Elizabeth Labelle)

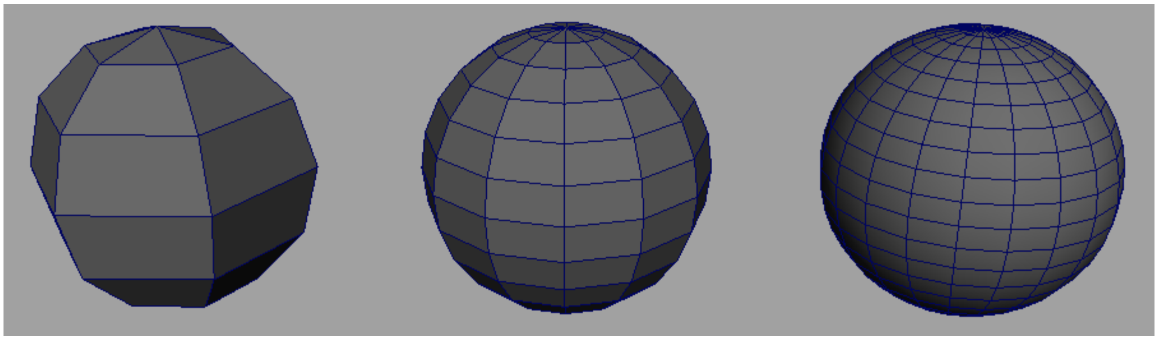
To allow our application visitors to feel as if they were actually holding a sword, 3D polygon models were created. The team used an application called Maya which was developed by the company Autodesk to create the models, although any 3D modeling tool could have been used in its place.

3D models can be broken down into three parts: vertices, edges, and faces. A vertice is a single point in a model. This point has an x, y, and z coordinate which lets the computer know where the point is in relation to every other point. An edge is a straight line drawn between any two points. A face is created by using edges to form a closed shape. The simplest shape is a triangle, which is made out of three points and three edges. Faces are usually categorized as being either a triangle (tri), a quadrangle (quad), or an n-gon for a face with more than 4 edges. The number of faces is equal to the number of polygons, and the terms can be used more or less interchangeably.



Above is a 3D model of a normal, six sided cube. The yellow dots are the vertices. The blue lines are edges. The orange square indicates one of the six faces, also known as polygons.

In polygonal modeling, since all shapes are made up of straight lines, it is difficult to create curved objects. The usual technique of implying curvature is to increase the number of vertices and edges to smooth the shape. This is commonly achieved through the use of subdivision, wherein every face in the model is divided into smaller faces. This can be done any number of times until the desired look is achieved. However, the increase in the number of vertices, edges, and faces increases the amount of time it then takes the computer to display the model.

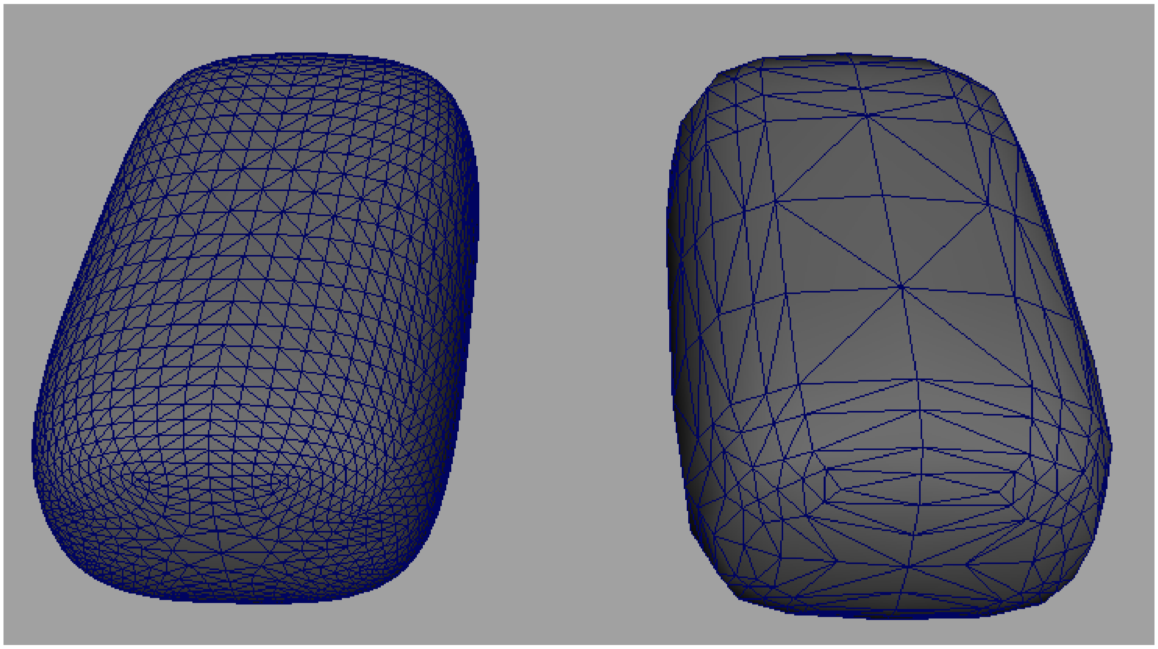


Above is an example of how subdivision creates a smoother surface. The left most model has 36 polygons. The middle model has 144 polygons. The right most model has 400 polygons.

The team took a few days to fine tune the number of polygons our application could display at a time before a noticeable frame rate drop occurred. The application was tested by taking a simple cylinder shape and associating it with a marker. The cylinder was then slowly subdivided and tested in the application over and over until the team noticed the video start to become lagged, or choppy. Both the team's experience and the documentation of the library indicated that the maximum polygon count of the models should be 1,500.

In the cases where the models exceeded this limit, a program called ZBrush, which was developed by the company Pixologic was used. Unlike Maya, ZBrush is a sculpting application, where a model is treated more like a ball of clay which can be manipulated. For sculpting to be effective, a large number of polygons are usually needed. It is not uncommon for ZBrush sculpts to have polygon counts in the millions. While this creates very detailed models, it is very difficult for computers to display them in a short amount of time. There have been a number of methods and tools developed to reduce the cost of displaying to a reasonable level.

In our case, the team used the Decimation Master plug-in for ZBrush to reduce our polygon count. Essentially, the plug-in looks at the model and identifies areas where faces are essentially flat or contiguous along a plane. In these cases, combining the faces into one larger face does not affect the shape of the model. The plug-in is capable of reducing models from millions of polygons down to hundreds of thousands of polygons. Our reduction was not as impressive, but we were able to reduce our models to within our 1,500 polygon limit.



Above is an example of how a model might be “decimated”, or have its polygon count reduced. The model on the left is the original mesh and the model on the right is the same mesh after a rudimentary decimation. This process brought the polygon count from 4608 polygons to 592 polygons. Most of the detail was removed from the center of each “side”. The edges, which need to be rounded and thus need more polygons to approximate smoothness, have more polygons left over once the process is done.

At the end of the modeling process, each model was triangulated, meaning all polygons were converted into only triangle faces. This was done because Papervision3D currently only works with triangular faces. The files were then saved in the Collada format with the extension .dae in order to be imported into our flash application.

Each model took approximately three hours to complete without textures as a low polygon model. It is estimated that an additional two or three hours would be needed to add textures. The team tried to be as accurate as possible by using reference photos of the artifacts that were taken in the museum. By putting these images in the background of the modeling program, the team was able to “trace” over the photo in three dimensions to keep the proportions of each model correct.

2.3 Educational Content (Elizabeth Labelle)

In addition to the augmented reality flash component, the website also contains areas which display educational content. The upper right hand corner displays the object label of the currently selected artifact. The object label is a short description of a particular artifact. The object label has the title and the artifact date in bold on the first line. The second line contains the area where the artifact was used. The third line contains the materials the artifact was made out of. The fourth line has information about the weight and size, if available. The last line contains the museum where the artifact can be found and its database accession number.

Below is an example of an object label. The artifact with accession number 1618 was used to generate it.

Ol alem (sword), probably 1800s
Maasai people (eastern Africa)
Iron; wood; leather
1 lb. 4 oz.
Higgins Armory Museum (1618)

Below the object label are a series of cycling blurbs. A blurb is a short fact about the currently selected artifact. Each member of the team did background research on specific areas of the world. Each team member then selected an artifact from their areas to use in the application. The research that was done for each area was then used to write each of the blurbs.

While the application is running, a set number of blurbs are displayed on the screen at once. After a set period of time, those blurbs fade out, and the next set of blurbs fade in to take their place. This cycling of blurbs was done for two reasons. The first reason was to conserve screen space, especially since the team could not enforce a particular screen size, as the application would be hosted online for anyone to view. The second reason was to have some additional movement on the page, to draw the viewer's eye to parts of the page other than the flash application. We had noticed that participants using the application tended to focus on the flash application, to the exclusion of all else.

Underneath the flash application are two images of the selected artifact. Originally, these photos were added to show close up detail of the artifacts, since the flash application was limited in the amount of detail we could display. The images also give the user an idea of what the artifact looks like, as the flash application models do not have textures which would show this.

When the user first visits the main application page, a preset artifact is loaded into the page based on an XML file. As soon as the user holds up a marker to their web camera, the flash application identifies the corresponding artifact and sends a message to the website. This message contains the artifact's accession number, which are a unique number and what the team is using to distinguish each piece. Once the website receives the message, a JavaScript function finds the XML file associated with that artifact. The name of the XML file is the accession number, with the .'s replaced with _'s in order to normalize file names.

Once the correct XML file has been identified, the JavaScript function reads in the file and uses the contents to update the object label, blurbs, and images on the screen. No refreshing of the entire page is necessary, so the flash application is never interrupted.

Higgins Armory Museum has over 4,300 artifacts currently in their online database. In order to allow any of these artifacts to be added to our application, it was decided to create an XML file for all of them. Rather than write each XML by hand, the team decided to write a program to convert the database file into the XML files needed. The Higgins Database is stored as a Microsoft Excel file. An API known as JExcel, or JXL can read, write, and modify Excel spreadsheets using Java.

To use the program, the excel database file is added to the Excel folder, which is at the same level as the Java program. The Excel file sheet that needs to be read should be named "Sheet1", which is the default name for Excel sheets. Once the application is run, the program prompts the user to enter the name of the Excel file. The user can enter the name with or without the .xls extension. The program then searches the Excel folder for that file. If the program does not find the file, the program ends. If it does find the file, the program begins converting each line into an XML file. Each XML is then saved in the XML folder. In the event that an XML file already exists, that file will be overridden with a newly generated version. The XML fields have been formatted using some escaped characters, in order to store the desired HTML formatting within the XML file.

Currently, the fields that are used to generate the XML file are the artifact accession number, StdTerm, ProbDate, Origin, Materials, Measure, Weight, and Label Text. The blurbs are by default generated by reading the Label Text column and creating a separate blurb for each sentence. Image tags are added to the XML, but the database does not contain image data, so they are left blank. Once each XML file has been generated, it can be modified using any text editor to add or change the information that will be displayed.

Below is an example of an XML file generated in this way.

```
<?xml version="1.0" encoding="UTF-8" ?>

<artifact>

        <photo1></photo1>

        <photo2></photo2>

        <blurbs>Africa did not have a copper or bronze age. Most bladed weapons were
instead made of iron.</blurbs>

        <blurbs> Iron was usually smelted in Africa through a process known as
bloomery smelting.</blurbs>

        <blurbs>African iron was thought to have mystical properties. Weapons made
for high ranking individuals were only made using local iron ore.</blurbs>

        <blurbs>This is a sword used by the Maasai people, who live in Kenya and
Tanzania.</blurbs>

        <blurbs> At the age of about 15 to 21, Maasai youths (called layok) are initiated
into the status of young manhood (called moran), at which point they are first allowed
to wear swords.</blurbs>
```

```
        <blurbs>Maasai men were grouped according to age. Each age group has a
distinctive style of weapon.</blurbs>

        <label> &lt;b&gt; Ol alem (sword), probably 1800s &lt;/b&lt;
&lt;br/&gt; Maasai people (eastern Africa)
&lt;br/&gt; Iron; wood; leather
&lt;br/&gt; 1 lb. 4 oz.
&lt;br/&gt; Higgins Armory Museum (1618)
        </label>

</artifact>
```

The < and > used in the above XML represent < and > respectively. They are used to create the <br/> and <b> tags needed to format the HTML. The above XML was generated based on the database entry for the artifact with accession number 1618.

IV. Library Demo (Matthew Lyon and Elizabeth Labelle)

For the two weeks from February 8, 2010 to February 19, 2010, the team showed a demo of the application. This demo was shown at Worcester Polytechnic Institutes Gordon Library. A table was set up just to the right of the entrance, to attract the attention of as many students as possible. A laptop with a web camera and an internet connection was set up, which students could use to test our application, which we had hosted online.

Additionally, mockup sword hilts had been made for the team by Bob Henning. These sword hilts had a short two inch piece of plastic affixed where a sword blade would normally be. The marker images were attached to these plastic tabs. When a student held up the sword hilt to the camera, the 3D sword model would overlay the sword hilt and plastic tab, giving the student a greater impression that they were actually holding a sword, rather than a piece of paper.

Because we chose to conduct a pilot program with a survey, we needed to liaise with the Institutional Review Board at WPI to ensure we were conducting a safe and ethical human trial. Over the course of several months, we compiled and presented all of the necessary documentation to the IRB who readily approved our survey as it posed no direct or indirect harm to any of our trial participants.

We did run into a few problems during the application process. We believed that our trial was simply a survey, meaning we could apply for exemption. As it turned out since we wanted our subjects to fill out a survey after interacting with our project in some manner we had crossed the exemption bounds. A further problem we were worried about was a formal informed consent process. Typically, a participant would be required to read and sign an informed consent document. However, our demo was designed to be quickly completed and the informed consent process would've taken longer to complete than the demo itself. Thus we were worried we would lose out on potential participants. Luckily, the IRB understood this and allowed us the stipulation of an oral consent process whereby we could simply inform the participant orally, cutting down on the amount of time needed by a great amount.

At the end of each test, students were asked to fill out an optional survey. The questions asked on the survey are shown below.

Which part of the demo interested you the most?
A. The virtual swords
B. The background information presented
C. The questions posed / educational potentials

Which aspect of the demo should we focus on improving?
A. The virtual swords
B. The background information presented
C. The questions posed / educational potentials
D. The user interface (how everything was presented)
E. Other ____

Was the demo educational?
No 1 2 3 4 5 **Yes**

How easy was the demo to use?
Difficult 1 2 3 4 5 **Simple**

What did you like about the demo?

What did you dislike?

Would you change anything?

With regards to the user interface:

A. The text was too big.
B. The text was too small.
C. The layout made it difficult to understand / navigate
D. Other ____
With regards to the virtual swords:
A. The video was too choppy.
B. Swords did not look realistic.
C. Not entertaining enough.

Roughly half of the students who participated in the demo filled out a survey. The results of these surveys are shown below.

Which part of the demo interested you the most?
# of A's *"Virtual Swords":* 10
# of B's *"The background information presented":* 1
# of C's *"The questions posed / educational potentials":* 1
Other Comments:
What background info?
Unaware B and C were presented

Which aspect of the demo should we focus on improving?
# of A's *"The virtual swords":* 4
# of B's *"The background information presented":* 2
# of C's *"The questions posed / educational potentials":* 1
# of D's *"The user interface (how everything was presented)":* 5
Other:
Read, then play
The sword reacts strangely compared to experience with a real sword, though it could just be the rendering.
Frame rate

Was the demo educational? (No 1 2 3 4 5 Yes)
# of 1's : 2
# of 2's: 0
# of 3's: 5
# of 4's: 0
# of 5's: 5

How easy was the demo to use? (Difficult 1 2 3 4 5 Simple)
# of 1's: 0
# of 2's: 0
# of 3's: 0
# of 4's: 0
# of 5's: 12

What did you like about the demo?

Sword holding is a neat concept
Quick, easy, and sharable
I liked playing with the sword
You wield a virtual sword!
It was interesting (different)
Very easy to use – very cool
Looks nice – accurate rendering
Virtual Swords
Self-explanatory

What did you dislike?

Too small of a sword
Nothing in particular
The video rendering was extremely choppy.
The video is too choppy.
Nothing
Cannot see side of blade
Nothing
Graphics

Would you change anything?

Multiple swords!
Limit it to not only be able to track when the image is seen
If you could add sound for it in some way that would be sweet (someone speaking or sword sounds)
Interface to actually show info clearly
I didn't realize there was text. It needs to be bigger. Also, possibly add different types of swords.
Improve the video
Nothing
Make it so you can see the side of the blade
Incorporate the edu bits into the video
Better graphics

With regards to the interface:

# of A's *"The text was too big"*:	0
# of B's *"The text was too small"*:	3
# of C's *"The layout made it difficult to understand /navigate"*:	1

Other:

There was text?
What text?
Need to elaborate
Combine everything into the video interface

With regards to the virtual swords:	
# of A's *"The video was choppy"*:	7
# of B's *"Swords did not look realistic"*:	0
# of C's *"Not entertaining enough"*:	1
Other:	
Inverse action (mirror image) was confusing	
Looked great!	

For the students who did not choose to fill out a survey, the team was able to obtain a small amount of information by watching how they interacted with the application. The most common response about the application was that the participants were unaware there was text on the screen. In a number of cases, the participants only became aware of the text when they read the survey questions asking about it. In some cases, participants went back to the application to see the text and gave us more verbal feedback.

The team determined that the flash application was occupying the majority of the participants' attention. The flash is a moving component which actively takes input from the user and responds, and is arguably the most interesting part of the application. While the team was happy the flash was interesting, it was decided that an attempt should be made to make the viewers more aware of the other portions of the page.

The application page was redesigned to push the flash more to the right of the screen to take up less of the viewing space. Additionally, the blurb section of the site was altered to have fade effects. The idea was that the minor motion of the fading in and out of text would attract the users' attention. The text of all areas of the page was additionally made larger.

Overall, participants in the Library Demo enjoyed the ability to hold and manipulate the 3D model. Many suggested that additional swords should be available. The team had already planned to incorporate more swords, but only one model had been created at the time. Participants also noted that the frame rate of the application was very low, and unpleasant. Modifications were made in an attempt to increase the rate to make the video seem smoother.

V. Technical Limitations (Matthew Lyon)

From the beginning of our project, we knew that we wanted to develop a Flash-based application specifically for its portability. Developing in Flash meant that we could open our application up to anyone with a browser, a web camera, and an internet connection. Otherwise, we would've been limited to specific platforms and operating systems, with no guarantee of cross-platform compatibility. However, Flash has no native support for 3D rendering, so it was essential that we find an open-source library that would provide the features we needed without degrading the experience.

Papervision3D is the 3D rendering solution currently utilized in the application. It was primarily chosen for its native integration with FLAR. FLAR came with pre-written helper classes for PV3D that made it much easier to interface between the two libraries. While there were other 3D options available, none of them seemed as fully-featured and ready for immediate deployment as PV3D. However, PV3D is still bound by the limitations of Flash. Seeing as Flash is meant to present a multimedia experience and not render 3D graphics in real-time, we had to balance the accuracy and detail of our models with the frame rate of the application. For instance, we limited the number of polygons per model to no more than 1500. Despite this limit, our application still cannot get much more than 20 frames per second on average.

Furthermore, even if rendering weren't a problem, we would still be limited by our hardware. Unless someone is using a very expensive web camera, it's likely that their webcam records at 30 frames per second at most. That means that the fastest we can have the camera check its view for a marker is thirty times per second. Thus even if we could render faster than 30 fps, our motion tracking could not perform above that level and interaction would feel sluggish at speeds faster than the capture rate of the camera.

Browsers are yet another technical limitation the project had to work around. While Flash is supported by all major browsers, there's still the problem of users either not having Flash installed in their browser or having the wrong version of Flash installed. Because of the libraries being used in the application, it only works with Flash Player 10. While worldwide penetration was initially a concern, statistics available from Adobe indicated worldwide ubiquity of upwards of 93%. That being said, we still ran into problems, not with embedding the Flash, but with varied HTML compatibility across browsers. It took several iterations to get the website into a state that was at least viewable across multiple browsers and more still to get it working properly across Internet Explorer, Firefox, and Chrome.

The documentation for both FLARToolkit (FLAR) and Papervision3D (PV3D) presented itself as another technical hurdle. In the case of FLAR, much of the library was commented only in Japanese, rendering the comments indecipherable. While it was possible to follow along strictly with the code, at points the code was too complicated to make any sense of it. In the case of PV3D, there was no useful API available, aside from reading through the poorly commented code of the entire library and hoping it made sense.

VI. Individual Research Papers

1. Africa (Elizabeth Labelle)

1.1 African Iron and Blacksmithing

Unlike many places in the world, Africa did not have a distinct Copper or Bronze Age. Copper was scarce in many parts of Africa, and therefore could not be easily used to create copper items or bronze items, since bronze is a mixture of copper and tin. Iron, copper, bronze, and brass were all came into use in Africa around the same time. (Reid, 1)

African iron smelting and forging began sometime between 1600 and 1400 BC. Early iron-working centers in Africa were Tanzania, Nok and Taruga in Nigeria, Meroe in the Sudan, and the Lake Victorian region of eastern Africa (Coe, 206) (Stock, 102).

The newfound technology of metals caused a profound impact in Africa, which previously had been relying heavily on stone tools and weapons. Tools created using the new metal caused an increase in agriculture, hunting, and warfare. This increase made it possible to create and sustain larger urban communities (Ross, 1).

Iron ore in Africa was the most abundant source of metal. As a result, it was the most commonly worked with. The iron ore was smelted using a process known as bloomery smelting.

A bloomery was usually a pit or a structure with a chimney-like top. The walls were as heat resistant as possible and usually made of dirt, clay, or stone. Near the bottom of the structure were one or more openings, which allowed air to enter the furnace, called tuyeres. A bellows could be used to pump in more air if the opening was not sufficient (Sauder, 1).

Iron found near the crust of the Earth is usually found as iron oxide. To get a pure iron, the oxygen needs to be removed. Wood was burned in the bloomery to create charcoal, which produced carbon fuel. Iron ore was then broken down into small pieces and heated above 900 degrees Celsius. The carbon monoxide would bind with the oxygen in the ore, which formed carbon dioxide and left the pure iron behind. Eventually, that molten iron fell to the bottom of the furnace.

This iron was mixed with impurities known as slag, which was usually composed of oxygen, silicon, iron, and other impurities present in the ore. The heat of the bloomery liquefied the slag, most of which would flow out of the iron and collect at the bottom of the furnace, though some slag always remained trapped in the meat;/ The mixture of iron and slag was called a bloom.

The bloom was very porous, and the spaces filled with slag. A smith took the bloom, reheated it, and hammered it to force out as much of the slag as possible. The result was wrought iron, which could then be forged into its final shape (Sauder, 1).

African smiths were in charge of turning the wrought iron into more useful forms. In Africa, the art of working metal was considered a form of creation. It was thought that spirits, spells, and sorcery could all interfere with the forging of metal. Smiths learned rituals in order to counteract these effects. Since special training was required to become a blacksmith, only the children of blacksmiths were allowed to become blacksmiths (Reid, 5).

Blacksmiths created weapons, tools used for agriculture, and currency used for trade. This gave them enormous influence over African wealth and development. The smiths were often called upon by village chiefs for counsel, which gave them a great deal of influence. However, they were also feared by many people because of the mystical power they were believed to possess (Coe, 207) (Reid, 5).

The iron itself was also thought to have inherent mystical properties. These properties were thought to be specific to African metal. Upon the introduction of foreign ores and metals as trade increased, items of particular importance were crafted from only those metals mined in Africa (Coe, 207).

The swords created with the worked metal were used for a number of different purposes. In many communities, when a boy came of age he was allowed to carry a weapon, and often did. Swords were used for ceremonial purposes, and only carried during those times. Others were used to show rank. Weapons used as a sign of rank were well made, often with iron mined in Africa. Many such blades were also decorated with bronze or copper, and had wire inlays in the hilts (Coe, 207, 214).

Weapons were also used for trade. Smiths crafted ineffectual blades which were dull and not specifically shaped to be used as weapons. These blades were then used as currency when trading. In addition, real weapons also became used for the same purpose. The currency blades were also often repurposed and used as weapons (Coe, 207).

2. Japan (Elizabeth Labelle)

2.1 History and Forging of the Japanese Sword

In Japanese, the term *katana* refers to any single bladed sword. However, over the years the term has been used to identify one sword in particular. Now the term refers to a Japanese, single edged blade with a slight curve, measuring at least 60cm.

Chokuto Blade (Irvine)

The shape and style of the *katana* has changed drastically over the years. By studying the curvature of the blade, the length, and the metal used, it is possible to estimate when the blade was made (3, Morimoto). The term *koto*, meaning old sword, is used to refer to blades made before the Muromachi Period, which began in 1333. *Shinto*, meaning new sword, is used to refer to blades made in the Momoyama and Edo Periods, lasting from 1573 to 1603 and 1603 to 1868 respectively (Tanobe).

Tachi blade (Irvine)

Beginning around 400 AD, the blades known as *chokuto* were made. These blades were straight, had a single cutting edge, and were made of high carbon steel. The *chokuto*'s cutting edge was better than bronze weapons of the time, but was not strong enough to be used for extensive warfare (Morimoto, 3).

Starting in 500 AD, the Japanese swords began to develop a curved blade. The blades were also made to be longer, and designed to be easily wielded with one hand. During the Heian Period, blades known as *tachi* and *tanto* were made (Tanobe) (Morimoto).

The time from 1185 AD to 1333 AD is known as the Kamakura Period. During this time, Japan was under military rule. The blade style changed again during Mongolian invasions in 1200 AD. The old design of the blades made it easy for them to chip and crack while the length of the blade made them difficult to use in close combat.

Katana Blade (Irving)

The solution was to create a blade with a soft core of metal and a stronger outer metal cover. The soft inner core provided flexibility to resist repeated strikes while the hard outer jacket held a sharper edge. The *tanto*, *uchigatana*, and *katana* were developed during this time. These blades were more effective in close quarters combat.

Conflicts in Japan continued until the middle of the sixteenth century. As a result, blades were rapidly produced, and the overall quality of each piece went down. Afterwards, sword smiths refocused their efforts on the craftsmanship of each sword. These blades were commonly used as a symbol of status and power. Swords made during this period were made with high quality metal, and were often decorated. Previously, decorations had been added to express the owner's religious faith. During this period, they were also used ornamentally (Tanobe). All *samurai* during this period were required to wear a *daisho*, a set of blades consisting of a *katana* and a *wakizashi* short sword (Morimoto, 5-6).

Katana blade quality declined again during the Edo Period as the power and status of the samurai waned. Sword forgery, engraving the names of master smiths onto poor quality blades, was common. The blade quality increased again around 1780 AD, when the nation was threatened with civil war.

Swords created after 1780 AD were known as *shinshinto*, the new new swords. Sword designs during this period mimicked both the *koto* and *shinto* styles.

Shinshinto Blade (Robinson)

In 1876, during the Meiji Restoration, the wearing of swords was outlawed and the *samurai* caste was disbanded. Many smiths gave up swordsmithing to pursue more profitable vocations. However, some swords were still made. These swords were known as *gendaito*, or modern swords. *Gendaito* were typically made using low quality materials due to lack of skilled smiths and materials.

Swords made after 1945 were called *shinsakuto*, or newly made swords. These swords were made in the aftermath of World War II, when more smiths became interested in the old sword making traditions. Despite the fact that swords were no longer a viable weapon in combat, the sword became a symbol of Japanese culture and a reminder of the nation's warrior spirit. The Japanese government eventually imposed restrictions on sword making, which had been elevated to an art form (Morimato, 7).

Shinshakuto Blade (Kapp)

2.2 Forging a Katana

Japanese *katana* were made from a special kind of iron known as *tamahagane*. This steel was made by smelting iron sand, called *satetsu*, in a furnace called a *tatara*. During the process, charcoal and *satetsu* were heated in the *tatara* until they reached a temperature between 1200 and 1500 degrees Celsius. This occurred over a period of three days. Some of the impurities were removed from the *satetsu* in the form of slag. (Kapp, 61-66)

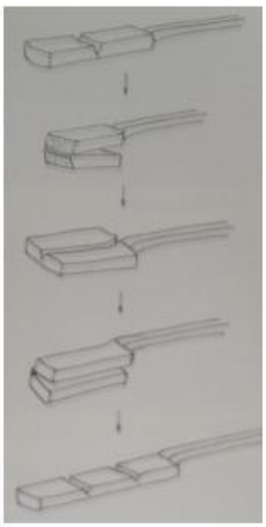
Once the steel is cool, it was broken into chunks and then sorted according to quality and the amount of carbon in each piece. Those sorting the pieces selected steel suitable for both the soft inner core of the blade, called the *shingane*, and the hard outer jacket steel, called *kawagane*.

After selection, the pieces went through further refinement to correct any problems with the steel. *Tamahagane* with a high carbon content, which made the steel too brittle in high amounts, were reheated in the *tatara* while oxygen was added. The oxygen bound with the carbon in the steel and left as carbon dioxide. For *tamahagane* with a low carbon content, which made the metal too soft, the steel was reheated in the *tatara* with more charcoal.

Once the *tamahagane* had the correct carbon content, it was reheated and hammered into one quarter inch plates. Those pieces were then sorted into those that would become the *kawagane* and those that would become the *shinagane*. The pieces were stacked to form a block which weighed approximately 5 pounds. Then they were fused to a steel handle with the same composition. The block was then wrapped in rice paper and coated in clay slurry. This would allow the metal to retain its form while being heated. (Kapp, 70) (Morimato, 9-12)

The metal was then heated to 1300 degrees Celsius, then hammered to form a single bar. Afterwards the bar was reheated and hammered several times until the bar was twice the original length.

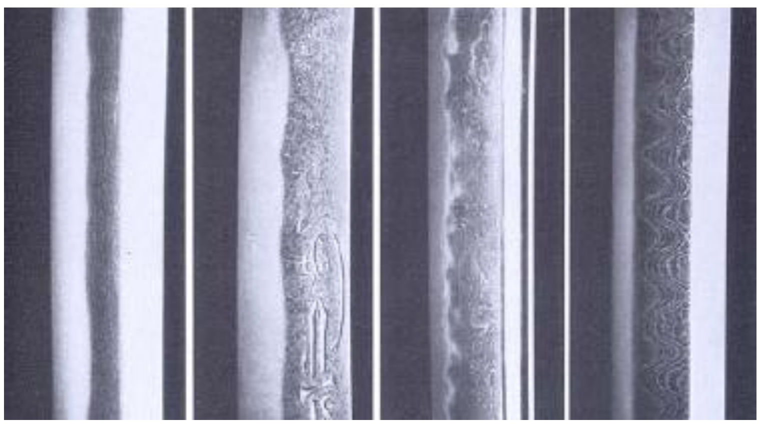
To form the hard *kawagane*, Japanese smiths would fold the metal upon itself over and over. To fold the steel, the smith would reheat the bar, then strike the middle with a chisel to create a crease. Once done, the smith would hammer one half of the bar, forcing it to fold backwards along the crease. Once the bar was folded fully backwards, it was struck with a hammer to fuse the metal together again. The bar was then heated and hammered until it was again twice the length. One fold usually took two to three reheatings. The steel was often covered in rice paper and clay slurry again to prevent carbon loss from oxygen in the air. (Morimato, 12)



Folding the tamahagane (Kapp)

Even after this initial folding process, the mixture of carbon and iron in the metal is homogenous. This would not produce a *kawagane* of sufficient quality. At that point, the smith would cut the bar into three pieces, stack them on top of each other, then hammer them together into one bar. It took three of these smaller pieces to make a short sword, and four to create the longer katana. The blade was then reheated and hammered into the appropriate length. Once done, the *awa-gitae*, or final forging could begin.

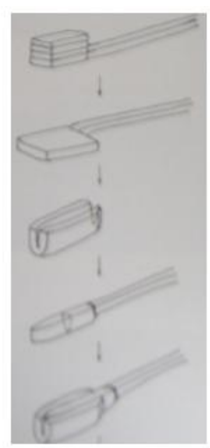
Many different folding styles existed. The way the metal was folded determined both the distribution of carbon in the iron, and the appearance of the blade once polished. Factors which influenced the surface pattern were hammer stroke strength, direction of the folds, and the quality of the metal used. Aesthetically pleasing surface patterns increased the value of the blade. (14, Morimato)



Above are examples of the different surface patterns created as a result of different folding styles. The patterns occur because the carbon and metal are not completely mixed together. (Image taken from Robinson)

The hard *kawagane* is wrapped around the softer *shingane*. Like the *kawagane*, *shingane* was made by heating stacks of metal from the *tatara* into metal bricks, which were then folded and hammered until they were twice the original length.

To fuse the *kawagane* and the *shingane* together, the smith first hammered a bar of *kawagane* into a 15 inch flat plate



Wrapping the kawagane around the shingane (Kapp) and heated it. The *shingane* was placed in the center and the heated *kawagane* was wrapped around it. At the tip of the blade, only *kawagane* was used in order to create a better piercing point. The metal was then heated to 1300 degrees Celsius and then hammered until the *kawagane* completely covered the *shingane*. (Kapp, 70-94)

Once the two had been fused together, the smith could work on the final shape of the blade. The metal was once again heated and hammered in order to create the *sunobe*, or blank, which was the basic shape of the blade. At this point, the blade was thicker than the final result would be and did not have any sharp edges. The smith would also create the *nakago*, the part of the sword covered by the hilt.

Once done, the smith would work on the *ha-saki*, or cutting edge of the blade. Six inches of the blade were heated at a time at 1100 degrees Celsius, then hammered flat to form a sharp edge. At this step the *kissaki* (piercing edge), *shinogi* (ridgeline), and *mune* (back of the sword), were also created. (Morimato, 18)

Once the overall shape had been created, the smith began to grind and file the *shiage*, the metal that formed the cutting edge. A metal planer known as a *sen* was used to remove metal to create a smooth, regular surface. The file was then used on the back and edge of the blade. The entire blade was then given a rough grinding with stone.

To create a perfect cutting edge, the edge of the blade was specially treated to turn the metal into Martensite. The Martensite could be easily sharpened and held the sharp edge, but was not flexible enough to hold its shape after extensive use. To combat this, only the cutting edge of the blade was made into Martensite. The rest of the blade was flexible enough to support the sword and keep its shape.

Heat treatment is used to turn the softer pearlite to the harder Martensite. Once completed, the difference between the two kinds of metal is visible in a polished sword. This region is called the *hamon* which, like the surface patterns, needed to be aesthetically pleasing.

To create the *hamon*, first the smith covered the sword in clay, creating a pattern he wished the final *hamon* to follow. This clay, or *tsuchi-dori*, provided insulation and slowed down the rate the metal cooled, allowing the formation of pearlite and ferrite instead of the harder martensite. The sections of the sword that needed to become Martensite had a thinner layer of *tsuchi-dori*. To prevent the resulting Martensite from making the edge of the blade too brittle, the smith applied the *tsuchi-sori* in thin strips applied perpendicular to the blade's edge.

Once the *tsuchi-dori* was dry, the blade was heated until it glowed red, then quickly quenched in water. This hardens the metal. The blade is reheated once more and quenched a number of times to reduce the stress on the blade from the initial quenching. The clay was then removed from the blade so the smith could check for flaws. If none were found, then a nitric acid and ethanol solution was poured over the blade to bring out the *hamon*.

The cooling process caused the metal to curve slightly due to the differences in temperature in the front and back of the blade. The smith adjusted the curvature using a process called *suronaoshi*. If the blade was too curved, the smith would strike the back of the blade with a hammer. If the blade was not curved enough, the smith held the back of the sword against a heated surface, then quenched the blade in water. The rapid heating and cooling caused the metal to contract, thus curving the blade. (Kapp, 82-94) (Morimato, 18-23)

Once the blade was finished, the smith would polish it and add decorative *hi* and carvings called *hiromono*. They would then add their signature, or *mei*. Afterwards, the blade was sent to a polisher who would clean and sharpen the blade. Next it was sent to a metalsmith to be fitted with a metal *tsuba*, or blade guard, and a *habaki*, which protected the blade from scratches from its sheath. The blade was finally sent to a woodworker, who would create a wooden sheath for the blade. The sheath was then decorated using a variety of materials. (Morimato, 23-25)

3. The Philippines (Elizabeth Labelle)

3.1 History and Culture

The Philippines, officially known as the Republic of the Philippines, is a country in Southeast Asia. The Philippine Archipelago consists of approximately 7,100 islands, most of which are volcanic in origin. The total land area is roughly 300,000 square kilometers. Only 19% of the land available is arable. The archipelago is divided into 79 provinces and 17 regions. The languages spoken in the Philippines are diverse, with estimates of the number of dialects around 500. The official spoken languages are Filipino and English. The other most common languages are Tagalog (upon which Filipino was based), Cebuano, Ilocano, Hiligaynon (also known as Ilonggo), Bicolano, Waray, Pampango, and Pangasinan. (Greaves)

The Philippines had a number of cultural exchanges through trade and immigration with other countries. Before Western colonization, two of the largest cultural influences were from India and China.

Beginning in 900 CE, Indian groups from Southeast Asia began migrating to the southern Philippines. Indian language, writing, and religion were introduced at this time. Examples of the effect of this culture taking root are in the use of Sanskrit by the Filipinos, as well as the adoption of head scarves. Some Filipino groups have superstitions rooted in Hindu lore.

In 982 CE, Filipino traders arrived in Canton and made their first contact with China. Trade between the two grew throughout the Sung (960 – 1127 CE), Yuan (1271-1368 CE), and Ming (1368 - 1644 CE) dynasties. The goods traded by the Filipinos, such as gold, beeswax, pearls, and edible bird's nests, were of great interest to China, who began to send traders back to the Philippines. Subsequent marriages meant that most Filipinos today have some measure of Chinese ancestry. From China, the Philippines learned how to manufacture gunpowder, new metallurgy techniques, and gong making. Additionally, staples of the Chinese diet, such as rice, noodles, and buns were adopted. The Chinese language was also influential, with over 1,500 Chinese words found in the Filipino language. (Greaves)

In the 14th century CE, Arab traders from Borneo and Malay began moving to the southern islands. As a result, there was a considerable Muslim presence in those areas, which continues today. These Muslims (later referred to as Moros by the Spanish) formed tribal groups, or sultanates. The Sulu Sultanate was formed in 1392 CE and became one of the strongest for a long time, rivaling even the Brunei Sultanate in Borneo. Other Sultanates of the time were the Maranao and the Maguindanao. These groups were resistant to colonial rule from both the Spanish and the Americans.

In 1521 CE, a Spanish expedition led by Ferdinand Magellan encountered the Philippines. The islands were later given their modern name by Lopez de Villalobos in 1542 CE, after Philip II. In 1564, a Spanish expedition led by Miguel Lopez de Legaspi attacked Cebu. The Spanish continued to establish leadership in small nearby communities with no former centralized rule. In 1571, Lopez de Legaspi established a Spanish city named Manila in the Philippines. By this time, the Spanish had secured their place in the Philippines. (Greaves)

However, the Filipinos were not happy with Spanish rule. Uprisings during that time occurred frequently. The introduction of the Jesuit order further sparked discontent as it began to acquire power and wealth. A secret society called the Katipunan was formed some time after 1892, when the inspirational figure Dr Jose Rizal was arrested. Later, Rizal was executed, leading to an uprising. Eventually, the uprising was stopped and a peace treaty was formed, though neither side upheld the agreements.

During the Spanish-American war, the Philippines tried to establish independence. However, they were instead transferred to American control in the Treaty of Paris made in 1898 CE to end the war.

One year later, the Katipunan began a revolt against America. The resulting costs of subduing the Filipinos combined with the economic troubles caused by the Great Depression in the 1930's forced America to grant them independence. The Philippines were later invaded by Japan from 1941 to 1945. In 1946 the Philippines finally declared themselves independent, and remain so today. (Greaves)

3.2 Weapons of the Philippines

The keris, also known as the kris or the kalis, was one of the most famous of the Moros' weapons. Different variations were found in every tribe. It was an asymmetrical dagger, most commonly thought of as having a wavy blade. While many keris did have a distinctive waved blade, straight blades were also common. Straight blades were often more practical in combat. (Federico)

In addition to being an effective weapon in combat, the keris was also used to show a man's rank or status in society. Some keris were passed down as family heirlooms. The keris was often worn as part of the everyday dress, as being seen without a weapon was analogous to being naked. This belief was common amongst

Philippine tribes. Additionally, the keris was thought to possess mystical powers, and often served as a talisman or charm. (Greaves) (Federico)

A keris blade was wide at the base and double edged. It could be used to deliver both chopping and slicing cuts. Older keris with wave patterned blades tended to have fewer waves with a greater depth and wider spacing. As time went on, more waves gradually appeared, with a tighter placement. The more waves a keris possessed, the greater its powers as a talisman were said to be. Additionally, engravings and inlays were added to the blade to further increase its power. Such additions included tree and leaf engravings and Islamic inscriptions. In some cases, Damascene patterning was put into the blade. Damascene patterning is the art of inlaying one kind of metal into another, for instance, inlaying gold designs onto a steel blade. (Federico)

Many blades also sported complex fullers, such as multiple full length fullers forming patterns along the blade to a single fuller running the length of the blade. Some keris also have ceremonial incisions shaped like arrow heads carved into the guard, also called a gangya. The lines of the gangya were designed to flow into the shape of the blade. Older keris had the gangya made separate from the blade and made to form a 90 degree angle, newer keris have the gangya more integrated with the blade and made to form a 45 degree angle. The hilt of the keris was either straight or slightly curved. Many different pommel designs and materials existed. Keris meant for a man of higher status often had hilts made of expensive materials like silver, ivory, and brass. (Federico)

The keris used by the Moro were typically not used as thrusting weapons. Many blades were rounded at the tip as a result. Most blades used by the Moro were anywhere from 18 to 26 inches in length. (Greaves) (Federico)

Another popular weapon used in the Philippines was the barong, also known as the barung. They were the favored weapon of the Sultanate of Sulu. (Greaves) The barong had a single, leaf shaped blade used as a slicing weapon. The blade tended to be both heavy and thick, which made it easier to slice deeply. Most blades used by the Moro were anywhere from 8 to 22 inches in length. (Federico)

The blade of the barong tended to be flat and slightly convex at the edge. Other blade styles included a convex grind for more than just the edge of the blade, and the creation of a swollen edge that spanned about 1/3 of the blade starting at the tip. Damascene patterns were sometimes added to the blade as decoration. (Federico) Barong blades were often laminated. (Greaves)

Pommel designs were common, with the most common being the cockatoo and serpent with a long ferrule, a metal band used for reinforcement or joining, of about 3 inches. The ferrule was made out of a variety of metals, such as silver, copper, or brass.

Some ferrules also had braided rings to aid the man's grip. Barong meant for men of greater status often had pommels made with more luxurious materials, such as ivory, carabao horn, and ebony. The carvings of the pommels also tended to be more elaborate. (Federico)

The largest Moro sword is called the kampilan. Blade lengths up to 40 inches were made. Unlike most Philippine weapons, the kampilan is two handed. Unlike the keris and the barong, the kampilan was not commonly worn when not heading to battle. (Federico)

The kampilan blade has a distinctive taper. It narrows at the forte, and gradually widens at the tip. This gives the blade a trapezoidal shape. Some kampilan had a spikelet at the tip of the blade. The spikelet was fragile, and often broke or fell off. Other kampilan have holes near the tip of the blade, sometimes filled with brass. Unlike the keris and barong, it is not thought that the blade was commonly engraved to show status, as the blade was not commonly worn outside of battle or court (where it would be rude to unsheathe). (Greaves) (Federico)

The hilt of the sword was large, to form a counter balance for the large blade. The hilt was commonly split in two. The hilt was traditionally bound to the hand of the wielder to prevent them from dropping it. The bindings used were called munsala, and were considered to have talismanic powers. Some munsala were attached for only these powers. Hilts were made of Philippine ebony and higher end hilts could be silver plated or made with ivory. (Federico)

4. Islamic Weapons (Elizabeth Labelle)

4.1 Mining and Metallurgy

Iron and steel were both heavily used in Islamic cultures. There was a wide distribution of iron mines throughout the Islamic areas. Some of the more prominent iron mines could be found in Spain, Sicily, the Libyan Desert, Egypt, Syria, Iraq, and Iran.

Since mines were so widely distributed, and the cultures surrounding them varied, mining techniques varied. There were essentially two kinds of mining: underground mining and open-cast mining. (al-Hassan)

One method of underground mining was to create shafts in the ground which would hopefully lead to metal deposits. Once a vein was reached, a horizontal shaft would be dug to access it. The techniques for creating the shafts were adapted from those used to create *qanat*, an underground water irrigation system.

Open-cast mining, also referred to as open-pit mining, was a method of extracting metal or minerals from an open burrow or pit. This method of mining was used when deposits of metals or minerals were found close to the earth. Open-cast mining was also performed when the material miners would need to dig through to reach the ore was too unstable to create a safe tunnel or shaft. (al-Hassan)

Three main types of iron and steel were used in Islamic regions: wrought iron, cast iron, and manufactured steel. Wrought iron had a low carbon content and was very soft. It was used in when the strength of the final product was not important. Wrought iron was used in the manufacture of steel. (al-Hassan)

Cast iron, by contrast, had a high carbon content. Together with wrought iron, it was used to create steel. Cast iron was hard and brittle, which made it unsuitable for use in blades on its own.

Manufactured steel had a carbon content between that of wrought iron and cast iron. It could be made from wrought iron by adding more carbon to the metal in a process known as cementation. The wrought iron was covered with charcoal and then heated until it was deemed the metal had absorbed enough carbon. It could also be made by removing carbon from cast iron. The cast iron would be heated while oxygen was added. The oxygen would bond with the carbon and be removed as carbon dioxide. Wrought iron and cast iron could also be combined until the desired ratio of metal to carbon in the result was achieved. Combining wrought iron and cast iron in this way allowed metal smiths to create patterns in the resultant metal. These patterns were known as *firind*. (al-Hassan)

One kind of steel, Damascus steel, was a specialty of Islam. Damascus steel is made from a mixture of wrought iron and cast iron. The mixture of the two kinds of iron resulted in a distinctive *firind*. The lighter metal is composed of iron carbide (also known as cementite), while the darker section is regular carbon steel. The distinct patterns become visible after the metal was treated with mineral sulphate. Eventually, the name

Damascus steel was given to all swords with a patterned blade. Damascus blades are made from steel with a high carbon content. (al-Hassan) (Coe)

4.2 Islamic Weapons

The two most commonly used weapons in Islamic regions were the straight sword and the saber. Arabian straight swords were one handed and had a double edged blade, a rounded pommel, and down turned crossguards. The design is similar to the Roman gladius. The straight sword was most often used while on foot. (Khalili)

The saber, by contrast, was a one handed weapon with a distinct, single-edged, curved blade. The blade was sometimes broader at the tip. Additionally, the hilt was often curved on one side. The saber was most often used while on horseback. (Khalili) Curved swords developed around the 8th or 9th century. These blades only gradually became more used than straight swords. The use of straight swords vs curved swords was about the same until around the 14th century. (Coe)

The design of Islamic swords differs from the design of Western weapons. Unlike Western swords, where the pommel was used as a counterbalance for the weight of the blade, Islamic swords used the pommel as only an end for the grip. The tang of Islamic blades was often shorter and broader than Western blades.

The guards of early Islamic swords resembled a cross with extensions called langets protruding from the edges and pointing down towards the blade. These langets gave the grip a firmer seating and created a better fit for the scabbard. (Coe)

Many Islamic blades were decorated with precious metals like gold, silver, and bronze. Arabia commonly decorated using gold because it was abundant there. Silver was commonly used throughout Islamic areas. In Persia, the technique of lacquering and enameling was common. Chiseling and engraving were also used to decorate blades and hilts. (Coe, 145-147).

The shamshir was a type of saber. It was one handed, and had a pronounced curve measuring anywhere from 5 to 15 degrees from tip to tip. The pronounced curvature made thrusting difficult, as the tip was not at a good angle. As a result, the shamshir became primarily a slashing weapon. The convex side of the blade was sharpened. The curvature also made it easier to quickly draw from its sheath, making drawcuts more effective. (Stone)

Image of an Indian Shamshir from Higgins Armory Museum

The blade had no pommel. The grip was formed by covering the tang with bone, ivory, or wood and fastening them with pins or rivets. The blade itself had very little taper until it reached the tip. The design of the shamshir originated in Persia during the 16th century. Designs similar to the shamshir were the Turkish kilij, the Mughal Empire's talwar, and the Arabian saif. (Stone, 550-553)

Turkish Kilij from Higgins Armory Museum

The Turkish kilij was another example of a single handed, single edged, curved blade used in the Islamic world. Earlier examples of the kilij had a very sudden pronounced curve at the distal end of the blade. The blade had a relatively thin width for until it began to reach the tip, at which point the blade became wider. This widening at the tip creates a *yelman*, or false edge, which increases its cutting ability. (Stone)

During the 18th century, the design of the kilij changed. The overall blade length became shorter and the curvature became more acute. In addition, the *yelman* became longer. A new cross guard design was added, which resembled a T shape. This made the blade more stiff while keeping the weight the same. The redesign improved the kilij's ability as a thrusting weapon, although it was still primarily used as a slashing weapon. (Stone, 356-357)

Turkish Yataghan from Higgins Armory Museum

The yataghan was a Turkish saber with an elongated S shape. It was a single handed sword with a single edge and no cross guard. Blade length varied from 23 inches to 31 inches. The sharp edge of the blade was made with steel, while the back was made with iron. Like many blade designs, having the softer iron in the back made the blade more flexible, and therefore more durable. The steel was more brittle than the iron, but could hold a sharper edge. Most yataghan were used on horseback as a slashing weapon. (Khalili) (Stone)

The *kard* was a single edged knife found in Persia. The blade was made of watered steel, and often had designs chiseled in near the hilt. The knife had no guard. The grip was usually made with either bone or ivory plaques. (Coe)

The *jambiya* is a single edged dagger used in Arabia and the Maghreb. The *jambiya* had a pronounced curve in the middle of the grip, and the pommel had a flat bottom. The blade had a very prominent curve, which often curved back towards the grip. Most *jambiya* were heavily decorated with precious metals like gold and silver, precious stones, amber, and coins. Regional differences were denoted by different hilt designs and the color of cords used to tie the blades to a person's sash. The *jambiya* was often worn for decoration. (Coe)

5. Medieval Weapons (Patrick Dignan)

The medieval period itself is not a very well defined era, and for every historian met, one will find they have discovered another definition of medieval. For the purposes of this paper, the medieval period is defined as the years between 500 AD and

Figure 1 - Spatha

the end of the 15th century. The medieval period, being a long period of time, saw many advances in sword technology and many different swords came and went in favor.

It is impossible to talk about medieval swords without discussing the spatha. Spatha were typically about 28 to 38 inches in length and two to four inches wide. These swords were of a composite material of iron and steel. The Romans introduced the spatha, with influences from early Celtic swords. These swords, or variants thereof would be in use up until about the 12th century by the Normans. Later, the Byzantines would use a sword called the spathion, a descendent of the spatha. Spathions were typically about three feet in length, double-edged, and possibly heavy.

Figure 2 - Cleaver Falchion

Another major type of sword from the medieval times is the falchion. Falchions were typically thick, single-edged, single-handed swords. They have been called reminiscent of the scimitars of Persia. There are two different major categories of falchion, the cleaver and cusped varieties. The cleaver falchion is typified by the Conyers falchion, and is decidedly less common than the cusped falchion. Cleaver falchions were typically thicker, with a curved edge, much like a meat cleaver. The cusped falchions were thinner, with a cusped tip. The falchions were important during the late medieval period and into the early Renaissance period, from about 1000 to 1500AD.

A commonly misconceived notion is that of the medieval broadsword. In fact, there were many swords that could be considered “broad”, however the term was first used in the 17th century to describe closed-hilt swords, rather than the broad swords of earlier periods. The term broadsword as originally used was to describe military swords as compared to thinner swords of nobility.

Figure 3 - Castillon Sword

One interesting example of a medieval sword that the Higgins Armory Museum has is the Castillon sword. The Castillon sword is a sword that was discovered in the River Dordogne in France. An English soldier fleeing the victorious French army probably cast off this sword. It has been remarkably preserved due to the sediment in the river. While the Armory has several other swords from this battle, others have been restored to show the blade more clearly. This example, on the other hand, was thrown into the river with its scabbard still on, and so much of the scabbard remains intact, allowing study of the materials it was made of. The Battle of Castillon was in the late medieval period, and was the deciding battle of the Hundred Year's War. It took place at Castillon, after the English commander John Talbot gave in to pleas from his commanders there to save them from the French army.


Figure 5 - The hand-and-a-half sword

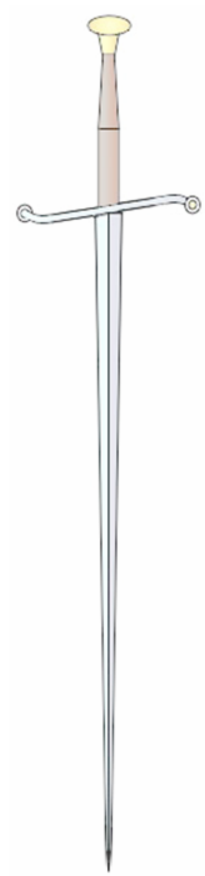


Figure 4 - The English Tuck or Estoc

John Talbot was well respected by both the English and the French. In fact, the French constructed a statue of him after the Hundred Years War. The French nickname for him was the "English Achilles".   He had actually been arrested by the French, and released on his word that he would not participate directly in the fighting of the Hundred Year's War, and indeed did not, though he was killed during the routing of the English at the age of 66.

It is interesting to note that at this point the land in which they were fighting had been English for around 300 years. The civilians in the area considered themselves English, not French. Indeed, when the captured Bordeaux, the citizens of Bordeaux actually threw the French army out of the city and let the English army in.

Immediately following this, however the English lost the war and were forced from the European mainland proper.

A particularly interesting sword is the estoc, or English tuck, type of sword. These were among the first truly anti-armor swords. They were a two-handed sword, typically long and used by cavalry. These swords were often sharpened only at the tip. Estocs typically were rigid and triangular or square in shape. These swords came about in the 14th century to combat armor, and replace heavier forms of anti-armor weapons such as maces and axes. Rapiers have been mistaken for estocs at times.

Perhaps the most popular sword of the medieval period was the bastard sword, or the hand-and-a-half sword. The name "bastard" comes from the French "espeé bastarde". These swords had handles that were long enough for use with two hands, but were light enough that they could be used with only one. Hand-and-a-half-swords were a development of the very late medieval period, starting as early as the 14th century and continuing in use into the 16th century. Bastard swords were smaller than typical true two-handed swords, so that they could be used with one hand as well.

Bastard swords can be of either flat or hexagonal shape. The former caters to more of a cutting style of fighting while the latter allows the addition of thrusting to the fighting style. The hexagonal shape allowed the hand-and-a-half swords to be used against plate armor that began to appear in the later years of the medieval period. These swords had cruciform hilts with grips that were typically "bottle-like" in shape.

Overall, the medieval period was one that resulted in a lot of change in the swords used. Initially swords were more similar to the Greek or Celtic swords, such as the spatha type of swords, however towards the end of the period, swords such as the bastard sword, with cruciform hilts and triangular or hexagonal shapes. These changes show the changes in fighting style as well as refinements in defenses, such as the introduction of plate armor towards the end of the medieval period. These defensive changes would come to play a larger role during the Renaissance period that followed the medieval period.

6. Swords of the Renaissance (Patrick Dignan)

The Renaissance period was one that showed great divergence in the variety and complexity of swords. It was a period that saw swords transition from the primary weapon of war to the secondary or even tertiary weapon of war. The Renaissance and Medieval periods have some chronological overlap, since such things are never clearly defined. For the purposes of this paper, the Renaissance period is defined as the time between 1350 and 1700 AD.

Some background is important to understand the state of swords and other arms in Europe leading into and at the beginning of the Renaissance period. Typical swords were meant for cutting, rather than thrusting. This was due to the lack of a prevalence of full plate armor, to a large degree. In addition, these swords were typically of the cruciform style, meaning that when held with the tip to the ground, they look similar to a cross. Other styles were present at the beginning of this period, with the falchion style being among the pre-eminent alternatives.

One of the signature changes that occurred during the Renaissance period was the increasing complexity of sword hilts. Prior to the Renaissance period, most sword hilts were fairly simple, typically with long straight quillions or a small, basic guard as seen on the spatha or Greek styled swords. One of the earliest changes seen was the addition of a forefinger hook to protect the forefinger when placed on the otherside of the quillions. The first appearance of the forefinger hook was in the 1340's (Coe). This was one of the first steps towards the creation of the rapier hilt. After this, hilt designs became varied.

The knuckle guard was perhaps the next addition to the hilt, which gave protection to the front of the hand of the sword. Early knuckle guards were simply swords where the quillions were bent back (Coe). This later changed, as the knuckle became an addition to the guard on some swords. In addition to the knuckle guard, some swords began to incorporate guards for the back of the hand in addition to the knuckle guard, and an additional ring above the quillions. Swords with these features began to resemble the rapier hilt that would come later in the Renaissance period.

Figure 1 - 2428 Artifact

Full plate armor was beginning to become more popular during the beginning of the Renaissance period. During the 1400's, plate armor became common enough (Long) that cutting swords were not sufficient, and swords capable of thrusting maneuvers became necessary. This lead to the development of new swords that were capable of these thrusting maneuvers.

One example of an early Renaissance period sword is the 2428 artifact at the Higgins Armory Museum. This artifact features quillions curved slightly towards the tip of the blade. It is an example of an early cut and thrust sword. It can be noted that none of the features noted as later developments are present on this artifact.

Figure 3 - Cinquedea from the Louvre

One of the more unique swords of the Renaissance period is the Cinquedea type. These swords are of Italian origins, with the name being Italian for “five fingers” (Coe). The swords were five fingers wide at the base of the blade. Calling a Cinquedea a sword is not necessarily accurate however, since Cinquedeas ranged in size from dagger length to full sword length (George). The Cinquedea style is notable for it’s place in civilian life. During the Renaissance period, a divide began to form between military swords and civilian swords (Coe). Cinquedeas were also very ornamental weapons.

Figure 2 - Katzbalger Replica

Another interesting sword style that evolved in the Renaissance period was the Katzbalger style, or "Brawler" style of German swords. These swords were used most often by Germanic mercenaries, the Landsknechte (Coe). One of their more distinctive features was the S shape the quillions had.

Figure 4 - Reitschwert Sword Depiction

One of the more advanced cruciform style swords of the time was the Reitschwert style sword. These swords were native to Saxony (Coe), in what is now southern Germany. The swords had advanced hilts, of the swept-hilt style similar to that of a rapier.

Figure 5 - Swept-hilt Rapier from Higgins Armory Museum

Perhaps the most important sword development of the Renaissance period was the development of the rapier style of swords and sword fighting. Rapiers are thin swords with hilts that defend the hand from attack. Rapiers were very light usually weighing less than 3lbs (Clement). The rapier became popular by 1600 (Coe), and was used typically by civilians, rather than in war. This continues along the theme of a separation between military arms and civilian arms. Rapiers created a different sort of fighting environment from previous swords. During the era in which rapiers were massively popular, there were numerous formal schools for learning how to fight with rapiers. While it is commonly thought that rapiers were the weapons of solely gentlemen of the era, they were also used as self-defense in urban areas (Clements).

Certainly the Renaissance was a time of change in many aspects of the world, from science to religion to swords. The leap from the sword as solely a military weapon to self-defense and even private dueling occurred during this period. In addition, the change from primarily cutting swords to cutting and thrusting shows the effects the popularization plate armor had on arms and the constant race between military offense and defense that continues to this day.

7. Swords of Greece and Rome (Matthew Lyon)

Despite the fact that the Greeks had already progressed to using iron rather than bronze to forge their weapons, the people of Central Europe, the Celts, still produced bronze grip-tongue swords as they had for centuries. The first grip-tongue swords appeared in Greece around 1200 BC and in less than three hundred years, the Greeks had already moved on from casting grip-tongue bronze swords to forging the same swords out of iron (Coe, p.20).

The use of iron created two significant obstacles. Bronze could be melted down and cast into whatever shape was needed. On the other hand, civilizations lacked the necessary technology to produce pure iron. Instead they were left with an impure metal that needed to have its slag impurities hammered out before it could be forged; this process was never able to entirely eliminate the slag (Coe, p.20). A much larger obstacle presented itself in the smelting process. Because charcoal was used, small amounts of carbon would react with the iron, turning the iron into an inconsistent amalgamation of iron and steel.

Iron is tough, but soft. Conversely, steel is harder, but more brittle than iron. Thus the ancient metalworker had to put in extra effort to uniformly distribute the small amount of steel that was accidentally produced or risk producing blades that had weak sections; too much steel could cause a blade to shatter from the brittleness, whereas too much iron resulted in a softer blade that may bend or not hold an edge. In the earliest stages of the Iron Age, some bronze weapons were still of superior quality compared to their iron equivalents, simply because the process for creating them had been perfected over the centuries. However, as new techniques such as plaiting and pattern welding were developed for working with iron and steel, the Bronze Age and its weapons were quickly discarded.

As the independent Greek city states developed, so too developed the need for a method by which they could defend themselves. Given the small populations of many poleis, a standing army was not an option as they lacked both the manpower and the resources to support such a force. The alternative for the Greeks was the hoplite – the citizen as soldier. Hoplites were required to provide their own equipment, thus swords were as much symbols of status as they were weapons. Swords would often be passed down from generation to generation, assuming their wielders survived combat. As a result of hoplites being responsible for their equipment, the burden of service fell primarily on the middle class. The poor couldn't afford the equipment and the rich could afford to provide equipment for less fortunate citizens and have the citizens fight on their behalf. Given that the "army" was thus comprised of untrained and undisciplined troops for the most part, the strategy it employed had to be simple and hard to deviate from. This led to the adoption of the famous phalanx formation which saw soldiers standing shoulder to shoulder with a shield in one hand and a spear, not a sword, in the other. The sword was simply a weapon of desperation, only seeing use once both the point and butt of a soldier's spear was broken.

After the hoplite sword came the kopis. This sword was designed as a heavy slashing weapon, with much of the weight of the blade towards the tip. This weight distribution allowed for more powerful swings which against the unarmored targets of the time were all that were necessary.

Eventually, the Celts arrived in southern Europe and completely overran the Romans. Realizing they were unable to withstand the full brunt of a Celtic charge head-on, owing in part to the Romans having a smaller stature and inferior equipment, the Romans adopted a new strategy which called for soldiers armed with a shield and gladius to advance in front of the main line. These swordsmen were known as principes and their primary role was to disrupt the Celtic charge by getting in close combat, an area less suited for the spear than the gladius. Over time, the Romans would abandon their defensive rear rank entirely, opting instead to arm all of its soldiers with the gladius and shield (Coe, p.23-24).

The gladius evolved out of the hoplite sword. Keeping roughly the same length, the gladius favored iron over bronze. The most significant change was dropping the leaf-shaped blade for a straighter blade more suitable for thrusting. This change is likely the result of the aforementioned change in strategy adopted to deal with the Celts; a Roman soldier would block the Celt's swing with his shield and while his opponent was still vulnerable from his attack, the Roman could easily stab his attacker, whereas a slash would be more difficult. There was a tradeoff however. While the gladius was better suited for thrusting making it ideal for taking down armored opponents, the blade was more susceptible to breaking when used for slashing (Coe, p. 27).

VII. Conclusion (Patrick Dignan)

Through the Higgins Armory Virtual Armory IQP, the team gained great insight into project management techniques, the use of experimental technologies, and interacting with people of varied skills. Throughout the project the team worked to improve the time management skills necessary to complete a large project with little oversight and few restrictions.

Some issues the team had were with the disconnect between the interactive and the research papers that were generated throughout the project. The research papers were meant to provide the basis for the educational content of the site. However, the creation of the application and the research for the papers was done separately, which lead to slowdowns when the team tried to integrate the two. One of the greatest assets to the team was the schedule laid out at the beginning of the project. This schedule helped the team determine how much time should be spent on each part of the project. By further breaking this down into a per-term weekly schedule, the team was able to set goals week-to-week.

For this project, our advisor gave us much more freedom in deciding upon a project topic and technology than was normal. We feel that having this additional freedom in topic was greatly beneficial to both our team and the museum, as it allowed us to explore a new and interesting technology. While the team was unable to tap into what we felt was the full potential of the medium, it still provided a new area of exploration in terms of virtual experiences, which could be valuable for future teams.

However, the team would recommend creating a full curriculum for the entire year in advance, to make the project outcomes more clear. The team worked mostly off of the normal three term schedule, making only some changes as time went by. This caused some communication issues for the team week to week as we tried to determine what was due each week.

Due to the experimental nature of the project, the team was forced to change its goals over the course of the project. Initially, a more physically related interactive was planned, with physical sword hilts. However, technical issues caused an unexpected delay in the project's implementation. A large amount of time was spent trying to overcome shortcomings inherent in the technology the team had chosen. The final project did not come as far as the team had originally envisioned, so the decision was made to limit the application to only a web presence. The large amount of time spent on technical issues caused a delay in the writing of research papers as well.

Fortunately, the project has many prospects for the future. One obvious possibility is to improve the user interface by moving the informational blurbs from the side of the interactive to inside of it, while displaying the information in an interactive fashion. This would rectify one of the major issues noted during the project demonstration in the library, which was that visitors hardly noticed the informational blurbs at all. Future projects could work to virtualize more pieces in the Armory. A larger array of artifacts would allow a more varied experience. Another possibility would be to distribute cheap, disposable hilts that Armory visitors can bring home to use with the interactive online. This would allow the museum to continue the experience after the visitor has left the museum. Other types of pieces are another area in which future teams could take the project. The project currently only has a limited selection of swords. The Armory has various types of pieces, including shields, pikes, and guns. Adding the complexity introduced by these new types of pieces would result in a more varied experience that can keep the visitor interested for longer.

An interesting possibility that would be a larger departure from the current project work, would be to create a game that allows users have a persistent interactive by creating a unique marker for each visitor. The visitor could then create a character that began with the visitor at home on their computer, and progress with them throughout their visit to the museum. This could be done in a video game-like fashion, to interest the modern generation.

The team also had the idea to allow the Armory's database to hold the models for the interactive in the database, so that the interactive could automatically draw on the database for models a marker is shown. This would allow more simple extension of the application for more pieces. This results in an economy of scale that future teams could utilize to markedly expand the exhibit.

Social media is a growing area that very few museums take advantage of at the moment. The project could potentially be integrated with Facebook or Twitter to let friends and family know about their loved one's visit to the Armory. This would also help the Armory gain exposure, through the free advertising.

Throughout the project, the team has faced various adversities while trying to create the vision that was described in the beginning of the term. From the presentation to the National Park Service and other local museums to the demo at the library, the interactive has progressed a great deal. At the end of the road, the project now has a theme much like the newly redesigned Higgins Armory Museum website and a much more polished overall feel. Markers no longer seen by the application are removed from the screen, users are notified if their systems do not meet the requirements rather than the application crashing, and the application is able to sustain higher frame rates than earlier implementations.

Appendix A. Original Project Proposals

Virtual Sword Exhibit Project Proposal (Matthew Lyon)

Vision Statement

In keeping with the theme of the Virtual Armory title, this project seeks to develop a virtual representation of the physical Armory. Using computer techniques such as data matrix scanning and augmented reality, the goal of this project is to create a new digital experience for the Armory while still retaining the tradition, history, and educational value of all the artifacts currently in the collection. Visitors will be able to interact with artifacts on a level that would not be possible except in a virtual environment. Furthermore the project intends to leave a legacy for future projects by creating a framework that's capable of persisting after the project team has concluded its work.

2 Stage Approach:

Stage 1: Semacode / Data Matrix linking to the online database

A data matrix is a 2-dimensional barcode, typically arranged in the shape of a square. Given that all (or at least most of) the items in the collection are catalogued in the database, their reference numbers or some other unique identifier can be stored in a data matrix. A program could be written that would enable a computer to scan the data matrix, through the use of a web camera in a static display or possibly the low resolution cameras included in many cell phones, and then instantly transfer the user to the database entry for the scanned artifact.

The scope of the project would entail the team determining:

1. The ID number to be stored in each data matrix

2. The encoding pattern the data matrix will employ

3. Some automated method of converting the ID number to the appropriate matrix and then printing it out

4. (largest part) A computer program that could capture the data matrix using some form of digital image capture and then link to the appropriate article in the database

- Possibilities

- Rather than having a single permanent data matrix affixed next to each artifact, for more popular artifacts, we could possibly provide copies to allow patrons to take the data matrix with them, almost as if it were a business card. This would essentially enable patrons to take a bookmark for their favorite artifact with them, thus providing a continuing experience with the Armory after they've left.

- If an appropriate handheld device could be discovered, the armory could also allow patrons to rent or borrow such devices (possibly for a small fee) and the handhelds would act as a personal tour guide, elaborating only those artifacts the patrons wish to know more about.

Largest Obstacle: Regardless of how much we automate the process, it will still take a substantial amount of time to print out the data matrices and then arrange them next to their corresponding artifact on display. Armory staff could be utilized, though this would likely result in increased costs.

Stage 2: Augmented Reality Artifact Displays

Unlike virtual reality, augmented reality does not seek to replace the user's reality with a separate artificial one. Rather, it seeks to improve the reality of the user in some way. Currently, patrons cannot fully experience most of the artifacts on display. Most weapons are mounted against a wall, allowing patrons to view only one of the two sides of the weapon. Chances are the sides are largely the same, however their viewable area is still diminished. Same for suits of armor, though I see those as being viewable from 3 of 4 sides. Furthermore, patrons aren't allowed to interact with the artifacts in terms of being able to pick them up, move them around, or peer inside. Utilizing augmented reality and high resolution models and textures, we could possibly change all that.

Similar to the data matrices from stage 1, we could develop our own designs or even use Armory logos and such which when recognized by a computer program would then dynamically and in real-time display a 3-dimensional model overlaid on top of our markers. Markers can be printed on just about any medium as long as it's still readable by the camera. This means we could print our markers on paper (such as in a brochure) and allow patrons to take them home for viewing at their leisure (assuming we made the program available for download on the website). Additionally we could make some models available online as well, enabling patrons to print out a small sampling of what they could experience if they visited the Armory. Depending on how we write the program, the models will also be interactive insomuch that users can tilt and rotate the marker in any way they wish (as long as it can still be recognized by the camera) and the model will respond by tilting or rotating in the proper direction. This would enable patrons to have a more hands-on experience with the artifacts in the collection as well as enabling them to see parts of the artifacts they've never seen before, such as the back-side or even the interior of some of the armor.

Largest Obstacle: We'll have to model each artifact we want to use individually. Modelling can take a long time, especially if we want a high-definition virtual representation that's as true to the original as possible. Additionally, development of the program itself could pose a major obstacle, though there are many toolkits and APIs in place (some of which I've listed here) that should make the job immensely easier.

Potential / Future of the Project

While our project may be limited to one or both of the stages as outlined, they should both be developed in such a way that they are completely extensible. As artifacts are swapped in and out of exhibits, our data matrix automation should continue to function without having to manually tweak the program. Similarly, if new 3D-models are developed for the augmented reality portion of the project, there should be an easy way to import them into the pre-existing program. Ideally, the augmented reality project could be expanded on in future projects once we lay the foundation for it.

Higgins Armory Virtual Battle Simulator (Elizabeth Labelle)

Overview

Our aim in this project is to create an interactive exhibit for museum visitors. Two virtual models will be available which can then be dressed up with armor, weapons, and shields. Once a visitor is finished setting up their models, a display of a battle between the two models will play.

It is our hope that such a display will be educational to the visitor, and also encourage discussions between visitors either using or viewing the display.

Care should be taken during the project to make the exhibit extensible for teams coming after us. If needed, a team should be able to easily add more parts to the exhibit.

Process

Ultimately, the process for this exhibit will be

1.) The visitor is presented with two models to equip with weapons and armor
2.) The visitor confirms their choices
3.) Our program determines the outcome of a battle between the two models
4.) A demonstration of the battle is shown to the visitor
5.) An explanation of the outcome is given

For this project, models will have to be created, so that a visitor may add weapons and armor to them. There are two main options for doing this.

- Autodesk Maya or a similar 3D modeling Program
  - Pros:
    - Ability to create very detailed 3D models
    - Allows for rotation and views from different angles
  - Cons:

- 3D models take a long time to make
- Less options available to viewer

- Flash
  - Pros:
    - A flash interactive could be easily added to a webpage
    - We could use images from the armory database
      - Allows for more options
  - Cons:
    - No feasible way to provide a 3D experience

Once the two models have been equipped by the visitor, we will need to find a reasonable way to compare the two models in order to determine who would win a theoretical battle. Things to keep in mind:

- What are the weapons and armor made out of?
- How feasible is the set up of each model? (Would they even be able to move? etc)
- What is the reach of the two combatants? (Bow vs. sword? Sword vs. polearm?)

Other things to consider:

- Results will probably be highly subjective.
  - A great deal of research will need to be done to justify our results.
- What time periods are we drawing from? (Only medieval? Modern day?)
- What places are we drawing from? (Europe? Spain? Anywhere in the world?)
- What weapons can the visitor choose from? (Swords only? Bows? Guns?)
- How much information should be available to the visitor?
  - Short descriptions of each piece
  - A general summary of how effective each model is
  - A battle summary explaining the reasons for the outcome
- How do we want to show our battle?
  - A movie of the fight created in real-time?
  - Game based? Battle commands based on equipment?

Requirements

Hardware

- Touch screen – approximately $400
  - Allows a visitor a more hands on experience

- o Computer to generate the results – approximately $200

Software

- o License to use either a 3D program or Flash
  - o WPI has educational licenses, which may be enough for our needs

Sword Making Project Proposal (Patrick Dignan)

Vision Statement

The goal of this project is to involve people in the process of real sword making by creating interactive videos. Create a series of videos and embed them into an interactive, which allows visitors to choose what steps they think would be the next reasonable step in the sword-making process. By showing the most successful result created by the group, the difference between an amateur modern craftsman and an expert historical craftsman can be demonstrated in an interesting way.

Process

In order to complete this project, the IQP team needs to acquire sufficient skills in metallurgy to create a sword, video recording and editing, as well as building an interactive display to go with it.

The project would consist of 3 parts

1. Making the sword and recording the videos
2. Creating the interactive display
3. Integrating the display, sword, and videos.

Challenges

Potential challenges include finding a forge where we can actually create the swords and film, actually making the sword, and creating a cohesive interface for the interactive.

<u>Expenses</u>

The two most expensive components in this project would be the computer system to run the interactive and the touchscreen for the interactive.

The costs can be estimated as follows:

Computer System: $300

Touchscreen Display: $400

Iron: $60

Unforeseen Expenses: $100

Total: $860

Appendix B. Future Project Ideas (Matthew Lyon)

1. Virtualizing the Entire Armory

The original proposal for the project entailed a 2 stage process. The first stage of the process was the virtualization of the entire Armory collection into a 3D

Make 3D models of every artifact and allow visitors to see any artifact, even those not on display, from anywhere in the world. Or, taking the project a step further, model entire rooms of the Armory, such as the Great Hall, and allow users to explore a space in augmented reality.

This would enable monetization of markers, giving the Armory a potential new source of income.

2. Porting the application to the IPhone

Much like this project leverages the prevalence of web cameras, a future project could harness the growing user base of iphone owners. Porting the app to the iphone would be a non-trivial project in that the iphone does not have native support for flash, so a different framework would have to be utilized. However, given the existence of Layar (layar.com) development should be relatively quick, painless, and easily deployed.

3. Augmented Reality Game

Using the base framework we've established, create some sort of game. Could be a local single-player game that takes place in a player's browser. Could be a social / mobile multi-player-based game that takes place on an iphone, etc. Possibilities are endless, though examples include a sword fighting game (see Wii Sports Resort) or a finesse game where players have to make slashes according to sword training forms described in historical texts.

Future Features for Our Project

Photo Booth

During the pilot we found that users wanted a way to capture themselves while using the application. Essentially, they wanted to be able to take a picture of themselves with the models they were interacting with overlayed on top of them so they could send photos to friends and family. This could be accomplished through a small technical addition to the existing project, but would enable a new level of interactivity. Additionally, it would provide the Armory with a method by which it could monetize the use of the application, providing a source of revenue to fund the project itself.

Sword Duels

A small addition to our project could have been the inclusion of some sort of interaction between multiple markers. Currently, the application is structured such that only one marker can be displayed at a time. However, during the pilot, a number of testers indicated that they would have enjoyed the ability to interact with another tester with a different marker. A sample suggestion was to implement some sort of sword dueling feature where collisions between multiple models would be detected and reacted to by the application.

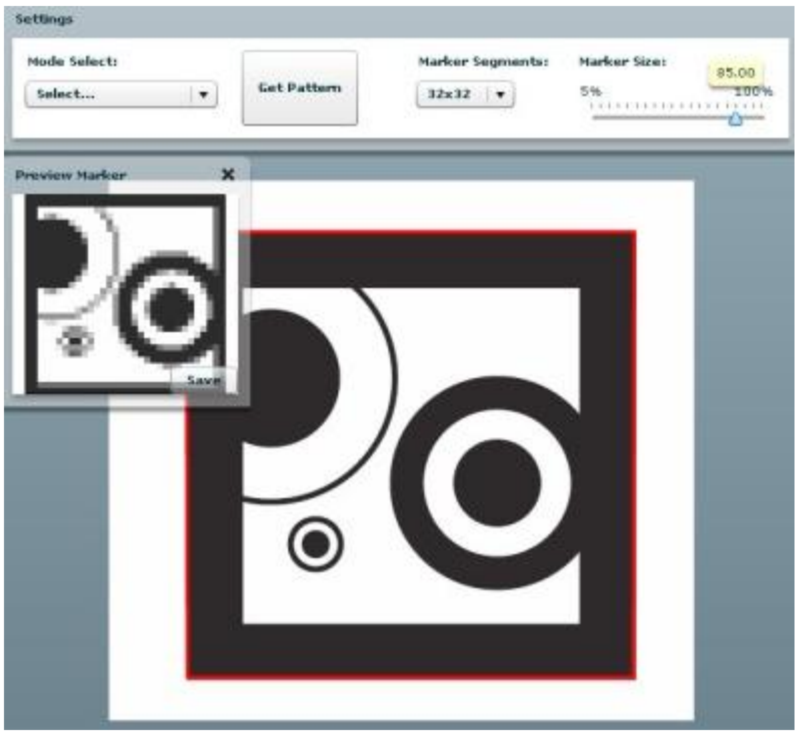
This feature was left out of the final application because it would have required a restructuring of the overall design of the application. The tie-in to the website required that only one marker be detected at a time in order to ensure that the right information was being displayed. For multiple markers, we would have had to redesign the entire website around the notion that information for multiple artifacts might need to be displayed at times. Furthermore, the additional programming to implement collision detection between models was beyond the scope of the project.

Appendix C. Technical Documentation for Extension (Elizabeth Labelle)

Generating Data Matrixes (also known as Marker Images)

Programs exist online which can take a two dimensional, black and white image and convert it into a pattern file. For this project, the ARToolKit Marker Generator was used. It can be found at:

http://flash.tarotaro.org/blog/2008/12/14/artoolkit-marker-generator-online- released/



Above is the ARToolkit Marker Generator program's interface.

This program requires Flash 10 and a web camera to use. Instructions can be found at the provided URL but the process is as follows:

1. Design the marker image and either print it out or save it on your computer. (Note: Marker image must be unique)

2. Plug in a web camera and run the application

3. In the drop down menu under "Mode Select" choose whether you would like to have the web camera read in the marker or have the application load it from a file.

4. The "Marker Segments" determines how many sections the marker image will contain. Eventually, these sections must all be identified by the flash application. (For this project, a Marker Segment of 16x16 was selected.)

5. Select the marker size using the slider.

6. If you are using the web camera to obtain the marker image, wait until the marker is enclosed in a red line. Then press the "Get Pattern" button.

7. A preview of the marker will appear. Make sure the marker image was generated correctly.

8. Hit save to create a .pat file.

Once the .pat pattern file has been generated, it can be used in the flash application.

<u>Adding a Model to the Flash Application</u>

To begin, first create a marker image pattern file (.pat) using the section above. Place the pattern file in the resources/Data folder.

Different model file extensions can be used, including Collada, Ase, 3dsMax, MD2, and Sketchup files. For this project, Collada files were used as we had the greatest success with them. For Collada files, the model must have a triangulated mesh (be made of only triangle polygons). Place the model in the resources/model folder.

The ARAppBase.as file in src/examples is the base for the application. It is responsible for setting up the camera and file loader for the application to use. It also sets up event listeners for IOErrors and SecurityErrors, which can be triggered during events such as when no web camera has been detected. These are all set up in the init() function. Some of the error handling, such as the response when no camera is detected, is located in the _onLoadCode() function.

The PV3DARApp.as file is where our application information goes. This is the file that needs to be modifed to add a new model and associate it with a marker image. First, a pattern file must be added. At the beginning of the PV3DArApp class, where the global variables are, add the following lines:

```
[Embed(source="../resources/Data/YYYY.pat",
                                        mimeType="application/octet-stream")]
private var patternX:Class;
private var mpatternX:FLARCode;
```

Where X is the new number. For instance if three models had already been created, they have probably been named detector1, detector2, and detector3, so your new detector should be detector4. (This naming scheme is not strictly necessary, but it is simpler.) YYYY.pat is the name of the pattern file you would like to add.

Next, take the pattern and convert it to an Augmented Reality pattern by pasting the following two lines into the _onInit() function.

```
mpatternX = new FLARCode(16,16);
mpatternX.loadARPatt(new patternX());
```

Next, a detector and a marker node need to be created. In the global variables at the top of the class add the following two lines:

```
protected var _detectorX:FLARSingleMarkerDetector;
protected var _markerNodeX:FLARBaseNode;
```

Next, in the _onInit() function under _scene = new Scene3D(); add the following line:

```
_markerNodeX = _scene.addChild(new FLARBaseNode()) as FLARBaseNode;
```

Next, associate the pattern from earlier with the detector, so when the pattern is held up to the web camera, the flash can respond. Paste the following two lines into the _onInit() function, just above the last line which creates an EventListener.

```
_detector2 = new FLARSingleMarkerDetector(_param, mpattern1, 80);
_detector2.setContinueMode(true);
```

Finally add the following section of code to the _onEnterFrame() function:

```
var detectedX:Boolean = false;
try {
    detectedX = _detectorX.detectMarkerLite(_raster, 80) &&
                _detectorX.getConfidence() > 0.5;
} catch (e:Error) {}

if (detectedX) {
    _detectorX.getTransformMatrix(_resultMat);
    _markerNodeX.setTransformMatrix(_resultMat);
    _markerNodeX.visible = true;
    if (_lastRead != X) {
        ExternalInterface.call("Refresh", "YYYYY.xml");
    }
    _lastRead = X;
} else {
    _markerNodeX.visible = false;
}
```

Where X is the number of the new model you are adding and YYYY.xml is the name of the XML file associated with that model. This code first creates a detector boolean. Next it tries to detect the marker image if it is not already detected. The 0.5 is the confidence percentage. This means that the application will assume the marker is displayed if it is 50% sure that it sees the marker. This value can be adjusted if necessary for a range from 0 to 1. If the marker was detected, then the model is displayed and a call is made to the HTML JavaScript to refresh the page with the new data. This call is only made if the application did not previously see the marker.

Generating Educational Content for the Website

All content on the site, save the flash application, is read in from XML files. On page load, a default artifact is selected and the information for that artifact is displayed. Once a new marker image is detected by the flash application, it sends a message to the JavaScript on the page with the new artifact accession number to display. The XML for that artifact is read in by the JavaScript and used to dynamically update the page. So all you need to do to add information for a new artifact is generate an XML file for that artifact and place it online.

A Java command line application was written which parses the Higgins Armory Database (provided to us as an Excel file) to create a default template for each artifact. The Java files were submitted as part of the IQP project materials and can be opened using any standard IDE such as Eclipse.

The file structure of the program is as follows: There is a src folder containing the ExcelRead.java class, an ExcelFiles folder which holds the Excel file to read, and an XMLFiles folder which holds all generated XML files. Additionally, the jxl.jar file must be referenced by the program. In Eclipse this can be checked by right clicking the project, selecting Build Path->Configure Build Path, selecting the Libraries tab, selecting Add JARs and navigating to the jxl.jar file.

Running the application results in a command line prompt asking for the name of the Excel file to read from. The name entered does not need to have the file extension in order for the application to read the file. If the program finds the file, it will attempt to parse each row in the excel sheet as a separate artifact, using specified columns to get specific information. If it does not find the file, it will print an error message and exit.

Currently the application tries to figure out which columns it needs to read by doing a String comparison with the titles of each column. The currently required fields are: AccessionNUmber, StdTerm, ProbDate, Origin, Materials, Weight, and LabelText.

LabelText is used to generate the blurb tags by splitting the LabelText based on periods. Each new sentence is made into a new blurb tag.

The label tag is generated from the StdTerm, ProbDate, Origin, Materials, Weight, and AccessionNum fields. This tag also has some basic html tag information added in the form of escaped HTML characters. This is used to create the bold title and the line breaks for each new line. (The , , and <br/> tags)

The photo tag is left blank as the Higgins Armory Database does not have image information.

The name of the file is the accession number with the .'s replaced with _'s to prevent some applications from seeing all text after a . as a file extension.

In this way, an XML file is generated for every artifact in the database. All files are then saved in the XMLFiles folder. Once these files have been generated, they can be modified using any standard text editor to add image file names, as well as edit the label and blurb information.

The Java Excel parser can also be modified to generate different XMLs if needed, such as if new column information is required.

Modifying the Website to Display New Sections

Currently, the website is set up to receive an XML file's name and parse the file based on the current tags: <artifact>, <photo1>, <photo2>, <blurbs>, and <label> (with their appropriate closing tags)

The init() function determines which XML file is initially used when the page is first loaded. It makes a call to the Refresh() function which does the actual replacement of the XML.

Refresh() takes a String which is the name of the XML file to read from. This String must be the file path needed to navigate from the application HTML page to the XML file, as they may not be in the same directory.

Refresh() first calls getMarker(), which does the actual parsing of the XML file. This is the function that would need to be modified to add or remove XML tags. The XML file is read in and made into a Marker object, which would also need to be modified to add or remove a tag.

Once the Marker object has been created, it is returned to the Refresh() function which then calls updateEverything().

updateEverything() is responsible for actually refreshing the data on the page. First it replaces the fading blurb text and selects which set of blurbs should be displayed first. Next it changes the two photos followed by the object label. Lastly, the time between blurb changes is set, based on milliseconds.

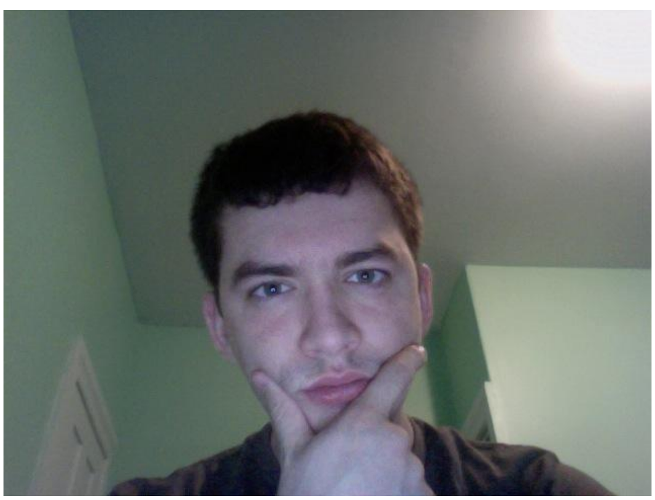
The flash application calls the Refresh function in order to swap the information. If a new function is used, then the flash must be modified to call the new function instead.

Appendix C. About the Authors

Elizabeth Labelle:

Elizabeth is currently a junior at Worcester Polytechnic University. She is currently pursuing a Bachelor of Science in Computer Science & Interactive Media and Game Development. She is from Acushnet, Massachusetts, which no one has heard of because it is primarily populated by cows, rather than people. In her free time she likes to play video games, read, and watch bad science fiction movies. She had a great time working on this project, and hopes to develop more programs using Augmented Reality.

Patrick Dignan:



Patrick Dignan is an endeavoring young man who enjoys working with open source software and powerful magnets. Currently a junior at WPI, he hopes to find enlightenment through the Interactive Qualifying Project's diverse set of requirements. Often found at Moe's on Monday evenings eating Mexican food, Patrick enjoys activities as varied as water polo and schoolwork. Next year, he plans to attend Worcester Polytechnic Institute for his senior year.

Matthew Lyon:

Matthew Lyon is a creature rarely seen outside of the Interactive Media and Game Development Lab. Perpetually sleep-deprived, he can be found staring into the soft glow of a computer monitor at all hours of the night. Primary roles for the project included lead programmer for the AR application, liaison with the Institutional Review Board, and coordinator of the pilot program with the Gordon Library

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