

Visualizing Pharyngeal Arch Nerve Growth and Muscle Innervation During Human Embryological Development

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Submitted in partial fulfillment of the requirement for the Degree of
Master of Science in Biomedical Visualization in the Graduate College
of the University of Illinois at the Chicago, 2012.
Chicago, Illinois

Table of Contents

I. Introduction.....	6
A. Overview of the study.....	6
B. Purpose of the study.....	6
C. Importance of the study.....	7
II. Conceptual context.....	7
A. Theory.....	7
B. Hypothesis.....	7
III. Research question.....	7
IV. Literature review.....	7
A. Why is human embryology/pharyngeal arch growth important to understand.....	8
B. Anatomy of pharyngeal arches and branchial arch nerves.....	8
1. Pharyngeal arch 1.....	9
2. Pharyngeal arch 2.....	9
3. Pharyngeal arch 3.....	10
4. Pharyngeal arch 4.....	10
5. Pharyngeal arch 6.....	10
C. Why animation?	10
D. Interactivity.....	11
E. Authoring tools for 3D interactivity.....	12
F. User interface/design.....	12
G. Educational models.....	13
H. Pharyngeal apparatus learning objectives.....	13
V. Research procedures.....	14
A. Methods of production.....	14
1. Preproduction.....	14
2. Production.....	17
a. Model creation workflows.....	23
b. Morphing workflow.....	26

3. Postproduction.....	27
a. User interface designs.....	27
b. Interactive program creation.....	28
B. Methods of inquiry.....	30
C. Population/sampling methods.....	30
D. Methods of analysis/interpretation of data.....	30
VI. Management of the project.....	30
A. Tasks.....	30
1. Preproduction.....	30
2. Production.....	31
3. Postproduction.....	31
B. Resources.....	31
C. Timeline.....	32
VII. Summary and discussion.....	33
A. Brief review of major points.....	33
B. Possible validity issues.....	34
C. Possible ethical issues.....	34
D. Results/outcomes.....	34
E. Implications.....	34
VIII. Appendices.....	35
Appendix A: DREM database.....	35
Appendix B: Authoring tools for 3D interactivity.....	38
Appendix C: Comparison of online survey services.....	39
Appendix D: User Interactivity Design.....	41
Appendix E: Script to control morphing animations (main page).....	42
Appendix F: Recruitment Letter.....	58
Appendix G: Informed consent form.....	60
Appendix H: Assessment survey.....	63
Appendix I: Assessment survey results.....	65
IX. Works cited.....	71

List of Tables

Table 1. Pharyngeal/ Branchial Arches and their Derivatives.....	9
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List of Figures

Figure 1. Arch 1 Flowchart:.....	14
Figure 2. Arch 2 Flowchart:.....	15
Figure 3. Facial Muscles Flowchart:.....	16
Figure 4. Arch 3 Flowchart:.....	16
Figure 5. Arch 4 Flowchart:.....	16
Figure 6. Arch 6 Flowchart:.....	17
Figure 7. Stage 13 Embryo with Incorrect Pixel Size Input:.....	17
Figure 8. Stage 13 Embryo with Correct Pixel Size Input:.....	18
Figure 9. Cranial Nerve V, VII, IX, and X Masks in Mimics, Stage 13:.....	19
Figure 10. Mimics Masks and 3D Objects, Stage 13:.....	19
Figure 11. Mimics Masks and 3D Objects, Stage 21:.....	20
Figure 12. Mimics Masks and Arches, Stage 13:.....	20
Figure 13. Extracted Embryo Head/Neck Regions:.....	21
Figure 14. Heads, Brains and Cranial Nerves V, VII, IX, X Exported from Mimics:.....	21
Figure 15: Exported Muscles, Stage 23:.....	22
Figure 16. Exported Muscles, Stage 20:.....	22
Figure 17: Sculpted Heads, Stages 10-23:.....	23
Figure 18. Sculpted Brains, Stages 10-23:.....	24
Figure 19. Composited Brains and Heads, Stages 10-23:.....	24
Figure 20. Sculpted Muscles, Stages 17-23:.....	24
Figure 21. Composited Muscles, Heads, and Brains, Stages 10, 15, and 23:.....	25
Figure 22. Cranial Nerve V, VII, IX, and X Morph Targets:.....	25
Figure 23. Low Polygon Facial Nerve:	26
Figure 24. Facial Nerve with Mesh Smooth Applied:.....	26
Figure 25. User Interface Designs, Landing Page:.....	27
Figure 26. User Interface Design, Main Page:.....	27
Figure 27. Unity Mega Morph Channels:.....	28
Figure 28. Final Interactive Program, Main Page:.....	29
Figure 29. Final Interactive Program, Information Page:.....	29

I. Introduction:

A. Overview of the study

Human embryology is a field that presents many challenges as numerous complex morphological changes occur quickly as the embryo develops. A solid understanding of this science allows the student to effectively and more easily understand complexities and relationships in adult human anatomy (Moore & Persuad, 2007). "Human embryology requires students to understand the simultaneous changes in embryos, but students find it difficult to grasp the concepts presented and to visualize the related processes in three dimensions" (Moraes & Pereira , 2010). Areas that are innervated by certain nerves are some of these hard to understand concepts which at first glance, may seem illogical; specifically the branchial arch nerves (cranial nerves V, VII, IX, and X).

There are many illustrations depicting embryonic development including the pharyngeal arches as they begin to develop and illustrations showing the anatomy at birth, once the arches have fully developed. However, there seems to be a lack of visual information that makes a connection between those two types of illustrations.

This project investigates how best to visually depict pharyngeal/branchial arch nerve growth and illustrate its relationship to the muscles each nerve innervates as the embryo develops and undergoes complex morphological changes.

3D morphing animations were created and compiled into an interactive program to give the user control to rotate around the models and the animations 3-dimensionally, as well as options to play, stop, pause and replay the individual animations. This interactive program was then shown to a group of students in order to test its overall effectiveness.

B. Purpose of the study

This research proposes to create the VEPAM (Visualizing Embryonic Pharyngeal Arch Morphology) project; 3D animations that will visually clarify and track branchial/pharyngeal nerve growth in order to illustrate the relationship between them and the muscles they innervate.

The animations will also visually explain the migration of the muscles derived from each arch. By tracking these nerves as the pharyngeal arches develop, the student will be able to visually connect the pharyngeal arch and nerve development to the final end product that we see in adult human anatomy. This will help to clarify why certain nerves innervate certain areas and muscles that may seem illogical when studying adult anatomy. "It is only when one sees the early stages in the development of these muscles that there seems any logic whatever in their arrangement, their innervation, or their blood supply" (Patten, 1946).

This research investigates how best to illustrate these complex changes and transform them into a clear, understandable and approachable format. The animations will be reviewed by experts in the field for accuracy.

C. Importance of the study

This study is important because it addresses and proposes to fix an apparent lack of visual understanding of the dynamic relationship between all the pharyngeal arch derivatives, specifically the cranial nerves associated with each arch and the muscles they innervate. This research project will be used to visualize the transformation of this embryological process into a sequence of events.

II. Conceptual context:

A. Theory

Animations have been shown to greatly improve understanding of dynamic concepts when compared to static images (Höffler and Leutner, 2007). Therefore, animating the pharyngeal arch nerves and the muscles they supply will enhance the student's understanding of this complex relationship. This understanding will aid in a greater overall understanding of human adult anatomy and abnormalities.

B. Hypothesis

This research proposes to create animations that will visually and dynamically depict pharyngeal/branchial arch nerve growth. In order to improve overall understanding in this area, these animations will illustrate the relationship of each nerve and the muscles it innervates as the embryo develops and undergoes complex morphological changes. These animations will be compiled into an interactive program, giving the user the ability to rotate around the objects as the animation plays. This interactive tool will help users to develop a spatial understanding of the relationship between the pharyngeal arch nerves and the muscles they innervate.

III. Research question

This research project investigates whether animations tracking the growth of the pharyngeal arch nerves and the muscles they innervate can help to explain and clarify why certain muscles are supplied by certain nerves. In adult anatomy, this may seem illogical, but with a greater understanding of the embryological origins of these relationships, understanding of this phenomenon may be improved.

The research question is best phrased as:

"Can animations that visually and dynamically depict pharyngeal/branchial arch nerve and muscle growth in the embryo, improve overall understanding of the relationship between the branchial nerves and the muscles they innervate?"

IV. Literature Review

A. Why is human embryology/ pharyngeal arch growth important to understand?

Understanding the principles and concepts of human embryology is very important for medical students, doctors, and health-care professionals. This understanding leads to a greater understanding of adult anatomy as well as birth defects (Sadler, 2006). "Understanding the developmental stages that a structure or region undergoes during its embryogenesis gives important clues not only to its normal structure, but also to reasons why anatomical variation can occur" (Carlson, 2002).

Pharyngeal arch development is a major component of head and neck development. "Because many components of the face are derived from the pharyngeal region, an understanding of the basic organization of this region is important" (Carlson, 2009). This provides the student with a strong foundation to use to make sense of structures during the study of adult human anatomy. In *Embryology in the medical curriculum*, Carlson illustrates exactly how important the understanding of structures in embryonic development are in understanding adult anatomy.

"Another important function of embryology is to provide a logical basis for understanding the overall organization of the human body. For example, every year when I discuss the organization of the pharyngeal arches and the contributions that each arch makes to the normal structures of the head and neck, I see light bulbs going on in the medical students' eyes as they realize that some structural associations that they have seen while studying gross anatomy really do make sense when viewed in a developmental context" (Carlson, 2002).

"With a greater knowledge of developmental mechanisms and the rapid pace of technologic innovation in the field, embryology is becoming an increasingly important component of the medical curriculum" (Carlson, 2002).

B. Anatomy of pharyngeal arches and branchial arch nerves:

"Each pharyngeal arch consists of a core of mesenchymal tissue covered on the outside by surface ectoderm and on the inside by epithelium of endodermal origin" (Sadler, 2006). Neural crest cells in addition to paraxial and lateral plate mesoderm contribute to the core of each arch. These neural crest cells are responsible for "contributing to skeletal components of the face" (Sadler, 2006). The musculature of each arch is derived from the original mesoderm of each arch and has a specific cranial nerve associated with it. The nerve of each arch travels with that particular arch's muscle cells as they migrate during development. "The path of the nerve in reaching the muscle suggests the path followed by the muscle arriving in its adult location" (Patten, 1946).

Therefore, each pharyngeal arch can be distinguished by its own muscular components and the specific cranial nerve associated with them (Sadler, 2006).

Table 1. Pharyngeal/Branchial Arches and their Derivatives:

Arch	Muscles	Nerves	Age (Days)	Carnegie Stage
1 (mandibular)	Muscles of mastication (temporalis, masseter, medial pterygoid, and lateral pterygoid), myelohyoid, anterior belly of digastric, tensor tympani, and tensor veli palatini. (cranial somitomere 4)	CN V-Trigeminal, V3 Maxillary branch	22	10
2 (hyoid)	Stapedius, stylohyoid, posterior belly of digastric, auricular, and muscles of facial expression (orbicularis oculi, orbicularis oris, risorius, platysma, auricularis, fronto-occipitalis, and buccinator) (cranial somitomere 6)	CN VII- Facial	22	10
3	Stylopharyngeus	CN IX- Glossopharyngeal	26	12
4	Constrictors of the pharynx, cricothyroid and levator veli palatini (occipital somites 2 to 4)	CN X- Vagus, Superior Laryngeal branch	26	12
6	Intrinsic muscles of the larynx (occipital somites 1 and 2)	CN X- Vagus, Recurrent Laryngeal branch	?	?

1. Pharyngeal Arch 1:

The first pharyngeal arch, also known as the mandibular arch, arises around day 22, or during Carnegie stage 10 (Carlson, 2009). The maxillary portion of trigeminal nerve, cranial nerve V, supplies the muscles of this arch. The muscles derived from this arch include; the muscles of mastication (temporalis, masseter, medial pterygoid, and lateral pterygoid), myelohyoid, anterior belly of digastric, tensor tympani, and tensor veli palatini. These muscles originate from cranial somitomere 4 (Larsen, 2001).

2. Pharyngeal Arch 2:

The second pharyngeal arch, also known as the hyoid arch, arises around day 22, or during Carnegie stage 10 (Carlson, 2009). The facial nerve, cranial nerve VII, supplies the muscles of this arch. The muscles derived from this arch include; stapedius, stylohyoid, posterior belly of

digastric, auricular, and muscles of facial expression (orbicularis oculi, orbicularis oris, risorius, platysma, auricularis, fronto-occipitalis, and buccinator). These muscles originate from cranial somitomere 6 (Larsen, 2001).

3. Pharyngeal Arch 3:

The third pharyngeal arch arises around day 26, or during Carnegie stage 12 (Carlson, 2009). The glossopharyngeal nerve, cranial nerve IX, supplies the muscle of this arch. Stylopharyngeus is the only muscle derived from the third arch and it originates from cranial somitomere 7 (Larsen, 2001).

4. Pharyngeal Arch 4:

The fourth pharyngeal arch arises around day 26, or during Carnegie stage 12. (Carlson, 2009) The superior laryngeal branch of the vagus nerve, cranial nerve X, supplies the muscles of this arch. The muscles derived from this arch include; the constrictors of the pharynx, cricothyroid and levator veli palatini. These muscles originate from occipital somites 2 to 4 (Larsen, 2001).

5. Pharyngeal Arch 6:

The recurrent laryngeal branch of the vagus nerve, cranial nerve X, supplies the muscles of this arch. The intrinsic muscles of the larynx are derived from the sixth arch and originate from occipital somites 1 and 2 (Larsen, 2001).

C. Why animation?

Animation is an extremely powerful tool for depicting morphological changes that occur as an embryo develops. Animation allows for fluid movements between stages of development, thereby providing the user with a complete visual story of what is occurring. Single static 2D illustrations that illustrate steps of a morphological process are limited in that they do not adequately relay the movement between steps or the time span during which the steps occur. "The advent of computer technology has enabled the portrayal of developmental phenomena as three-dimensional model images in sequential depictions of changes proceeding in the fourth dimension of time. This 'morphing' technique is a powerful adjunct to gaining understanding of the complexities of rapidly changing tissues, organs, and relationships occurring during embryogenesis" (Sperber, Sperber, Guttman, 2010).

Animation also allows the student to easily view the embryo in three-dimensions. "Computer animation can clarify instruction by allowing students to visualize complex, dynamic processes in an interesting presentation" (Thatcher, 2006). By using animation to illustrate complex aspects of embryology, the material becomes more accessible and comprehensible. These animations provide students with the tools they need to better understand and visualize the information correctly.

Research by Marsh, Giffen and Lowrie, (2008) has also shown that animations of embryology help in long-term memory retention in medical students. In addition, research conducted by Höffler and Leutner (2007) demonstrated that overall, learning from animations is more successful than learning from static images.

In his article, *Embryology in the medical curriculum*, Carlson investigates how students learn embryology and how it is taught in medical schools. In most medical schools, embryology is taught as a lecture-based course with textbooks and usually without a lab. He states that a "...challenge to printed texts is the representation of dynamic processes in which three-dimensional structure changes over time" (Carlson, 2002). These complex morphological and dynamic processes would therefore be best shown in an animation, where these processes could be viewed most effectively in 3 dimensions.

Research done by Schleich and Dillenseger, investigated the use of 3d animation as a tool for understanding embryology of the heart. They understood that embryology is a difficult subject for students to understand because of the complexities and dynamic changes that occur during development. They discovered that 3d animation allowed them to most effectively illustrate the difficult spatial changes that are occurring in 3-dimensions (Schleich & Dillenseger, 2001).

D. Interactivity

"Interactivity is presented as an attribute of learning environments that enhances the quality of educational materials and that can facilitate learning" (Domagk, Schwartz & Plass, 2010). Domagk, Schwartz and Plass, in their research study, investigated interactivity, what it entails, and factors that need to be considered when constructing and designing an interactive tool for instruction. They narrow the broad term of interactivity down to three main groups; (1) "interaction on human communication," (2) "computer-mediated human communication," and (3) "human-computer interaction" (Domagk, Schwartz & Plass, 2010). This last category is applicable in the field of educational technology and the interactivity of this research project will best fall into this category. Domagk, Schwartz and Plass point out that many believe that the more interactivity in a product, the better the quality of the product and therefore it will produce better learning outcomes. They also point out that others believe that the amount of interactivity does not necessarily create a greater understanding, and that it may actually "impose an excessive extraneous cognitive load due to large amounts of information that need to be processed or the generation of split-attention that can interfere with learning" (Domagk, Schwartz & Plass, 2010). Domagk, Schwartz, and Plass, point out a few forms of interactive controls that are important in an effective interactive product. These include; "control over pacing," which provides the user with navigation features such as start, stop, pause, and replay, "control over content," which includes allowing the user to choose chapters or units from a menu, and "control over representation," which allows the user to control the modality or angle of view (Domagk, Schwartz & Plass, 2010).

Research conducted by Tabbers and Koeijer also examined learner control in animated multimedia programs. They speak about how important learner control is, especially when animations are being presented with a lot to learn and understand in a short time frame. "Giving

learners control over animated multimedia instructions seems an effective and easy-to-implement way to enhance learning" (Tabber & Koeijer, 2009).

E. Authoring Tools for 3D Interactivity

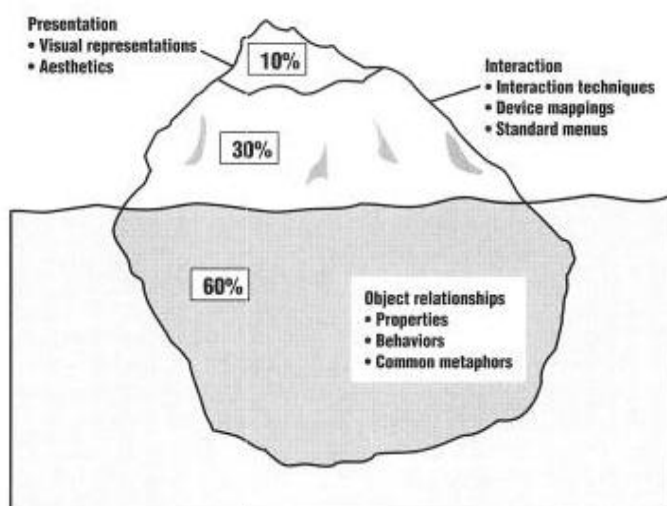
There are various tools that may be used to compile animations into an interactive program including Unity 3D, Adobe Flash, Adobe Acrobat 3D pdf, and Html 5. Important considerations for choosing the most appropriate tool includes accessibility, file size, compatibility with 3D software programs, and possible limitations.

Some of these tools allow the user to rotate around the animations as they play. This will give the user a greater understanding of the concept in 3dimensions. Including user controls such as these, as well as stop, play, pause, replay and other 3d navigational tools, will allow the user to easily navigate through the animations, thereby enhancing the learning experience and improving comprehension (Tabber & Koeijer, 2009).

Refer to Appendix B: Authoring Tools for 3D interactivity (p. 38) for a comprehensive table of the different authoring tools.

F. User Interface/Design

When creating a successful user interface design, attention to the user's interaction and experience is important. The goal should be to keep the user interface as efficient and straightforward as possible. "I should be able to "get it"-what it is and how to use it without expending any effort thinking about it" (Krug, 2006).



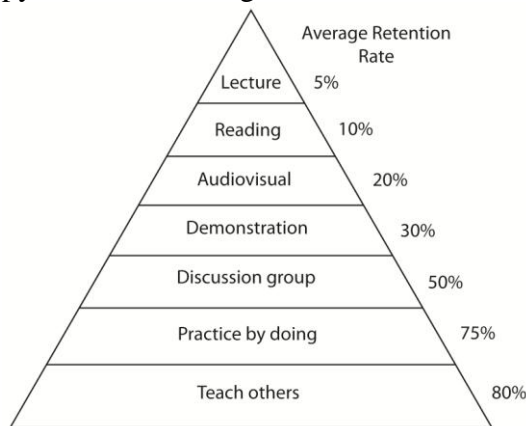
The look-and-feel iceberg, (IBM, 1992)

Mandel (1997) uses IBM's iceberg model as a theory of good user interface design. He states that although presentation "is the most obvious part of a user interface, the presentation aspects aren't the most important part of the interface" (Mandel, 1997). When designing the presentation

aspects of the interface, the designer must also strive not to overuse elements and detract from the user's experience. The second area of the iceberg model is interaction. This section covers what tools the user will be given to navigate through the program. Finally, the most important section of the iceberg model is about object properties and their relationship to other objects. In this section, designers are concerned with figuring out how to best make the user understand and successfully grasp the objectives of the program (Mandel, 1997).

G. Educational Models:

The University of Michigan's medical school teaches their Gross Anatomy course based on the "educational principles of active learning." This educational model can be summarized in a pyramid of learning:



(The University of Michigan, 2000)

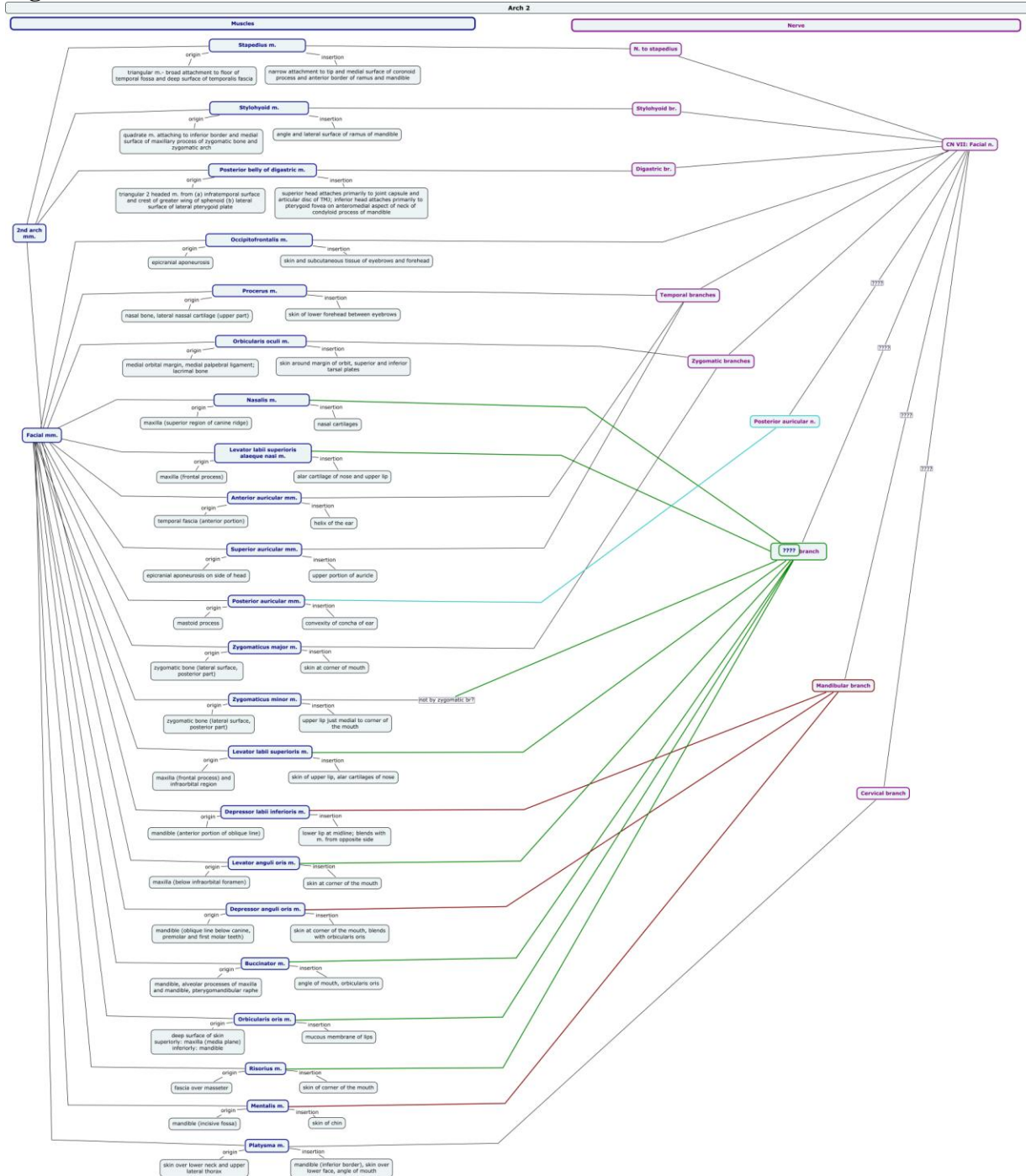
This pyramid shows that students who watch an animation with narration will have a 20% average retention rate of the material. This model reinforces the idea to create animations of the pharyngeal arch muscles and cranial nerves associated with them. These animations will greatly supplement the lectures medical students are receiving, providing the students with a greater understanding of the material and a greater ability to teach others. Once they are able to teach others, the pyramid of learning dictates they will have an 80% retention rate of the material. This is a significant increase from the average retention rate from only listening to lectures and reading.

Students develop a greater understanding of a concept when they can find patterns and understand fundamental relationships (Bransford, Brown & Cocking, 2000). My animations will help students understand the embryological origins of pharyngeal arch muscles and their relationship to the cranial nerves by which they are supplied, which will solidify and clarify the patterns seen in adult anatomy. This will give the student a greater understanding of the pharyngeal arches and adult human anatomy.

H. Pharyngeal Apparatus Learning Objectives:

After reviewing the PowerPoint (*Development of the Pharyngeal (Branchial) Apparatus...*) used by Dr. Pescitelli while teaching embryology to medical students at the University of Illinois at Chicago, the four main learning objectives in understanding the pharyngeal arches include:

Figure 2. Arch 2 Flowchart:



In addition to this chart, another chart for arch 2 was created. This flowchart was based on information from Raymond Gasser's article, "The Development of the Facial Muscles in Man," which details the morphogenesis and development of the facial muscles.

Figure 3. Facial Muscles Flowchart:

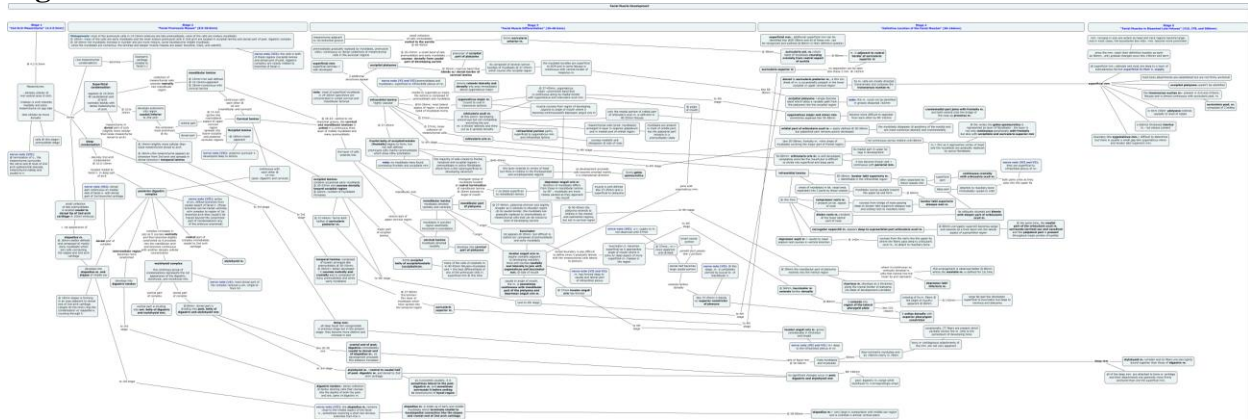


Figure 4. Arch 3 Flowchart:

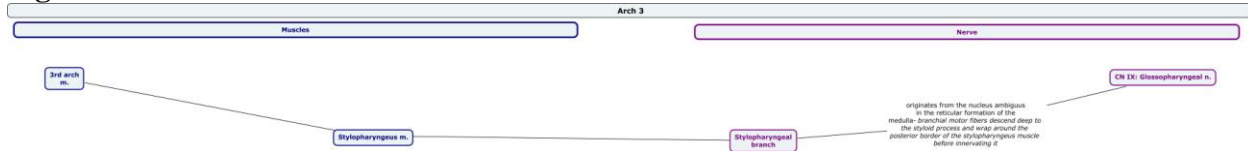


Figure 5. Arch 4 Flowchart:

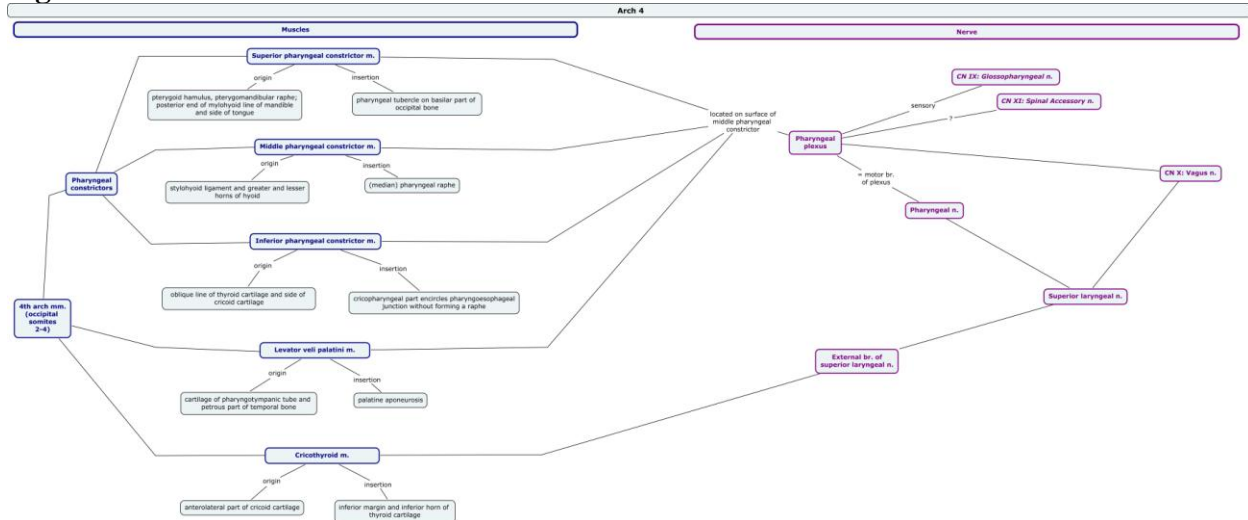
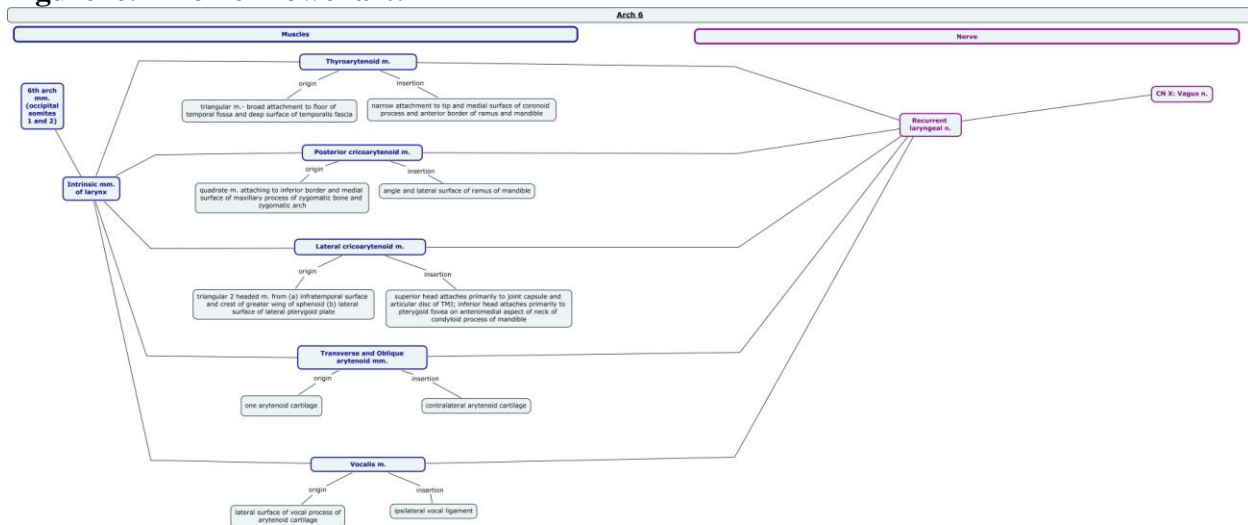


Figure 6. Arch 6 Flowchart:



2. Production

Data from the Virtual Human Embryo Project, digital images of serial sections from embryos in the Carnegie collection, was purchased and used to create accurate reference models of Stage 10-23 embryos. The data was brought into Materialise's Mimics, a program used to extract accurate 3D models from imaging data. Determining the correct slice distance and pixel size for each sliced section of the stages was important in ensuring the accuracy of the models. Measurements found on the Virtual Human Embryo Data's website and additional information included with the purchased data was used to determine this information. Refer to Appendix A: DREM Database (p. 35) for the pixel size and slice distances used in Mimics.

Figure 7. Stage 13 Embryo with Incorrect Pixel Size Input:

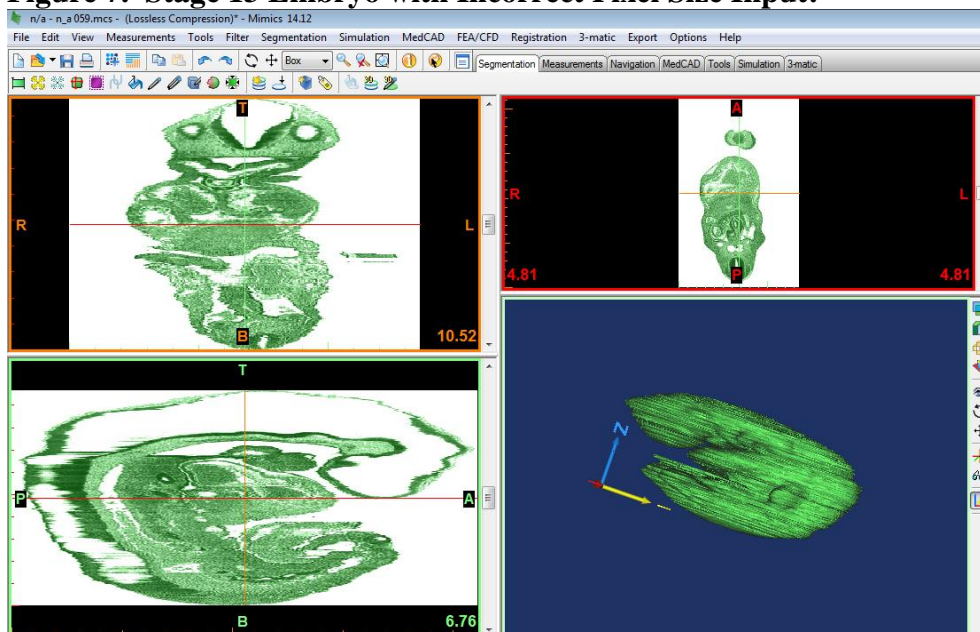
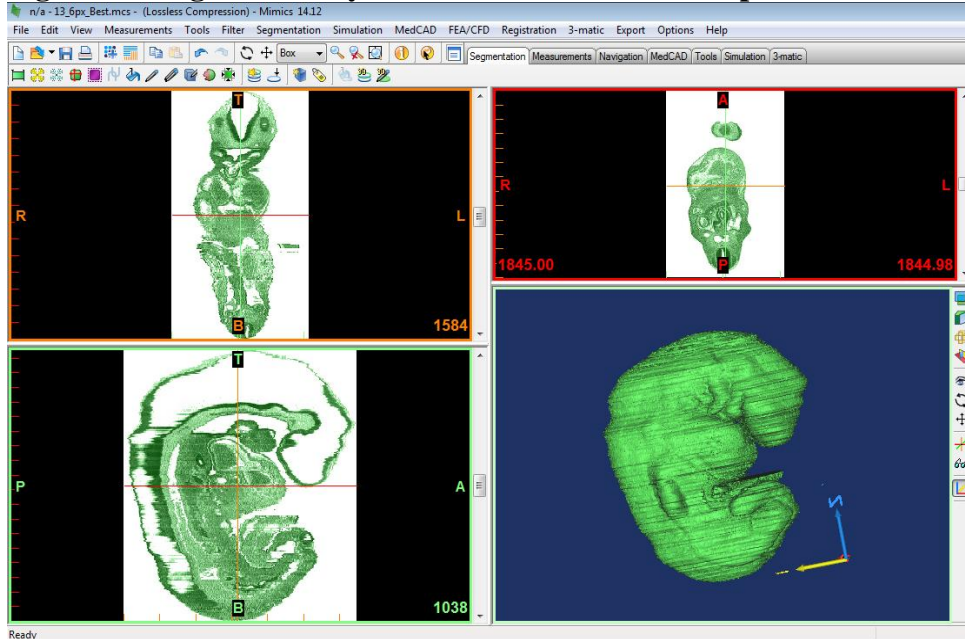


Figure 8. Stage 13 Embryo with Correct Pixel Size Input:



Using mask layers and tools in Mimics, the overall shape of the embryo's head/neck regions, brains, muscle masses, and nerves of each arch were extracted from the necessary stages. Content experts in the field were consulted during this process to ensure accuracy.

Note not all muscles derived from each arch were created. Muscles too small to be extracted from Mimics or not found in the data, were excluded to preserve the integrity of the project. In addition, information from Raymond Gasser's article, "The Development of the Facial Muscles in Man," was used to determine which muscles from arch 2 were present at Stage 23.

The following muscles were not included in the final project:

Arch 1: Tensor veli palatini, Tensor tympani

Arch 2: Stapedius, Procerus, Nasalis, Levator labii superioris alaeque nasi, Levator labii superioris, Depressor labii inferioris, Risorius, Mentalis

Arch 4: Levator veli palatini, Cricothyroid

Arch 6: Arch 6 was represented as a muscle mass whose muscles have yet to differentiate into Thyroarytenoid, Post. cricoarytenoid, Lat. cricoarytenoid, Transverse and oblique arytenoids, Vocalis

Figure 9. Cranial Nerve V, VII, IX, and X Masks in Mimics, Stage 13:

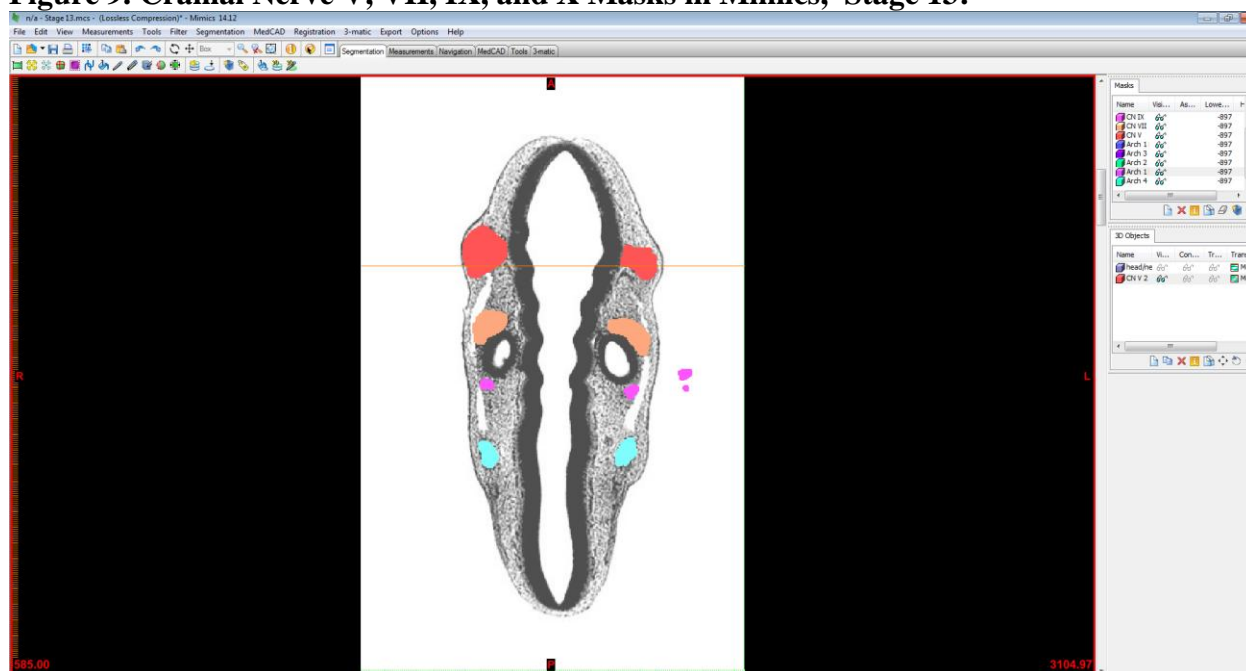


Figure 10. Mimics Masks and 3D Objects, Stage 13:

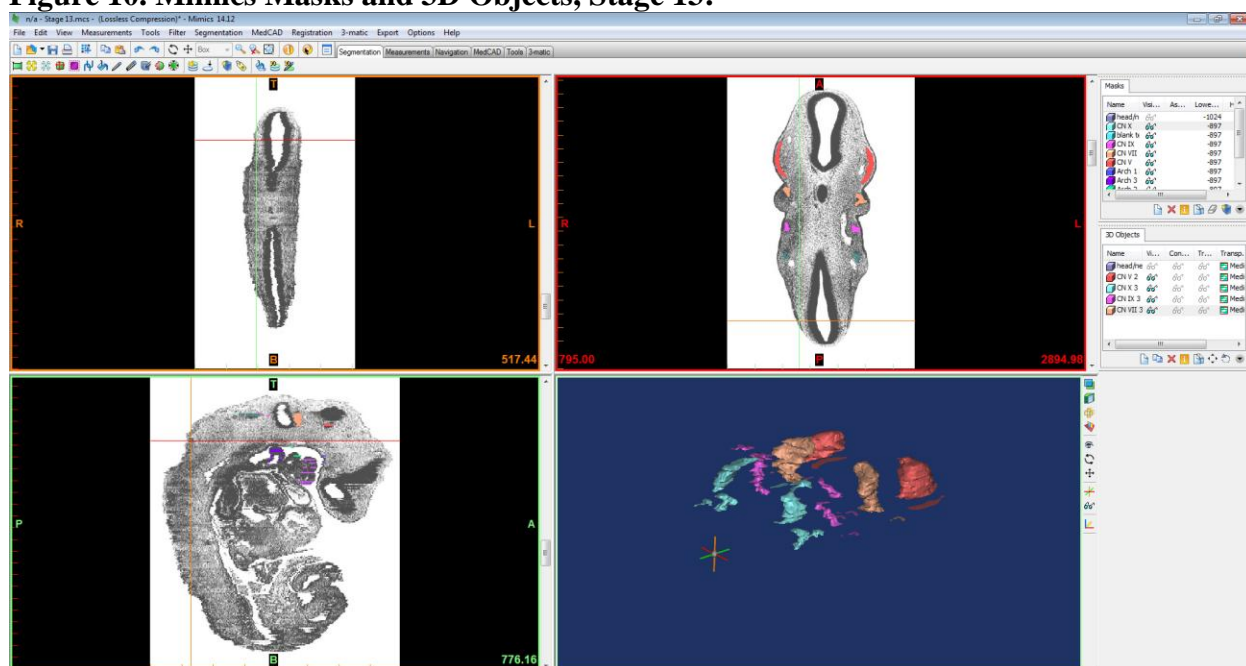


Figure 11. Mimics Masks and 3D Objects, Stage 21:

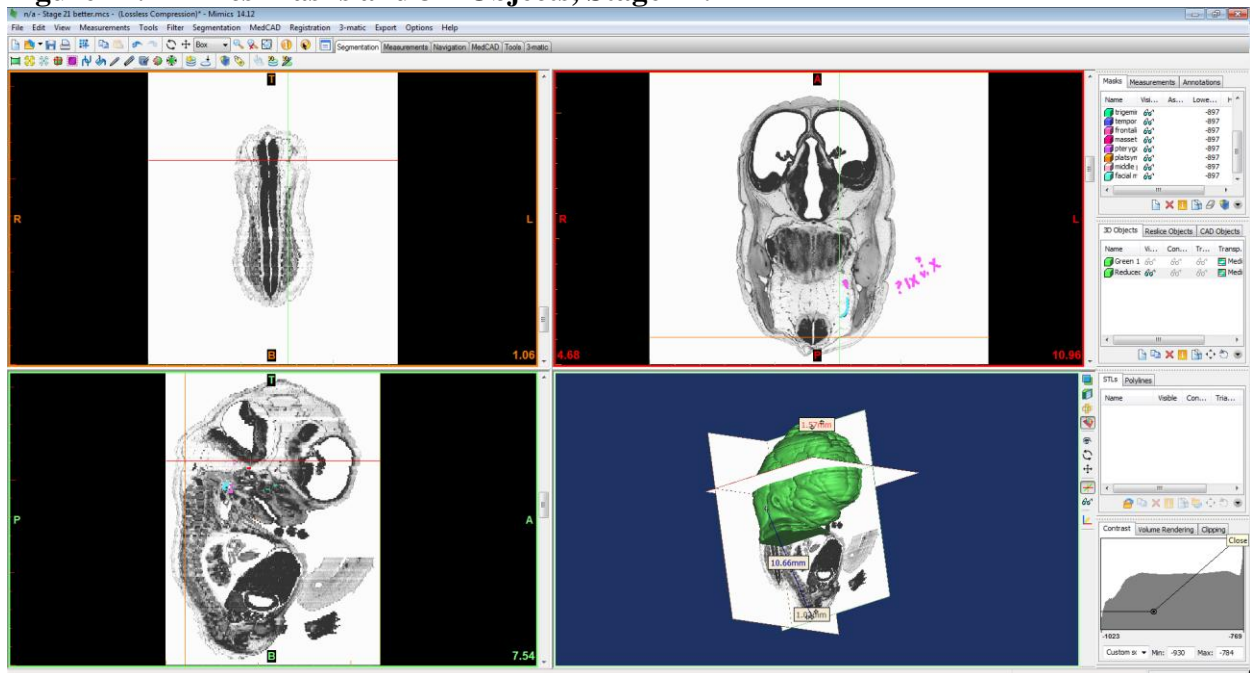
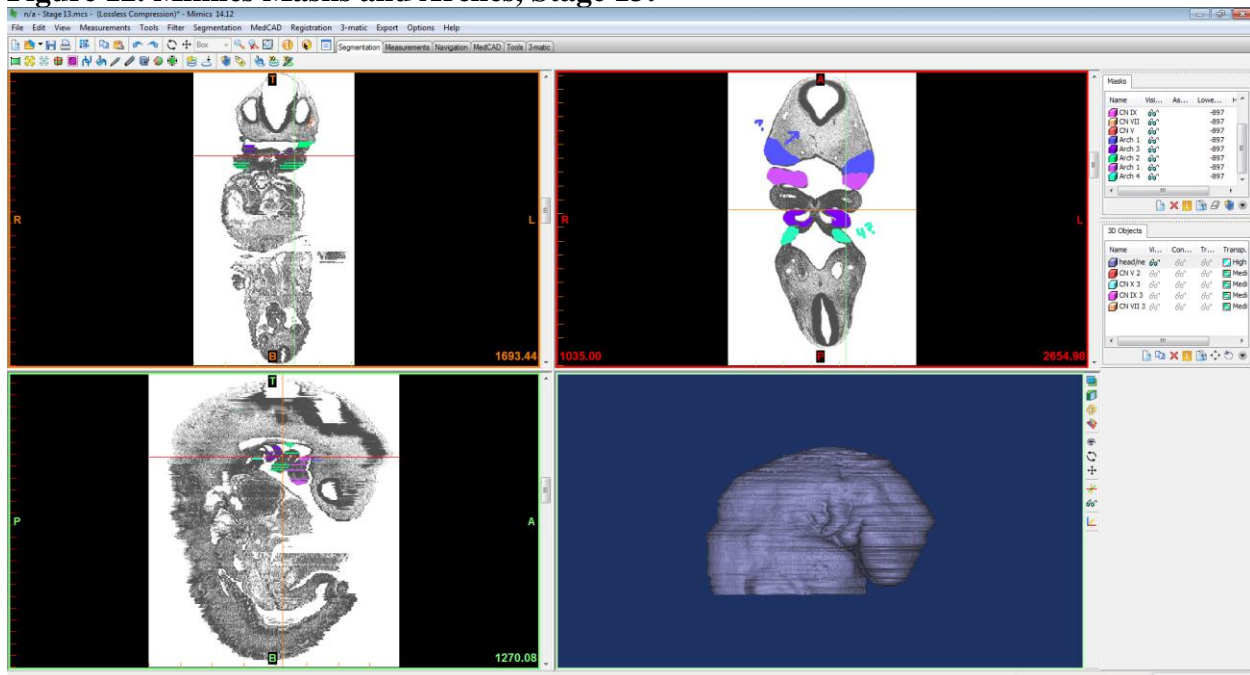


Figure 12. Mimics Masks and Arches, Stage 13:



These models were used as crucial references in addition to other published images of the embryos from before they were sectioned.

Measurements of the extracted heads, brains, and muscles taken in Mimics were used when creating the heads, brains, and muscles in Mudbox and 3dsMax.

Figure 13. Extracted Embryo Head/Neck Regions:

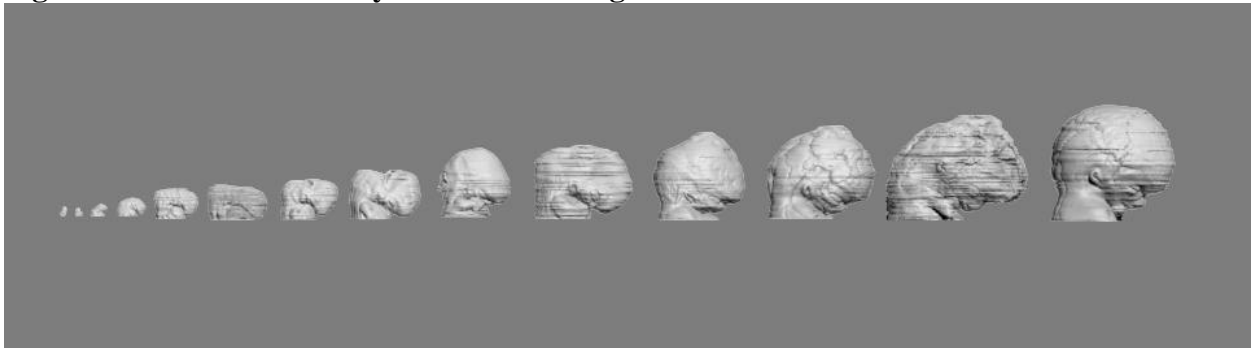


Figure 14. Heads, Brains and Cranial Nerves V, VII, IX, X Exported from Mimics:

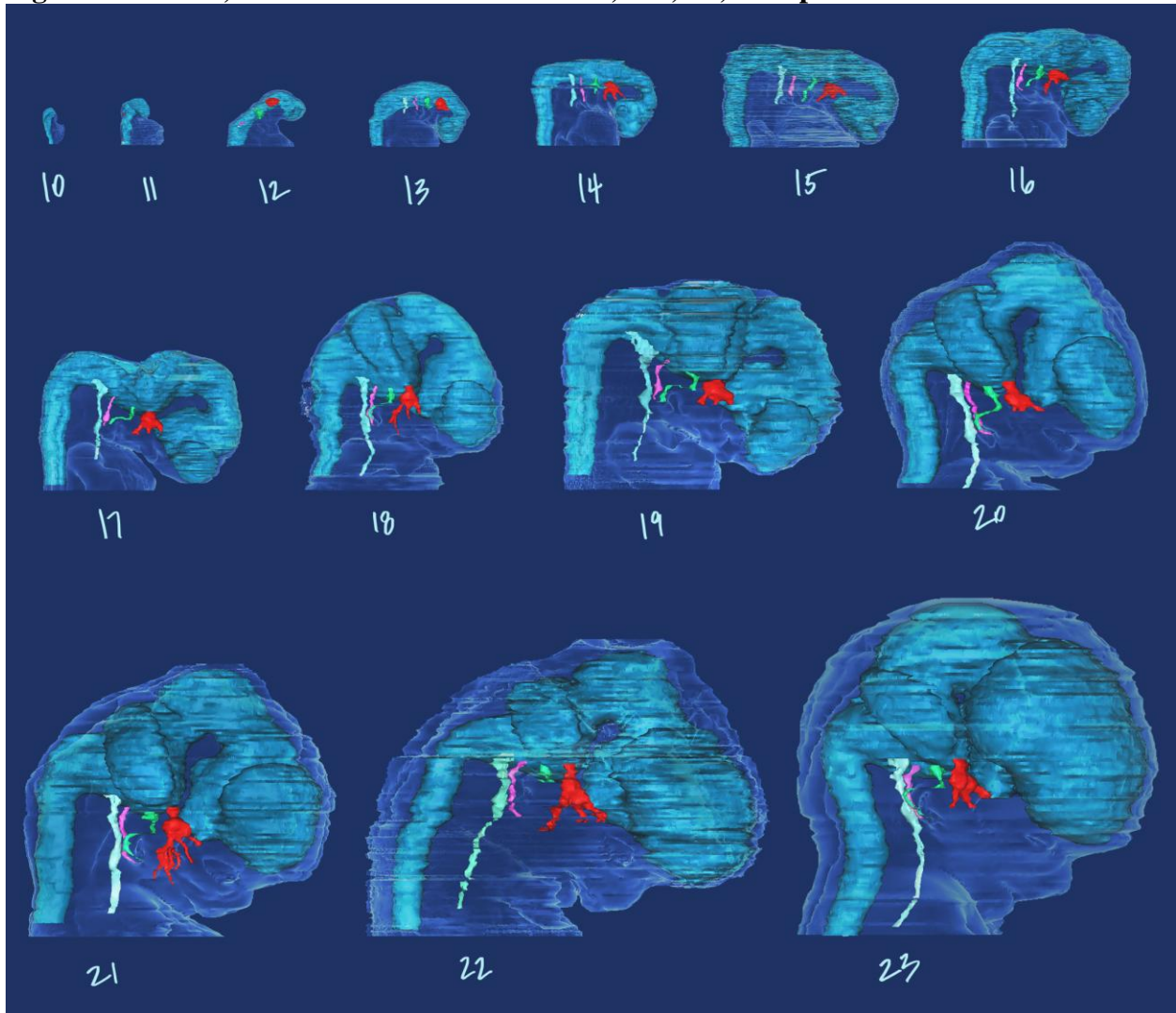


Figure 15: Exported Muscles, Stage 23:

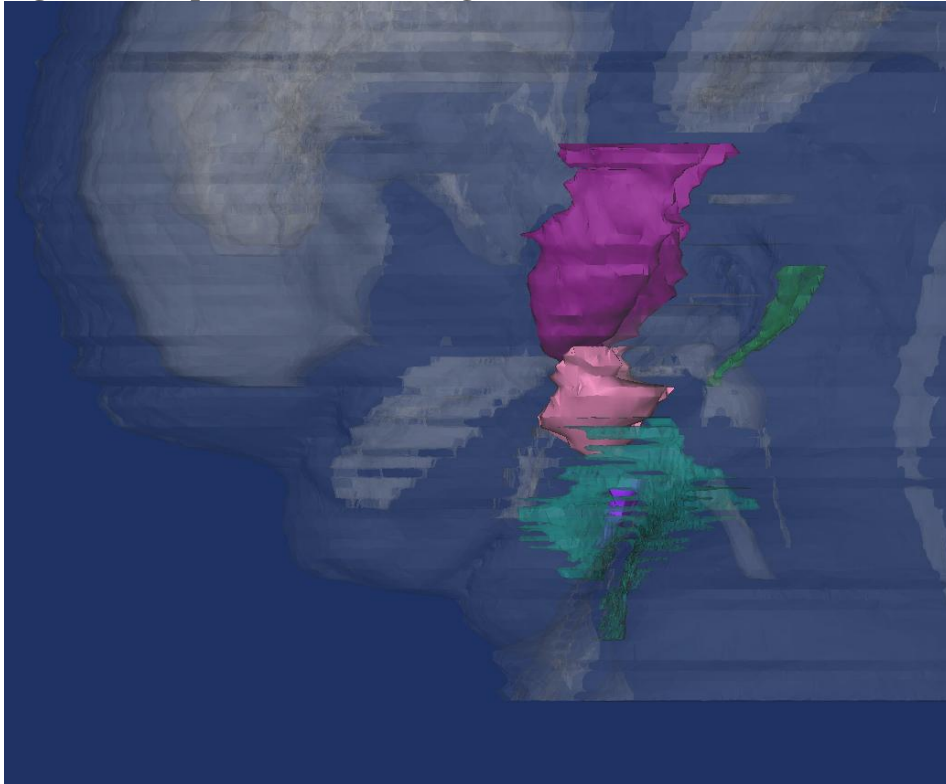
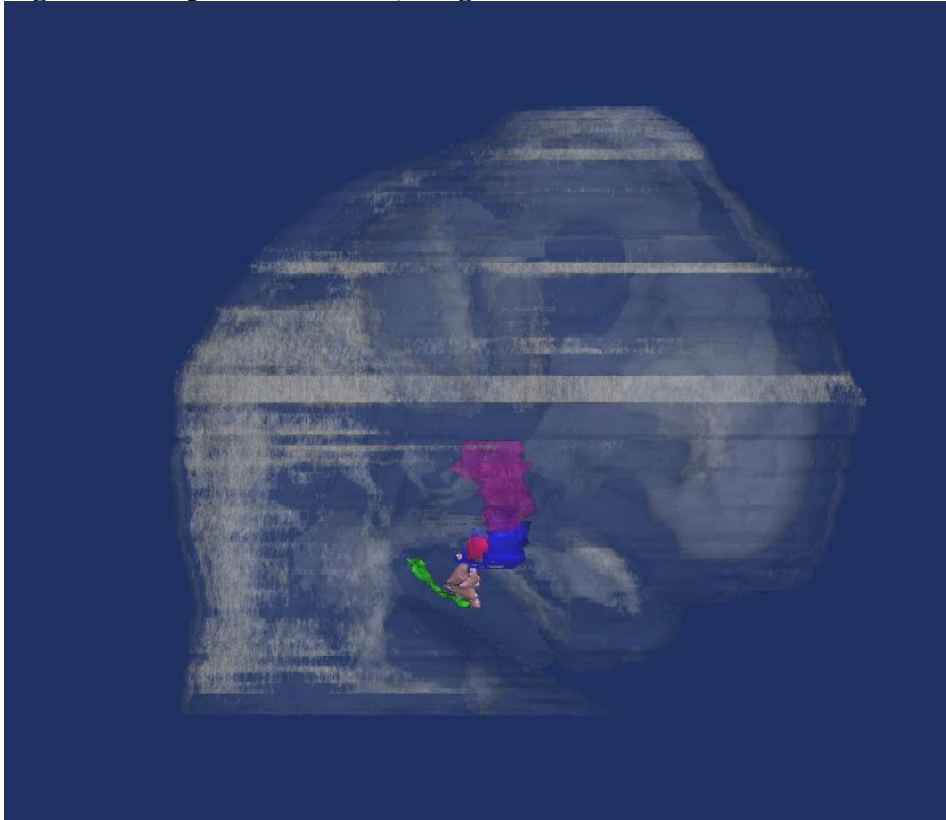


Figure 16. Exported Muscles, Stage 20:



1. Model Creation Workflows

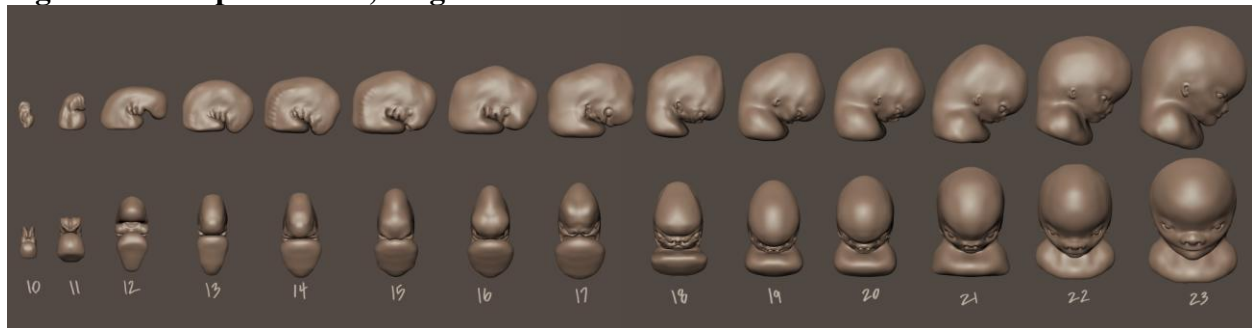
Using these references, clean models of the heads, brains, and muscles were all sculpted in Autodesk's Mudbox. Head, brain and muscle models were created for each specific stage to be used as morph targets in Autodesk's 3dsmax. In order to morph between the brains of each stage, for example, the same number of polygons had to be maintained from brain to brain in each stage. This requirement was taken into account when deciding upon the best workflow for creating all the models.

Content experts, data extracted from the Virtual Human Embryo Project, textbooks, and online resources were referenced and utilized throughout all of these processes to ensure accuracy in all the models.

Embryo Heads:

Starting with a primitive sphere shape in Mudbox, the Stage 23 head was sculpted first. Once this model was finished, it was saved as Stage 22 and adjusted accordingly. Once the Stage 22 model was finished, it was saved as Stage 21 and adjusted accordingly and etc. down the line toward Stage 10. By working from the last stage to the earliest, it made it easier to make sure vertices of different regions of the head, such as the eyes and nose, would track well when the embryo morphed. This prevented the nose from morphing into the chin, or the eye morphing to a cheek or ear area. This workflow also ensured that each stage's model would have the same number of polygons and vertices.

Figure 17: Sculpted Heads, Stages 10-23:



Brains:

The workflow for the creation of the brains was essentially the same as with the head/neck regions. The only difference was in the base model used to create the Stage 23 brain. Z-brush was used to create a simple low polygon shape that mimicked the brain. Z-brush was chosen because the Stage 23 brain had multiple bends to it and as opposed to starting with a sphere in Mudbox and trying to sculpt it to mimic the brain, z-spheres were used to build the base brain from scratch, which allowed for more control. This model was imported into Mudbox and sculpted to match the brains exported from Mimics. The already sculpted heads were also included in the file, to ensure the brains fit in the heads correctly.

Figure 18. Sculpted Brains, Stages 10-23:

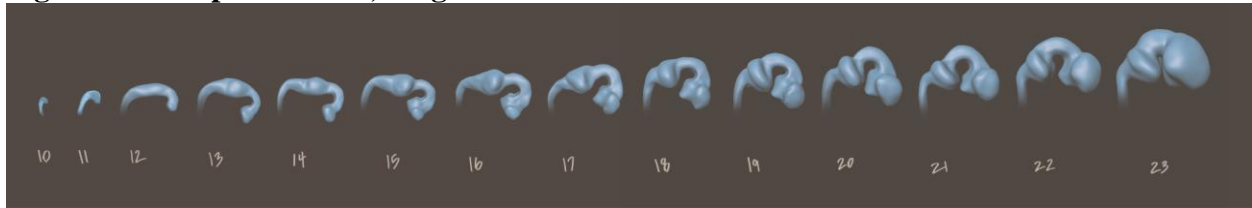
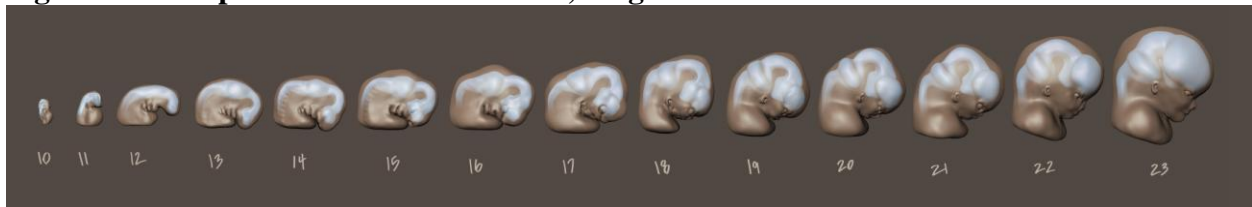


Figure 19. Composited Brains and Heads, Stages 10-23:



Muscle Masses:

A number of primitive spheres were created in 3dsmax and arranged in 3D space based on muscles extracted from the Stage 23 embryo in Mimics. Next, all the spheres were attached to become one object. The number of spheres was dependent on the number of muscles derived from its relative arch. Once the spheres were one object, it was brought into Mudbox and sculpted based on the data extracted from Mimics. The same workflow of working from last stage to earliest stage was utilized here as well. The individual muscles ("spheres") were sculpted and pushed nearer to each other as it got closer to stage 10. Eventually all the muscles converged into a single muscle mass that represented that arch in the earlier stages. The previously sculpted heads were also included in the file to ensure the muscles fit correctly in the heads.

Figure 20. Sculpted Muscles, Stages 17-23:

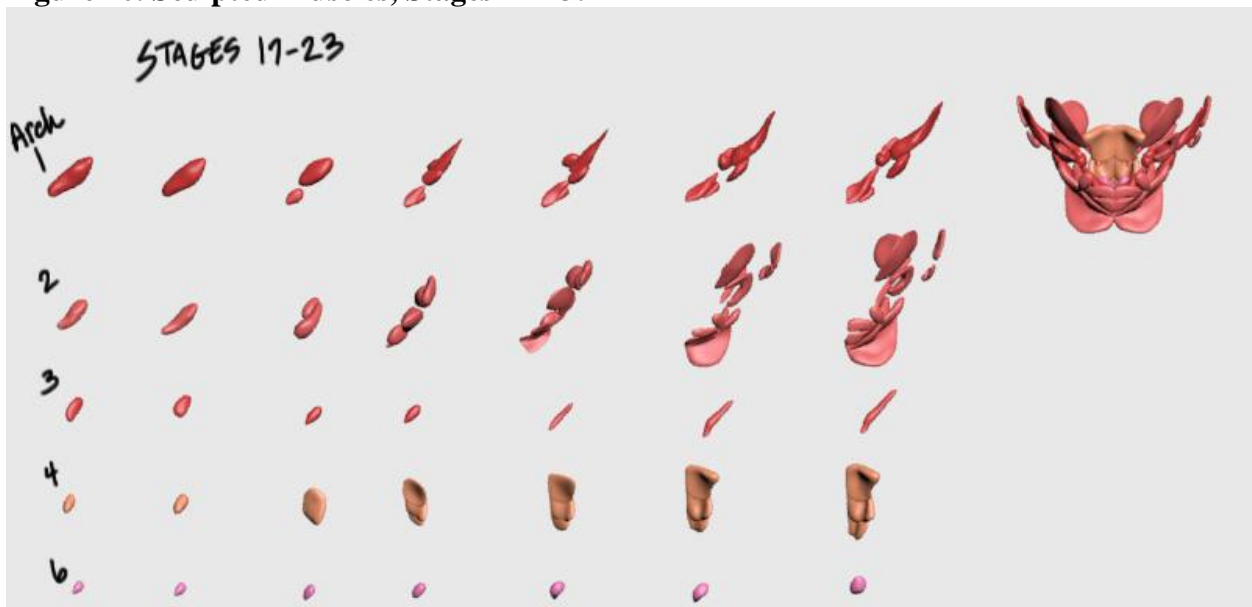
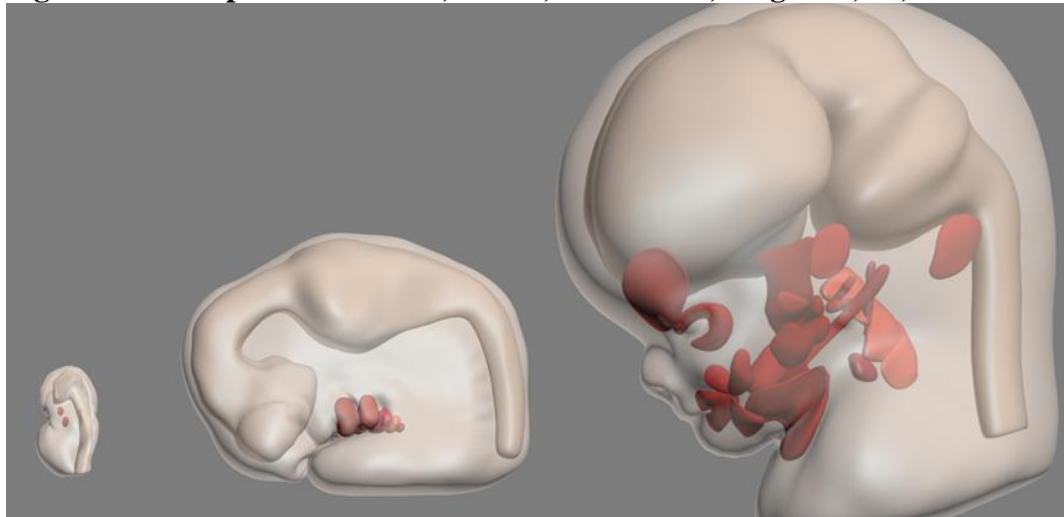


Figure 21. Composited Muscles, Heads, and Brains, Stages 10, 15, and 23:



Nerves:

The nerves and their branches were created as low polygon objects in 3dsmax by extracting polygons from a base primitive box. Once the nerves and their respective branches present at Stage 23 were created, the nerve was cloned and adjusted to fit with the brain and muscle masses of that stage. The polygons that made up the branches were relaxed stage by stage until by stage 10, the nerve was just a ganglion with no branches. Afterwards, a mesh smooth modifier was applied onto the nerves to smooth out their appearance. The pathways of the nerves was determined by following the migration of the muscle models that were created earlier.

Figure 22. Cranial Nerve V, VII, IX, and X Morph Targets:



Figure 23. Low Polygon Facial Nerve:

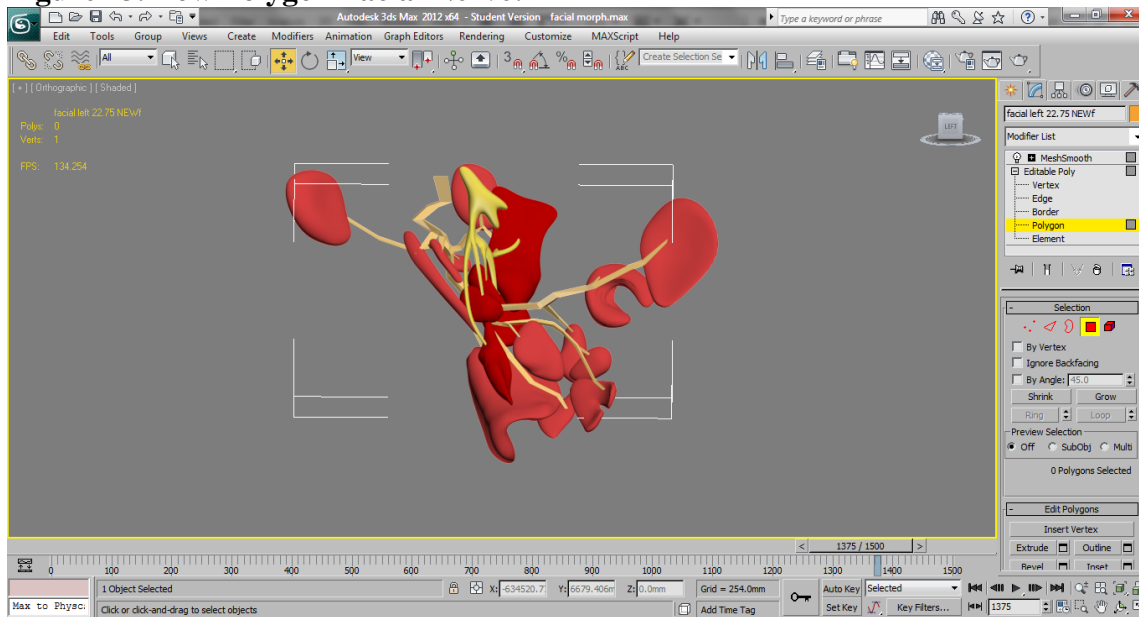
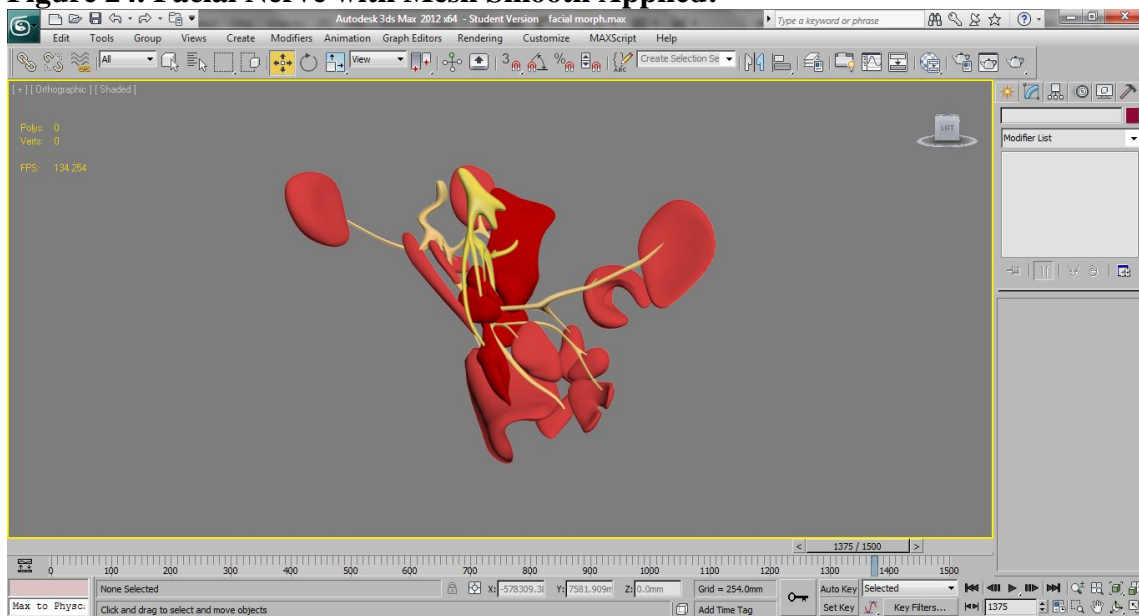


Figure 24. Facial Nerve with Mesh Smooth Applied:



2. Morphing Workflow

Once all the head models were created for each stage, a morph modifier was applied on the Stage 10 head. All the models were loaded in as morph targets and animated. This same process was applied to the brains, muscles and nerves. The only difference was with the facial nerve, for which the morph modifier was applied on the Stage 23 nerve, as opposed to the nerve for Stage 10. This was important in preventing polygon stretching once the nerve was brought into Unity.

3. Postproduction:

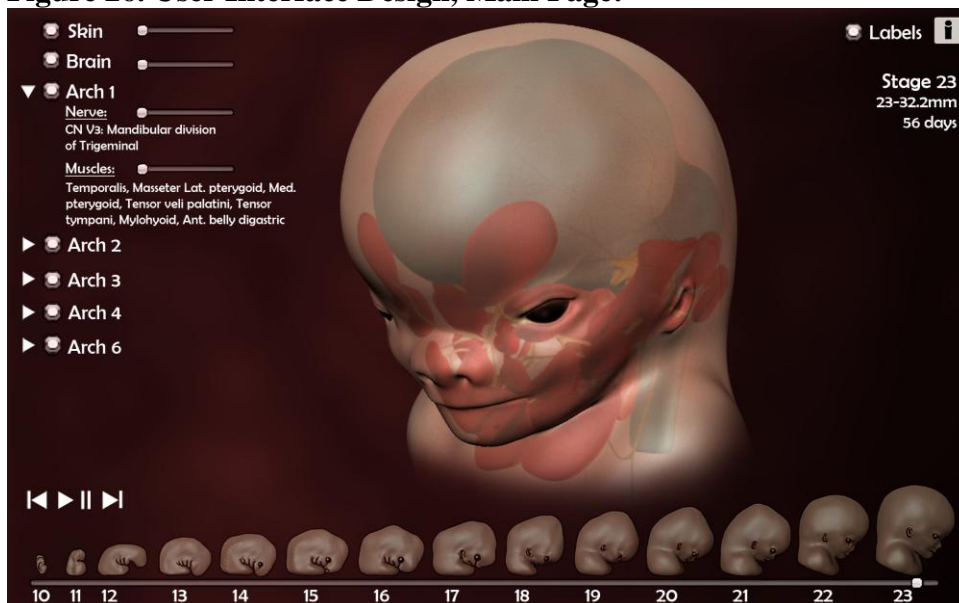
1. User Interface Designs

User interactivity and interface designs were developed. The user interactivity design detailed out what type of user interactivity would be included and how the animations would play and be controlled. Refer to Appendix D: User Interactivity Design (pg. 40) for the user interactivity design. User interface designs for the landing and main pages were also created. These functioned to layout exactly the look and feel of the user interface. Care was taken to keep the designs simple and engaging, while complementing the main models and their animation.

Figure 25. User Interface Designs, Landing Page:



Figure 26. User Interface Design, Main Page:

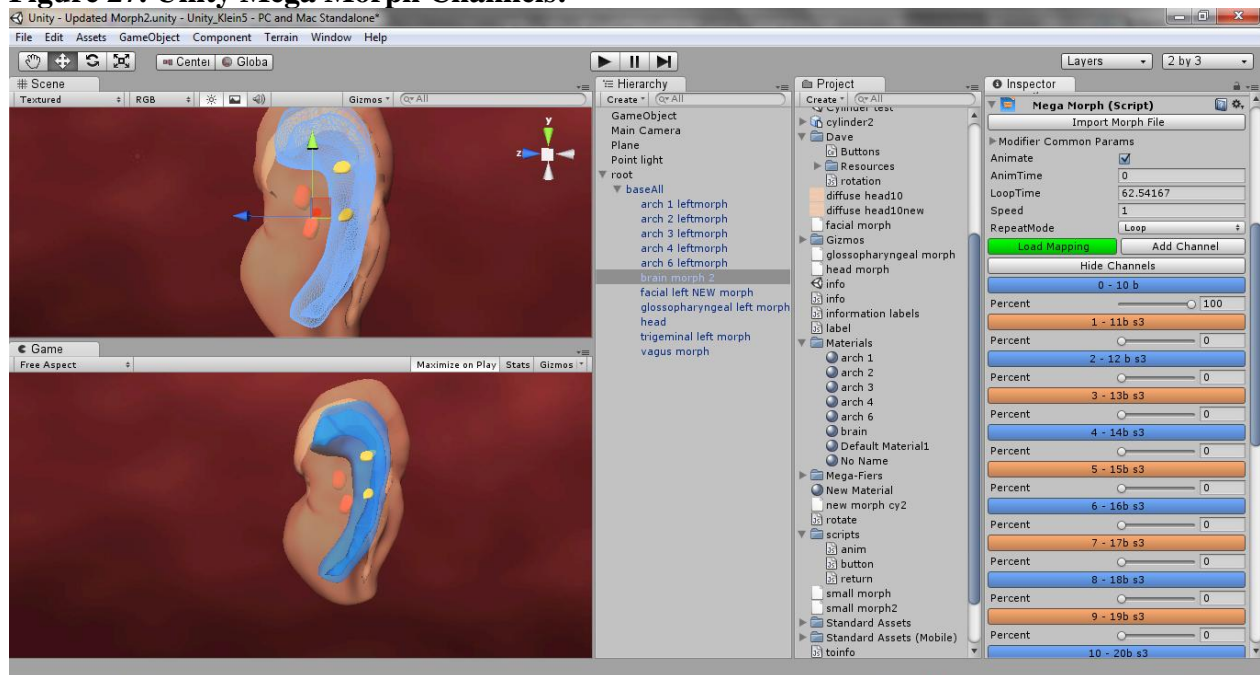


2. Interactive Program Creation

After the animations were created, they were compiled using an authoring tool that added the component of interactivity. After comparing the pros and cons of different possible 3D authoring tools, Unity 3D was chosen as the top choice. Refer to Appendix B: Authoring Tools for 3D Interactivity, p. 40)

Using MegaFiers, a Unity plug-in created by Chris West, the morphing animations were brought into Unity. Vertex animation usually unsupported in Unity, was made possible through this plug-in. The MegaFiers' Morph modifier, once applied to an object, brought all the morph channels from 3dsmax into Unity to be controlled and animated. Once in Unity, scripts were created and assigned to the objects to allow for user interactivity and control. Refer to Appendix E: Script to Control Morphing Animations, Main Page (pg. 42) for the script used to control the animations.

Figure 27. Unity Mega Morph Channels:



The final interactive program allows the user to rotate around the models as the embryo morphs and develops. In addition, the user has the ability to hide different components of the animation in order to focus and improve understanding of each arch and its respective muscles and nerves. Slider controls for opacity and saturation levels provide the user with additional tools to highlight specific models and focus on how the different components relate to each other.

Figure 28. Final Interactive Program, Main Page:

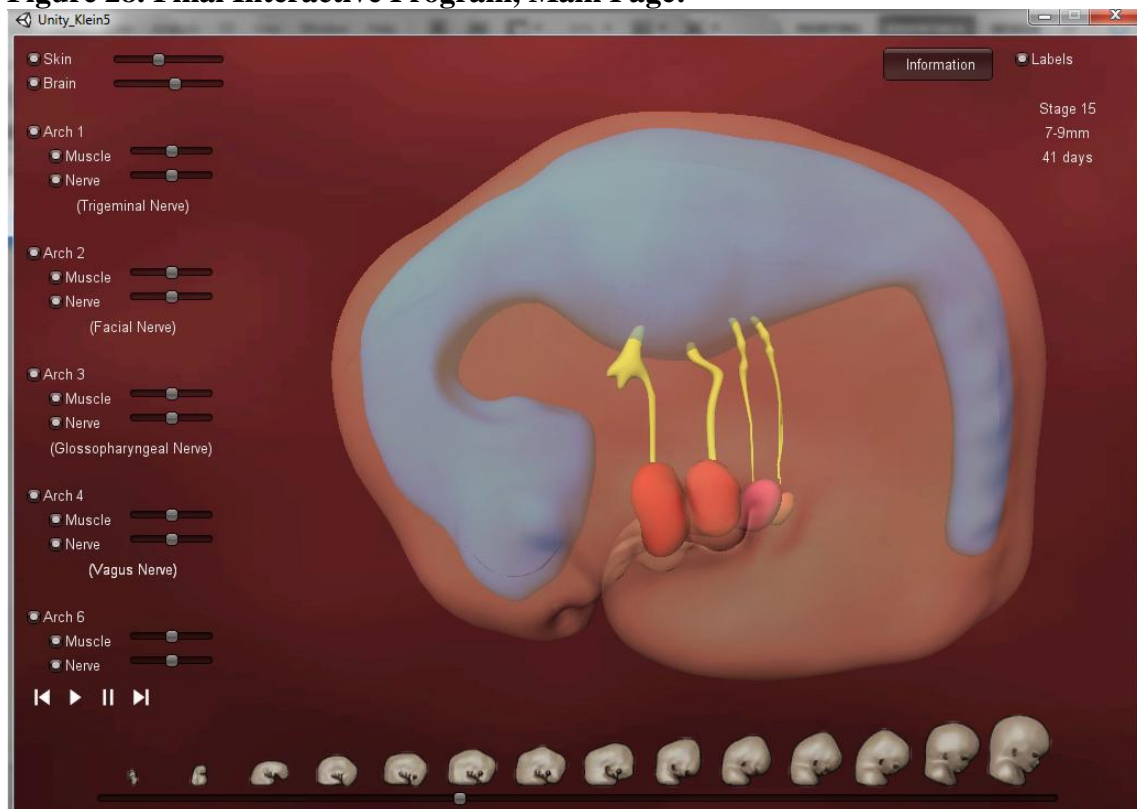
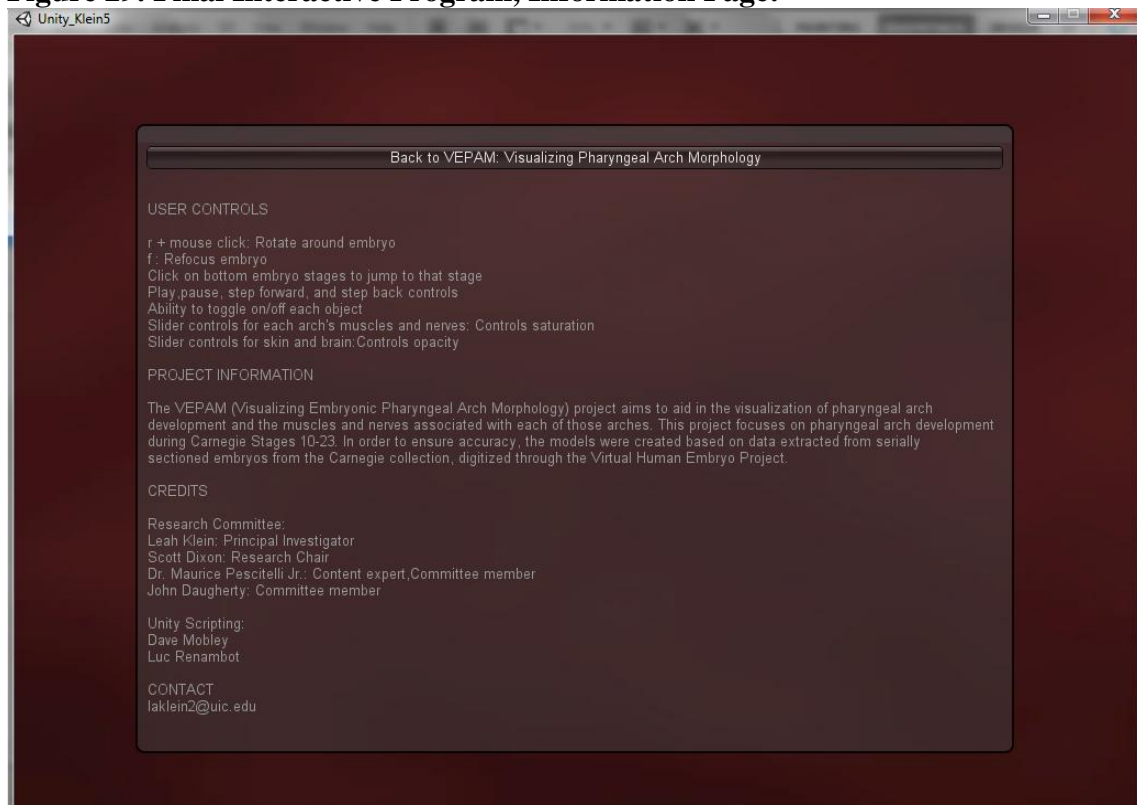


Figure 29. Final Interactive Program, Information Page:



B. Methods of Inquiry

The completed animations were tested on a pool of medical students enrolled in the University of Illinois at Chicago's ANAT 440: Gross Human Anatomy course during the spring semester of 2012. All testing was anonymous and an IRB exemption application was submitted and approved by the Office for the Protection of Research Subjects (OPRS) at the University of Illinois at Chicago.

During the week of testing, students received an email explaining the research and what to expect if they chose to participate. The informed consent form, links to the interactive program and assessment survey were attached to this email. Refer to Appendix F: Recruitment Letter (pg. 58) and Appendix G: Informed Consent Form (pg. 60) for those documents.

After interacting with the program, the students were asked to complete an online assessment survey. This survey allowed the student to rate and comment on the overall effectiveness of the animations and interactive program as a study tool. Results will be analyzed to evaluate the interactive as a learning tool.

After comparing different online survey services, SurveyMonkey's basic plan was chosen to create the assessment survey. Refer to Appendix C: Comparison of Online Survey Services (pg. 39), for a comprehensive list of the different online survey programs.

C. Population/Sampling Methods

Medical students enrolled in ANAT 440: Gross Human Anatomy course during the spring semester of 2012 were targeted for this research. Participation was voluntary and anonymous.

These students are studying the foundations of human anatomy as part of their medical school coursework and their preparation for taking the United States Medical Licensing Examination (USMLE). The expert advice and evaluation from these students will be guiding forces in further developing this tool as a study resource for future medical students.

D. Methods of Analysis/Interpretation of Data

Data from the assessment survey was analyzed using SurveyMonkey's analysis tools. This data provided useful feedback on how effective the animations were and how students rated them as a study tool. This information combined with committee feedback served as qualitative data used to evaluate the overall effectiveness of the interactive program.

Five students participated in the research study and all of the students reported they would recommend or use this animation in the future. Most found the interactive program easy to navigate around in, however some mentioned the rotation of the embryo was difficult to control. One student mentioned being able to watch the animations in reverse would have been useful as well. When asked if the animations were useful in helping them better understand the material, the answers ranged from slightly useful to very useful. Many wrote that labels would greatly enhance the interactive program and help improve understanding. One wrote that the animation

helped tell a story that could be understood as opposed to having to memorize static images. Another student wrote the interactive program was great for putting everything together and that they never truly understood what the arches really meant until now. Overall the students found the content to be well organized and the speed of the animations to be just about right.

When asked whether the animations met their learning needs as a student, the answers ranged from not at all to moderately well. The students were asked to name the weaknesses of the animations and what suggestions they may have to improve them. Some thought labels, more explanations and possibly adding a voiceover would help improve the program. One found the missing muscles from the arches to be misleading and another suggested including the sensory branches of the nerves as well. A couple mentioned improving the control for orientating and rotating the embryo and including zoom controls.

One student mentioned how the program really allowed their brain to tangibly understand the fetus in 3 dimensions, but found it difficult to picture themselves ever using the program more than once or how it would improve their exam scores. Another suggested allowing for the user to view one arch and nerve at a time and for 3D rotation around the embryo. These controls are currently included in the program, so these comments showed that the way these controls were being communicated to the user could be improved. Most of the students thought the addition of labels would greatly improve the program and increase its educational value.

Refer to Appendix I: Assessment Survey Results (pg. 65) for the responses to the assessment survey questions.

VI. Management of the project

A. Tasks

1. Preproduction:

A. Research

1. Anatomy of branchial arches and the morphological changes that occur within them during development.
2. Cranial nerves V, VII, IX, and X
3. Muscles supplied by cranial nerves V, VII, IX, and X

B. Flowchart creation for each arch

C. Determine which models need to be constructed and creation workflow

2. Production:

A. Create 3D models for each stage

B. Animate morph targets for each model

3. Postproduction:

A. Composite animated sequences

B. Compile into interactive program

C. Present animations to students; administer survey to test effectiveness

D. Write paper

B. Resources

People:

Scott Dixon (committee chairperson)
 Dr. Maurice Pescitelli Jr. (committee member/content expert)
 John Daugherty (committee member)

Unity Scripting Help:
 Dave Mobley
 Luc Renambot

Scientific Resources:

Cross sections of embryos (Carnegie collection : Bill Discher)

Software:

Materialise Mimics
 IHMC CmapTools
 Autodesk 3dsMax
 Autodesk Mudbox
 Pixologic ZBrush
 Unity 3D

C. Timeline

	2011					2012			
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Write Proposal									
Create Assessment Survey									
Submit BHIS Project Committee Recommendation Form									
Submit Proposal for Approval									
IRB Exemption Application									
Pre-Production									
Organize DREM data									
Mimics: Data Extraction									
Production									
Modeling									
Animation: Individual Models and Synchronization with all muscles									

	2011					2012			
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Post-Production									
Unity testing									
UI Design									
Scripting									
Product ready to test									
Administer animations/interactive program and assessment survey to medical students									
Evaluate/Analyze results									
Write Paper									
Final Presentation									

VII. Summary and Discussion

1. Brief Review of Major Points

"Developmental anatomy is a powerful adjunct to an in-depth understanding of gross anatomical pattern" (Carlson, 2002). In his article, *Embryology in the medical curriculum*, Carlson explains that anatomy of the head and neck often appears as a mass of seemingly incoherent structures and names to students and is therefore an area that many students struggle to make sense of in adult anatomy. However, once the student is exposed to the developmental organization of these structures and crucial patterns of development that originate from these precursors, the student is then able to fully understand adult anatomy (Carlson, 2002).

2D illustrations are limited when explaining complex visual and morphological changes in human development. Current animations regarding the pharyngeal arches and components within them do not visually show the whole story or track the nerves associated with each arch as the muscles they supply migrate. Therefore, there is a strong need for this type of visual, which will be a tremendous tool for students as they study embryology.

This project also is significant to the field of medical illustration because it investigates how best to visually translate a complex mechanism in a clear and understandable manner. Medical illustrators are constantly concerned with the idea of storytelling through images. It is important to include all pertinent information, while maintaining extreme accuracy and at the same time making the "story" appealing and clear to the targeted audience.

This project also provides insight into using the MegaFiers plug-in and Unity 3D to create clean morphing animations. Using these tools, increased user interactivity is achieved, providing the user with tools to better visualize the animations in 3-dimensions.

2. Possible Validity Issues

Data from the assessment survey was used to evaluate the student's use of the animations as a study tool. In addition to this data, content experts in the field provided validation to determine the research fulfilled the established goals and the content was shown correctly.

3. Possible ethical issues

The participating students remained anonymous and had the ability to opt out of the study at anytime. An IRB exemption was obtained in order to proceed with the testing and avoid possible ethical issues.

4. Results/outcomes

Overall appreciation of the animations was shown through the results of the assessment survey. All of the participants said they would either recommend or use the animation in the future. The assessment survey provided extremely useful feedback in how to increase the educational value of the interactive program and improve its use. Most of the students felt the addition of labels and improved control over the rotation of the embryo was needed. Refer to Methods of Analysis/Interpretation of Data (pg. 30) for discussion of the results and Appendix I: Assessment Survey Results (pg. 65) to view the students' responses.

Continued work is planned to improve the quality and value of the interactive program. The addition of updating labels to animate with the dividing muscles and nerves will be useful in educating students about the individual muscles and nerve branches associated with each arch. Improved textures for each of the objects will also help improve the aesthetic component of the interactive program. In addition attention will also be paid to the rotation controls and how best to improve them.

5. Implications

This research showed that animations that visually depict concepts that students have a difficult time visualizing have the potential to improve overall understanding. After the above mentioned improvements are made to this research, the educational value of the interactive program will greatly improve and help students better identify the individual structures developing from each arch. This program could then be made available to students to study with and professors to use as a teaching tool in their classrooms.

VIII. Appendices

Appendix A: DREM Database

Stage 10: [6330] 5 μm slices

greatest length after fixation: 2.83 mm

211 sections (DREM) / 425 sections total

Mimics Import info:

pixel size(x and y) : 1.6 μm

slice distance(z) : 10.07 μm

Stage 11: [6344] 6 μm slices

greatest length after fixation: 2.5 mm

407 sections (DREM)/407 sections total

"missing" 4 sections: S068, S081, S213, S231- copied and renamed previous section

Mimics Import info:

pixel size (x and y) : 1.86 μm

slice distance(z) : 6 μm

Stage 12: [8943] 8 μm slices

greatest length after fixation: 3.9 mm

439 sections (DREM)/ 439 sections total

"problem sections": S30, S129- copied and renamed previous section

Mimics Import info:

pixel size (x and y) : 3.54 μm

slice distance(z) : 8 μm

Stage 13: [836] 15 μm slices

greatest length after fixation: 4.0 mm

247 sections (DREM)/247 sections total

Mimics Import info:

pixel size (x and y) : 5.88 μm

slice distance(z) : 15 μm

Stage 14: [6502] 10 μm slices

greatest length after fixation: 6.7 mm

661 sections (DREM)/ 1109 sections total

Mimics Import info:

pixel size (x and y) : 7.58 μm

slice distance(z) : 10 μm

Stage 15: [721] 15 µm slices
greatest length after fixation: 9.0 mm
138 sections (DREM)/ 558 sections total

Mimics Import info:
pixel size (x and y) : 12 µm
slice distance(z) : 60.65 µm

Stage 16: [6517] 8 µm slices
greatest length after fixation: 10.5 mm
311 sections (DREM)/ 1103 sections total

Mimics Import info:
pixel size (x and y) : 18 µm
slice distance(z) : 28.37 µm

Stage 17: [6520] 10 µm slices
greatest length after fixation: 14.2 mm
187 sections (DREM)/ 1073 sections total

Mimics Import info:
pixel size (x and y) : 16 µm
slice distance(z) : 57.38 µm

Stage 18: [4430] 15 µm slices
greatest length after fixation: 14.0 mm
147 sections (DREM)/ 837 sections total

Mimics Import info:
pixel size (x and y) : 17.65 µm
slice distance(z) : 85.41 µm

Stage 19: [9325] most are 15 µm slices, but in heart region: 63 @ 8 µm and 42@ 10 µm
greatest length after fixation: 17 mm
312 sections (DREM)/980 sections total

Mimics Import info:
pixel size (x and y) : 23 µm
slice distance(z) : 109.7 µm

Stage 20: [426] 40 µm slices
greatest length after fixation: 20 mm
199 sections (DREM)/ 397 sections total

Mimics Import info:

pixel size (x and y) : 19 μm
slice distance(z) : 79.8 μm

Stage 21: [4090] 40 μm slices
greatest length after fixation: 22.2 mm
195 sections (DREM)/ 393 sections total

Mimics Import info:
pixel size (x and y) : 20 μm
slice distance(z) : 80.62 μm

Stage 22: [H983] note: (not from Carnegie collection), from Boyd collection @ Univ. of
Cambridge in Cambridge, England)
10 μm slices
greatest length after fixation: 28 mm
203 sections (DREM)/ 2151 sections total

Mimics Import info:
pixel size (x and y) : 35.29 μm
slice distance(z) : 105.96

Stage 23: [9226] 12 μm slices
greatest length after fixation: 31mm
209 sections (DREM)/2090 sections total

Mimics Import info:
pixel size (x and y) : 30 μm
slice distance(z) : 120 μm

Appendix B: Authoring Tools for 3D Interactivity

		Unity 3D	Adobe Flash	Adobe Acrobat 3D pdf	Html 5
Additional information		"ultimate tool for video game development, architectural visualizations, and interactive media installation" (Goldstone, 2010).	"multimedia platform used to add animation, video, and interactivity to web pages" (Adobe Flash, 2011).	"permits the use of interactive 3D content in the widely available and familiar PDF format" (Witmer & Ridgely, -).	"language for structuring and presenting content for the World Wide Web, a core technology of the Internet" (HTML5, 2011).
		It is also a tool used to create real-time 3D animations	85% of the most-visited web sites use Flash, 75% of web video is viewed using the Flash Player, 98% of enterprises rely on the Flash Player, and 70% of web games are made in Flash	to view: Acrobat Reader 8.1+ (may require user to update in order to view 3D pdf) to create: requires full version of Acrobat 3D	need Javascript or CSS 3 to provide animation and interactivity within web pages
Platforms:	Microsoft Windows	yes (graphics engine: Direct3D, OpenGL)	yes	yes	does not run on Windows XP
	Mac OS X	yes (graphics engine: OpenGL)	yes	yes	
	Web:		"is the world's most pervasive software reaching 99% of Internet-enabled desktops in mature markets"		
	Internet Explorer	yes (Unity Web Player plugin)	yes		yes (but missing elements)
	Firefox	yes (Unity Web Player plugin)	yes		yes
	Safari	yes (Unity Web Player plugin)	yes		yes
	Netscape	yes (Unity Web Player plugin)	yes		
	Opera	yes (Unity Web Player plugin)	yes		yes
	Google Chrome	yes (Unity Web Player plugin)			yes (most compatible)
	Camino	yes (Unity Web Player plugin)			
	iPhone/iPad application	yes (graphics engine: OpenGL ES)	not supported		yes
	Google Android	yes	yes	no	
	Blackberry Tablet OS		yes		
	HP webOS		yes		
	Nintendo Wii	yes	yes (Flash 7 via Opera browser)		
	Microsoft Xbox 360	yes			
	Sony PlayStation 3	yes	yes (Flash 9)		
Importable Assets:		assets automatically imported and re-imported if asset updated	embed animations into Flash file, code interactivity with Action Script 3.0	need plugin: tetra 4D-possible limitations with textures and animation. Right Hemisphere's 3DS Max export plugin	
	3ds Max	yes		yes	
	Maya	yes			
	Blender	yes			
	Modo	yes			
	Zbrush	yes			
	Cinema 4D	yes			
	Cheetah 3D	yes			
	Photoshop	yes			
	Allegorithmic Substance	yes			
File Size			small	small	

(Goldstone, 2010; Adobe Systems Inc., 2011; Unity (game engine), 2011; Nyman, 2009, HyperWrite, 2007; Kahney, 2010; Meijer, 2011; Adobe Forums, 2011; Echterhoff, 2011; Radwan & Dana, 2011; W3Schools, 2011; The Editor, 2011, Adobe Flash, 2011)

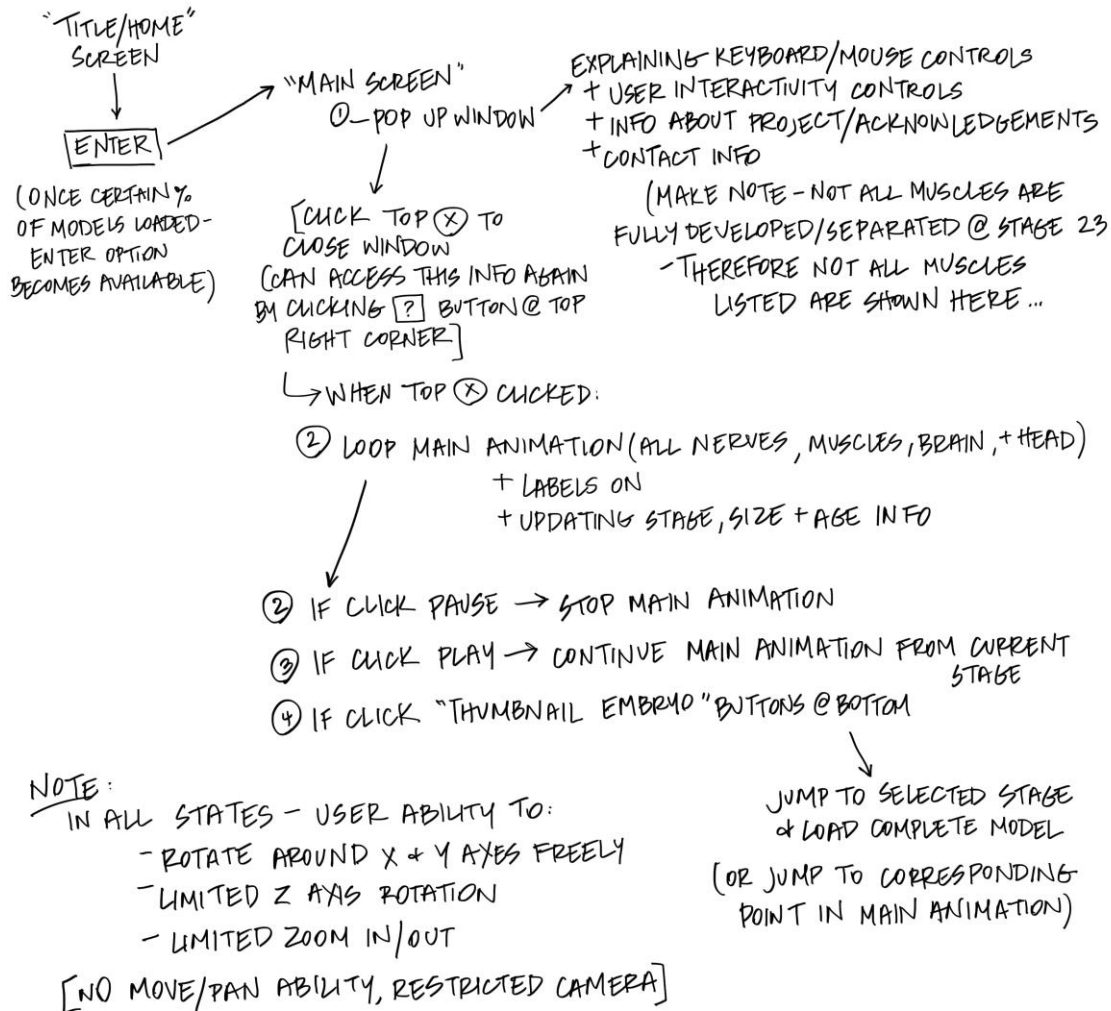
Appendix C: Comparison of Online Survey Services

	Survey Monkey (Basic)	Survey Monkey (Select)	Zoomerang (Basic)	Zoomerang (Pro)
Cost	Free	\$24 per month (or save- Billed \$204 annually =\$17 per month)	Free	\$19 per month
Design Features				
# of Questions per survey	10	Unlimited	12	Unlimited
# of Responses per survey	100	Unlimited	100	Unlimited
Easy to use web based survey tool	yes	yes		
# of Survey templates	31	51	6	100+
# of Types of questions	15	15	10	10
Printable PDF version	no	yes		
Randomize and sort answer choices	yes	yes	yes	yes
Validate/require survey responses	yes	yes		
Easy drag/drop design			yes	yes
Design survey from scratch or from template			yes	yes
Collection Features				
Send survey out via weblink, email or Twitter	yes	yes	send through Zoomerang	send through Zoomerang
Embed survey into page or on website	yes	yes	yes	yes
Enhanced security	no	yes	no	no
Analysis features				
Real-time results	yes	yes	yes	yes
Multiple custom reports	no	yes		

View individual responses			yes	yes
Filter and cross tabulate responses by custom criteria	no	yes	no	yes
Download responses	no	yes		
Create & download custom charts	no	yes	no	yes
Share responses	no	yes		
Text Analysis	no	no (but can upgrade to Gold - \$25 per month/\$300 annually)		
Data Export	no	yes	no	yes

Appendix D: User Interactivity Design

⇒ USER INTERACTIVITY DESIGN ⇐



SIDE CONTROLS:

ON/OFF TOGGLE
OPACITY CONTROL } FOR EACH OF THE FOLLOWING:

- SKIN (HEAD MODEL)
 - BRAIN
 - ARCH 1
 - ARCH 2
 - ARCH 3
 - ARCH 4
 - ARCH 6
- ON/OFF TOGGLE FOR WHOLE ARCH (MUSCLES + NERVE)
- SEPARATE OPACITY CONTROL FOR EACH ARCH'S MUSCLES & NERVE

- ACCORDION FLYOUT MENU FOR EACH ARCH

- REVEAL OPACITY CONTROLS FOR NERVE + MUSCLES

- LIST NERVE + MUSCLE NAMES

→ (ALL MUSCLES FROM THAT ARCH - EVEN IF NOT SHOWN)

Appendix E: Script to Control Morphing Animations (Main Page)

```
using UnityEngine;
using System.Collections;

public class Buttons : MonoBehaviour {

    public MegaMorph arch1;
    public MegaMorph arch2;
    public MegaMorph arch3;
    public MegaMorph arch4;
    public MegaMorph arch6;
    public MegaMorph head;
    public MegaMorph brain;
    public MegaMorph trigeminal;
    public MegaMorph facial;
    public MegaMorph vagus;
    public MegaMorph glosso;
    public Animation baseAll;
    public AnimationState take001;

    const int LEFT_MARGIN = 10;
    const int RIGHT_MARGIN = 10;
    const int TOP_MARGIN = 10;
    const int BOTTOM_MARGIN = 10;
    const int TEXT_HEIGHT = 22;
    const int SPACER = 20;

    const int BUTTON_WIDTH = 75;
    const int SLIDER_WIDTH = 100;
    const int PLAY_BUTTON_WIDTH = 30;

    const int SLIDER_BUTTON_WIDTH=75;

    const int PADDING = 5;
    const int COL = 20;
    const int ROW = 20;

    const float ANIM_TIME = 62.5f;

    private float skinSlider = 40.0f;
    private float brainSlider = 100.0f;
    private float developmentSlider = 0.0f;
    private float muscle1Slider = 50.0f;
```

```
private float nerve1Slider = 50.0f;  
private float muscle2Slider = 50.0f;  
private float nerve2Slider = 50.0f;  
private float muscle3Slider = 50.0f;  
private float nerve3Slider = 50.0f;  
private float muscle4Slider = 50.0f;  
private float nerve4Slider = 50.0f;  
private float muscle6Slider = 50.0f;
```

```
private bool skinBool = true;  
private bool brainBool = true;
```

```
private bool arch1Bool = true;  
private bool arch2Bool = true;  
private bool arch3Bool = true;  
private bool arch4Bool = true;  
private bool arch6Bool = true;  
private bool muscle1Bool = true;  
private bool muscle2Bool = true;  
private bool muscle3Bool = true;  
private bool muscle4Bool = true;  
private bool muscle6Bool = true;  
private bool nerve1Bool = true;  
private bool nerve2Bool = true;  
private bool nerve3Bool = true;  
private bool nerve4Bool = true;
```

```
private bool labelsBool = true;
```

```
public Texture2D button10Image;  
public Texture2D button11Image;  
public Texture2D button12Image;  
public Texture2D button13Image;  
public Texture2D button14Image;  
public Texture2D button15Image;  
public Texture2D button16Image;  
public Texture2D button17Image;  
public Texture2D button18Image;  
public Texture2D button19Image;  
public Texture2D button20Image;  
public Texture2D button21Image;  
public Texture2D button22Image;  
public Texture2D button23Image;
```

```
public Texture2D stepBackImage;  
public Texture2D playImage;
```

```

public Texture2D pauseImage;
public Texture2D stepForwardImage;

public Texture2D iImage;

bool play = false;

float percent = 0;
const float FINAL_PERCENT = 98f;

// Use this for initialization
void Start ()
{
    button10Image = (Texture2D)Resources.Load ("10 button", typeof(Texture2D));
    button11Image = (Texture2D)Resources.Load ("11 button", typeof(Texture2D));
    button12Image = (Texture2D)Resources.Load ("12 button", typeof(Texture2D));
    button13Image = (Texture2D)Resources.Load ("13 button", typeof(Texture2D));
    button14Image = (Texture2D)Resources.Load ("14 button", typeof(Texture2D));
    button15Image = (Texture2D)Resources.Load ("15 button", typeof(Texture2D));
    button16Image = (Texture2D)Resources.Load ("16 button", typeof(Texture2D));
    button17Image = (Texture2D)Resources.Load ("17 button", typeof(Texture2D));
    button18Image = (Texture2D)Resources.Load ("18 button", typeof(Texture2D));
    button19Image = (Texture2D)Resources.Load ("19 button", typeof(Texture2D));
    button20Image = (Texture2D)Resources.Load ("20 button", typeof(Texture2D));
    button21Image = (Texture2D)Resources.Load ("21 button", typeof(Texture2D));
    button22Image = (Texture2D)Resources.Load ("22 button", typeof(Texture2D));
    button23Image = (Texture2D)Resources.Load ("23 button", typeof(Texture2D));

    stepBackImage = (Texture2D)Resources.Load ("Step Back", typeof(Texture2D));
    playImage = (Texture2D)Resources.Load ("play", typeof(Texture2D));
    pauseImage = (Texture2D)Resources.Load ("pause", typeof(Texture2D));
    stepForwardImage = (Texture2D)Resources.Load ("Step Forward",
typeof(Texture2D));

    iImage = (Texture2D)Resources.Load ("i", typeof(Texture2D));

    arch1 = GameObject.Find ("arch 1 leftmorph").GetComponent<MegaMorph>();
    arch2 = GameObject.Find ("arch 2 leftmorph").GetComponent<MegaMorph>();
    arch3 = GameObject.Find ("arch 3 leftmorph").GetComponent<MegaMorph>();
    arch4 = GameObject.Find ("arch 4 leftmorph").GetComponent<MegaMorph>();
    arch6 = GameObject.Find ("arch 6 leftmorph").GetComponent<MegaMorph>();
    brain = GameObject.Find ("brain morph 2").GetComponent<MegaMorph>();
    head = GameObject.Find ("head").GetComponent<MegaMorph>();

```

```

        trigeminal = GameObject.Find ("trigeminal left
morph").GetComponent<MegaMorph>();
        vagus = GameObject.Find ("vagus morph").GetComponent<MegaMorph>();

        facial = GameObject.Find ("facial left NEW
morph").GetComponent<MegaMorph>();
        glosso = GameObject.Find ("glossopharyngeal left
morph").GetComponent<MegaMorph>();

        baseAll = GameObject.Find ("baseAll").GetComponent<Animation>();
        take001 = animation["Take 001"];

        arch1.looptime = ANIM_TIME;
        arch2.looptime = ANIM_TIME;
        arch3.looptime = ANIM_TIME;
        arch4.looptime = ANIM_TIME;
        arch6.looptime = ANIM_TIME;
        head.looptime = ANIM_TIME;
        brain.looptime = ANIM_TIME;
        trigeminal.looptime = ANIM_TIME;
        vagus.looptime = ANIM_TIME;
        facial.looptime = ANIM_TIME;
        glosso.looptime = ANIM_TIME;

        arch1.animtime = 0f;
        arch2.animtime = 0f;
        arch3.animtime = 0f;
        arch4.animtime = 0f;
        arch6.animtime = 0f;
        brain.animtime = 0f;
        head.animtime = 0f;
        trigeminal.animtime = 0f;
        vagus.animtime = 0f;
        facial.animtime = 0f;
        glosso.animtime = 0f;

        play = true;
    }

    // Update is called once per frame
    void Update ()
    {
        if(play)
            animate (true);
        else
            animate (false);
    }

```

```

        developmentSlider = arch1.animtime / ANIM_TIME * 100f;
    }

    void animate(bool b)
    {
        arch1.animate = b;
        arch2.animate = b;
        arch3.animate = b;
        arch4.animate = b;
        arch6.animate = b;
        brain.animate = b;
        trigeminal.animate = b;
        head.animate = b;
        vagus.animate = b;
        facial.animate = b;
        glosso.animate = b;

        if(b)
        {
            baseAll.Play ();
            float t = ANIM_TIME * (float)percent/100 + Time.deltaTime;
            percent = t * 100/ANIM_TIME;

            if(percent >= FINAL_PERCENT)
            {
                percent = 0;
                play = false;
            }
            else
            {
                take001.time = t;
                arch1.animtime = t;
                arch2.animtime = t;
                arch3.animtime = t;
                arch4.animtime = t;
                arch6.animtime = t;
                brain.animtime = t;
                head.animtime = t;
                trigeminal.animtime = t;
                vagus.animtime = t;
                facial.animtime = t;
                glosso.animtime = t;
            }
        }
    }

```

```

        else
        {
            baseAll.Stop();
        }
    }

void setPercent(double apercent)
{
    if(apercent < 0)
        apercent = 0;

    if(apercent >= FINAL_PERCENT)
        apercent = FINAL_PERCENT;

    percent = (float)apercent;

    float t = ANIM_TIME * (float)percent/100;
    take001.time = t;
    arch1.animtime = t;
    arch2.animtime = t;
    arch3.animtime = t;
    arch4.animtime = t;
    arch6.animtime = t;
    brain.animtime = t;
    head.animtime = t;
    trigeminal.animtime = t;
    vagus.animtime = t;
    facial.animtime = t;
    glosso.animtime = t;
}

void OnGUI()
{
    int width = Screen.width;
    int height = Screen.height;

    // skin radio and slider //
    skinBool = GUI.Toggle (new
Rect(LEFT_MARGIN,TOP_MARGIN,BUTTON_WIDTH,TEXT_HEIGHT), skinBool,
"Skin");
    skinSlider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN +
BUTTON_WIDTH + PADDING,TOP_MARGIN +
PADDING,SLIDER_WIDTH,TEXT_HEIGHT),skinSlider,0.0f,100.0f);

```

```

        if(!skinBool)
        {
            Color c = new Color(head.gameObject.renderer.material.color.r,
head.gameObject.renderer.material.color.g, head.gameObject.renderer.material.color.b, 0);
            head.gameObject.renderer.material.color = c;
        }
        else
        {
            Color c = new Color(head.gameObject.renderer.material.color.r,
head.gameObject.renderer.material.color.g, head.gameObject.renderer.material.color.b,
skinSlider/100);
            head.gameObject.renderer.material.color = c;
        }

        // brain radio and slider //
        brainBool = GUI.Toggle (new Rect(LEFT_MARGIN,TOP_MARGIN +
TEXT_HEIGHT,75,TEXT_HEIGHT), brainBool, "Brain");
        brainSlider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN
+BUTTON_WIDTH + PADDING, TOP_MARGIN + TEXT_HEIGHT +
PADDING,SLIDER_WIDTH,TEXT_HEIGHT),brainSlider,0.0f,100.0f);

        if(!brainBool)
        {
            Color c = new Color(brain.gameObject.renderer.material.color.r,
brain.gameObject.renderer.material.color.g, brain.gameObject.renderer.material.color.b, 0);
            brain.gameObject.renderer.material.color = c;
        }
        else
        {
            Color c = new Color(brain.gameObject.renderer.material.color.r,
brain.gameObject.renderer.material.color.g, brain.gameObject.renderer.material.color.b,
brainSlider/100);
            brain.gameObject.renderer.material.color = c;
        }

        // arches //
        arch1Bool = GUI.Toggle (new Rect(LEFT_MARGIN,TOP_MARGIN +
TEXT_HEIGHT*3, BUTTON_WIDTH,TEXT_HEIGHT), arch1Bool, "Arch 1");
        muscle1Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*4), BUTTON_WIDTH,TEXT_HEIGHT),
muscle1Bool, "Muscle");
        muscle1Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*4),
BUTTON_WIDTH,TEXT_HEIGHT),muscle1Slider,0.0f,100.0f);

```



```

        nerve1Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*5), BUTTON_WIDTH,TEXT_HEIGHT),
nerve1Bool, "Nerve");
        nerve1Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*5),
BUTTON_WIDTH,TEXT_HEIGHT),nerve1Slider,0.0f,100.0f);
        GUI.Label (new Rect(LEFT_MARGIN + SPACER,TOP_MARGIN +
(int)(TEXT_HEIGHT*6), BUTTON_WIDTH+BUTTON_WIDTH,TEXT_HEIGHT),
"(Trigeminal Nerve)");

doArch(arch1, trigeminal, arch1Bool, muscle1Bool, nerve1Bool, muscle1Slider,
nerve1Slider);

        arch2Bool = GUI.Toggle (new Rect(LEFT_MARGIN ,TOP_MARGIN +
TEXT_HEIGHT*8, BUTTON_WIDTH,TEXT_HEIGHT), arch2Bool, "Arch 2");
        muscle2Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*9), BUTTON_WIDTH,TEXT_HEIGHT),
muscle2Bool, "Muscle");
        muscle2Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*9),
BUTTON_WIDTH,TEXT_HEIGHT),muscle2Slider,0.0f,100.0f);
        nerve2Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*10), BUTTON_WIDTH,TEXT_HEIGHT),
nerve2Bool, "Nerve");
        nerve2Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*10),
BUTTON_WIDTH,TEXT_HEIGHT),nerve2Slider,0.0f,100.0f);
        GUI.Label (new Rect(LEFT_MARGIN + SPACER,TOP_MARGIN +
(int)(TEXT_HEIGHT*11), BUTTON_WIDTH+BUTTON_WIDTH,TEXT_HEIGHT), "(Facial
Nerve)");
doArch(arch2, facial, arch2Bool, muscle2Bool, nerve2Bool, muscle2Slider,
nerve2Slider);

        arch3Bool = GUI.Toggle (new Rect(LEFT_MARGIN ,TOP_MARGIN +
TEXT_HEIGHT*13, BUTTON_WIDTH,TEXT_HEIGHT), arch3Bool, "Arch 3");
        muscle3Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*14), BUTTON_WIDTH,TEXT_HEIGHT),
muscle3Bool, "Muscle");
        muscle3Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*14),
BUTTON_WIDTH,TEXT_HEIGHT),muscle3Slider,0.0f,100.0f);
        nerve3Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*15), BUTTON_WIDTH,TEXT_HEIGHT),
nerve3Bool, "Nerve");

```

```

        nerve3Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*15),
BUTTON_WIDTH,TEXT_HEIGHT),nerve3Slider,0.0f,100.0f);
        GUI.Label (new Rect(LEFT_MARGIN + SPACER,TOP_MARGIN +
(int)(TEXT_HEIGHT*16), BUTTON_WIDTH+BUTTON_WIDTH,TEXT_HEIGHT),
"(Glossopharyngeal Nerve)");
        doArch(arch3, glosso, arch3Bool, muscle3Bool, nerve3Bool, muscle3Slider,
nerve3Slider);

        arch4Bool = GUI.Toggle (new Rect(LEFT_MARGIN ,TOP_MARGIN +
TEXT_HEIGHT*18, BUTTON_WIDTH,TEXT_HEIGHT), arch4Bool, "Arch 4");
        muscle4Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*19), BUTTON_WIDTH,TEXT_HEIGHT),
muscle4Bool, "Muscle");
        muscle4Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*19),
BUTTON_WIDTH,TEXT_HEIGHT),muscle4Slider,0.0f,100.0f);
        nerve4Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*20), BUTTON_WIDTH,TEXT_HEIGHT),
nerve4Bool, "Nerve");
        nerve4Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*20),
BUTTON_WIDTH,TEXT_HEIGHT),nerve4Slider,0.0f,100.0f);
        GUI.Label (new Rect(LEFT_MARGIN + SPACER,TOP_MARGIN +
(int)(TEXT_HEIGHT*21), BUTTON_WIDTH+BUTTON_WIDTH,TEXT_HEIGHT), "(Vagus
Nerve)");
        doArch(arch4, vagus, arch4Bool, muscle4Bool, nerve4Bool, muscle4Slider,
nerve4Slider);

        arch6Bool = GUI.Toggle (new Rect(LEFT_MARGIN ,TOP_MARGIN +
TEXT_HEIGHT*23, BUTTON_WIDTH,TEXT_HEIGHT), arch6Bool, "Arch 6");
        muscle6Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*24), BUTTON_WIDTH,TEXT_HEIGHT),
muscle6Bool, "Muscle");
        muscle6Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*24),
BUTTON_WIDTH,TEXT_HEIGHT),muscle6Slider,0.0f,100.0f);
        nerve4Bool = GUI.Toggle (new Rect(LEFT_MARGIN +
SPACER,TOP_MARGIN + (int)(TEXT_HEIGHT*25), BUTTON_WIDTH,TEXT_HEIGHT),
nerve4Bool, "Nerve");
        nerve4Slider = GUI.HorizontalSlider(new Rect(LEFT_MARGIN + SPACER +
BUTTON_WIDTH,TOP_MARGIN + (int)(TEXT_HEIGHT*25),
BUTTON_WIDTH,TEXT_HEIGHT),nerve4Slider,0.0f,100.0f);
        GUI.Label (new Rect(LEFT_MARGIN + SPACER,TOP_MARGIN +
(int)(TEXT_HEIGHT*21), BUTTON_WIDTH+BUTTON_WIDTH,TEXT_HEIGHT), "(Vagus
Nerve)");

```

```

doArch(arch6, vagus, arch6Bool, muscle6Bool, nerve4Bool, muscle6Slider,
nerve4Slider);

// play buttons //
if(GUI.Button (new Rect(LEFT_MARGIN,height-TEXT_HEIGHT * 3 -
SLIDER_BUTTON_WIDTH,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), stepBackImage,
"label"))

    setPercent ((arch1.animtime - ANIM_TIME/14)*100/ANIM_TIME);

if(GUI.Button (new Rect(LEFT_MARGIN + PLAY_BUTTON_WIDTH,height-
TEXT_HEIGHT * 3 -
SLIDER_BUTTON_WIDTH,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), playImage,
"label"))
{
    if(percent >= FINAL_PERCENT)
        percent = 0;
    play = true;
}

//        baseAll.Play ();
if(GUI.Button (new Rect(LEFT_MARGIN +
PLAY_BUTTON_WIDTH*2,height-TEXT_HEIGHT * 3 -
SLIDER_BUTTON_WIDTH,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), pauseImage,
"label"))

    play = false;
//        baseAll.Stop();
if(GUI.Button (new Rect(LEFT_MARGIN +
PLAY_BUTTON_WIDTH*3,height-TEXT_HEIGHT * 3 -
SLIDER_BUTTON_WIDTH,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), stepForwardImage,
"label"))

    setPercent ((arch1.animtime + ANIM_TIME/14)*100/ANIM_TIME);

// calculate offsets for developmental slider //
float interval = (width - 2*SLIDER_BUTTON_WIDTH)/14;
int offset = (int)(interval/2 - SLIDER_BUTTON_WIDTH/2);
int numoffset = (int)(interval/2 - PLAY_BUTTON_WIDTH/2);

// jumpTo buttons //
if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 0 +
offset,height-TEXT_HEIGHT * 2 -
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button10Image, "label"))
    setPercent(100/14 * 0);
if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 1 +
offset,height-TEXT_HEIGHT * 2 -

```

```

SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button11Image, "label"))
    setPercent(100/14 * 1);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 2 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button12Image, "label"))
    setPercent(100/14 * 2);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 3 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button13Image, "label"))
    setPercent(100/14 * 3);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 4 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button14Image, "label"))
    setPercent(100/14 * 4);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 5 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button15Image, "label"))
    setPercent(100/14 * 5);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 6 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button16Image, "label"))
    setPercent(100/14 * 6);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 7 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button17Image, "label"))
    setPercent(100/14 * 7);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 8 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button18Image, "label"))
    setPercent(100/14 * 8);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 9 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button19Image, "label"))
    setPercent(100/14 * 9);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 10 +
offset,height-TEXT_HEIGHT * 2-

```

```

SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button20Image, "label"))
    setPercent(100/14 * 10);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 11 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button21Image, "label"))
        setPercent(100/14 * 11);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 12 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button22Image, "label"))
        setPercent(100/14 * 12);
    if(GUI.Button (new Rect(SLIDER_BUTTON_WIDTH + interval* 13 +
offset,height-TEXT_HEIGHT * 2-
SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH,SLIDER_BUTTON_WIDTH),
button23Image, "label"))
        setPercent(100/14 * 13);

    float oldSlider = developmentSlider;
    // development slider //
    developmentSlider = GUI.HorizontalSlider(new
Rect(SLIDER_BUTTON_WIDTH,height-TEXT_HEIGHT * 2,width-
SLIDER_BUTTON_WIDTH*2,TEXT_HEIGHT), developmentSlider, 0.0f, 100.0f);
    if(oldSlider != developmentSlider)
        setPercent (developmentSlider);

    // development slider labels //
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 0 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "10");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 1 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "11");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 2 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "12");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 3 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "13");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 4 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "14");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 5 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "15");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 6 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "16");
    GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 7 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "17");

```

```

        GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 8 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "18");
        GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 9 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "19");
        GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 10 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "20");
        GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 11 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "21");
        GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 12 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "22");
        GUI.Label (new Rect(SLIDER_BUTTON_WIDTH + interval* 13 +
numoffset,height-TEXT_HEIGHT,PLAY_BUTTON_WIDTH,TEXT_HEIGHT), "23");

        // information labels //
        labelsBool = GUI.Toggle (new Rect(width - RIGHT_MARGIN -
BUTTON_WIDTH - PLAY_BUTTON_WIDTH
,TOP_MARGIN,BUTTON_WIDTH,TEXT_HEIGHT),labelsBool, "Labels");
        if(labelsBool)
        {
            string stage = "";
            string mm = "";
            string days = "";

            switch((int)(developmentSlider/ (100/14)))
            {
            case 0:
                stage = "Stage 10";
                mm = "1.5-3.6mm";
                days = "28-30 days";
                break;
            case 1:
                stage = "Stage 11";
                mm = "1.4-5mm";
                days = "28-30 days";
                break;
            case 2:
                stage = "Stage 12";
                mm = "3-5.4mm";
                days = "29-31 days";
                break;
            case 3:
                stage = "Stage 13";
                mm = "3.9-6mm";
                days = "30-33 days";
                break;
            case 4:

```

```
        stage = "Stage 14";
        mm = "5-7mm";
        days = "33 days";
        break;
case 5:
    stage = "Stage 15";
    mm = "7-9mm";
    days = "41 days";
    break;
case 6:
    stage = "Stage 16";
    mm = "8-11mm";
    days = "39 days";
    break;
case 7:
    stage = "Stage 17";
    mm = "11-14mm";
    days = "41 days";
    break;
case 8:
    stage = "Stage 18";
    mm = "13-17mm";
    days = "44 days";
    break;
case 9:
    stage = "Stage 19";
    mm = "16-18mm";
    days = "45-47 days";
    break;
case 10:
    stage = "Stage 20";
    mm = "18-22mm";
    days = "49 days";
    break;
case 11:
    stage = "Stage 21";
    mm = "20-26.4mm";
    days = "49-52 days";
    break;
case 12:
    stage = "Stage 22";
    mm = "23.4-27.5mm";
    days = "52-55 days";
    break;
case 13:
    stage = "Stage 23";
```

```

        mm = "23-32.2mm";
        days = "56 days";
        break;
    default:
        stage = "";
        mm = "";
        days = "";
        break;
    }
    // GUI.Button (new Rect(width - RIGHT_MARGIN -
PLAY_BUTTON_WIDTH, TOP_MARGIN,
PLAY_BUTTON_WIDTH,PLAY_BUTTON_WIDTH), iImage);
        GUI.Label (new Rect(width - RIGHT_MARGIN - BUTTON_WIDTH -
SPACER ,TOP_MARGIN + TEXT_HEIGHT *2,BUTTON_WIDTH,TEXT_HEIGHT), stage);
        GUI.Label (new Rect(width - RIGHT_MARGIN - BUTTON_WIDTH -
SPACER ,TOP_MARGIN + TEXT_HEIGHT *3,BUTTON_WIDTH,TEXT_HEIGHT), mm);
        GUI.Label (new Rect(width - RIGHT_MARGIN - BUTTON_WIDTH -
SPACER ,TOP_MARGIN + TEXT_HEIGHT *4,BUTTON_WIDTH,TEXT_HEIGHT), days);
    }

}

    public void doArch(MegaMorph muscle, MegaMorph nerve, bool archBool, bool
muscleBool, bool nerveBool,float muscleSlider,float nerveSlider)
    {
        if(!archBool)
        {
            Color c = new Color(muscle.gameObject.renderer.material.color.r,
muscle.gameObject.renderer.material.color.g, muscle.gameObject.renderer.material.color.b, 0);
            muscle.gameObject.renderer.material.color = c;
            Color c1 = new Color(muscle.gameObject.renderer.material.color.r,
nerve.gameObject.renderer.material.color.g, nerve.gameObject.renderer.material.color.b, 0);
            nerve.gameObject.renderer.material.color = c1;
        }
        else
        {
            if(!muscleBool)
            {
                Color c = new Color(muscle.gameObject.renderer.material.color.r,
muscle.gameObject.renderer.material.color.g, muscle.gameObject.renderer.material.color.b, 0);
                muscle.gameObject.renderer.material.color = c;
            }
            else
            {

```



```

        Color c = new Color(muscleSlider/100,
muscle.gameObject.renderer.material.color.g, muscle.gameObject.renderer.material.color.b,
100);
        muscle.gameObject.renderer.material.color = c;
    }
    if(!nerveBool)
    {
        Color c1 = new Color(nerve.gameObject.renderer.material.color.r,
nerve.gameObject.renderer.material.color.g, nerve.gameObject.renderer.material.color.b, 0);
        nerve.gameObject.renderer.material.color = c1;
    }
    else
    {
        Color c1 = new Color(nerveSlider/100, nerveSlider/100,
nerve.gameObject.renderer.material.color.b, 100);
        nerve.gameObject.renderer.material.color = c1;
    }
}
}
}
}
}

```

Appendix F: Recruitment Letter

This letter was emailed to medical students enrolled in the University of Illinois at Chicago's ANAT 440: Gross Human Anatomy course during the spring semester of 2012.

During the week of testing, students received this letter in an email, explaining the research and what will be expected if they choose to participate. The informed consent form, links to the interactive program and the assessment survey were also attached to this recruitment letter and sent to all the students in the class directory.

Students may choose to not participate in this research study. No identifying information will be asked of the participants to ensure anonymous testing.

Dear Student,

You are invited to participate in a survey that will evaluate the effectiveness of a 3D interactive program in teaching embryology in ANAT 440: Gross Human Anatomy course.

As part of my research project as a graduate student in Biomedical Visualization at the University of Illinois at Chicago, I recently created animations that visually and dynamically depict branchial/pharyngeal arch nerve and muscle growth during human development.

The data collected from the survey will be used to determine the usefulness of these animations as a study tool. Your participation is important.

Attached to this email, please find the informed consent form. If you elect to participate in this research, please click on the link below to download and view the interactive. Please spend as much time with the interactive and included animations as needed. After viewing the animations, you will be asked to complete a short 10 question assessment survey that will be used to evaluate the animations as a study tool.

Download Instructions:

- 1) Click on appropriate link below for your operating system (Windows and Mac OS X versions available)
- 2) Download file folder
- 3) Unzip folder and Extract all contents
- 4) Double click VEPAM application to run program. Window will pop up- click Play!
- 5) Watch and interact with the morphing embryo - Click "information" button on top right to learn more about keyboard controls and project information.

6) Once you have explored the interactive program. Please complete the short assessment survey to rate the interactive. Click here to access the survey:

<http://www.surveymonkey.com/s/RPPYTWB>

Windows Version:

<https://lklein.egnyte.com/h-s/20120411/2b9cae31961f4398>

Mac OS X Version:

<https://lklein.egnyte.com/h-s/20120411/41c3f5713b664bc8>

Assessment Survey: <http://www.surveymonkey.com/s/RPPYTWB>

Please feel free to contact me with any questions.

Thank you in advance for your participation,

Leah Klein

laklein2@uic.edu

Appendix G: Informed Consent Form

University of Illinois at Chicago Research Information and Consent for Participation in Biomedical Research

Visualizing Pharyngeal Arch Nerve Growth and Muscle Innervation During Human Embryological Development

You are being asked to participate in a research study. Researchers are required to provide a consent form such as this one to tell you about the research, to explain that taking part is voluntary, to describe the risks and benefits of participation, and to help you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Principal Investigator: Leah Klein: laklein2@uic.edu, 832-971-4745
Department of Biomedical and Health Information Sciences
Biomedical Visualization Program
Faculty Sponsor: Scott Dixon, MS: sdixon3@uic.edu, 312- 996-6721

You will be utilizing an interactive 3D computer-based model designed to improve understanding of human embryology pharyngeal arch nerve growth and its relationship to the muscles they supply.

Why am I being asked?

You are being asked to be a participant in a research study about the effectiveness of animations used to improve understanding of human pharyngeal arch nerve growth and its relationship to the muscles it innervates.

You will be asked to answer an assessment survey. Survey results will be used to analyze how effective the animations are in visualizing the relationship between pharyngeal arch nerves and the muscles they innervate.

You have been asked to participate in the research because your field of study is related to medicine and knowledge of human anatomy. As a medical student, the understanding of adult anatomy is important. Being able to visualize the relationship between adult structures and human embryology may be critical in gaining greater understandings of structures and their relationships.

Your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future dealings with the University of Illinois at Chicago. **If you decide to participate, you are free to withdraw at any time without affecting that relationship.**

What is the purpose of this research?

This research is being done to better understand pharyngeal arch nerve growth and its relationship to the muscles it innervates.

Human embryology is a field that presents many challenges as numerous complex morphological changes occur quickly as the embryo develops. A solid understanding of this science allows the student to effectively and more easily understand complexities and relationships in adult human anatomy. This research proposes to create animations that will visually clarify and track branchial/pharyngeal nerve growth in order to illustrate the relationship between them and the muscles they innervate. By tracking these nerves as the pharyngeal arches develop, the student will be able to visually connect the pharyngeal arch and nerve development to the final end product that we see in adult human anatomy. This will help to clarify why certain nerves innervate certain areas and muscles that may seem illogical when studying adult anatomy.

What procedures are involved?

After agreeing to participate in this research, you will be asked to download and interact with the 3D interactive program, where you will be able to watch and navigate through animations depicting pharyngeal arch nerve and muscle growth. After watching the animations, you will be asked to complete an assessment survey to evaluate the animations as an effective study tool.

What are the potential risks and discomforts?

There are no potential risks or discomforts associated with this research.

Will I be told about new information that may affect my decision to participate?

During the course of the study, you will be informed of any new findings, such as changes in the risks or benefits resulting from participation in the research or new alternatives to participation, that might cause you to change your mind about continuing in the study. If new information is provided to you, your consent to continue participating in this study may be re-obtained.

Are there benefits to taking part in the research?

By participating in this research you will help evaluate the effectiveness of the animations in increasing understanding of the relationship between the pharyngeal arch nerves and muscles. This will benefit students studying anatomy and embryology.

What other options are there?

You have the option to not participate in this study.

What about privacy and confidentiality?

Participation in the survey is completely anonymous.

Will I be reimbursed for any of my expenses or paid for my participation in this research?

You will not be offered payment for being in this study.

Can I withdraw or be removed from the study?

If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without affecting your studies at UIC.

Who should I contact if I have questions?

Contact the researcher Leah Klein at 832-971-4745 or at laklein2@uic.edu if you have any questions about this study or your part in it, or any questions, concerns or complaints about the research.

Faculty Sponsor: Scott Dixon, 312- 996-6721

What are my rights as a research subject?

If you have questions about your rights as a research subject or concerns, complaints, or to offer input you may call the Office for the Protection of Research Subjects (OPRS) at 312-996-1711 or 1-866-789-6215 (toll-free) or e-mail OPRS at uicirb@uic.edu.

What if I am a UIC student?

You may choose not to participate or to stop your participation in this research at any time. This will not affect your class standing or grades at UIC. The investigator may also end your participation in the research. If this happens, your class standing or grades will not be affected. You will not be offered or receive any special consideration if you participate in this research.

Remember:

Your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship.

Consent:

I have read (or someone has read to me) the above information. I have been given an opportunity to ask questions and my questions have been answered to my satisfaction. I understand that by completing the pre test survey, I agree to participate in this research.

Appendix H: Assessment Survey

Please complete this survey to evaluate your satisfaction with visualizing and comprehending pharyngeal arch nerve and muscle growth during human development using the 3D animations.

1. Would you recommend or use this animation in the future?

- ☐ Yes
- ☐ No

2. How would you rate this animation's ease of use?

- ☐ Very easy to use
- ☐ Somewhat easy to use
- ☐ Somewhat difficult to use
- ☐ Very difficult to use

3. *Please explain:*

Type comments here

4. How useful were the animations in helping you understand the material?

- ☐ Extremely useful
- ☐ Very useful
- ☐ Moderately useful
- ☐ Slightly useful
- ☐ Not at all useful

5. *Please explain:*

Type comments here

6. Was the content well organized?

- ☐ Extremely organized
- ☐ Very organized
- ☐ Moderately organized
- ☐ Slightly organized
- ☐ Not at all organized

7. Qualify the pace of the animations:

- Much too quickly
- Somewhat too quickly
- About the right speed
- Somewhat too slowly
- Much too slowly

8. How well did the animations meet your learning needs as a student?

- Extremely well
- Very well
- Moderately well
- Slightly well
- Not at all well

9. What are the weaknesses of these animations?

<i>Type comments here</i>

10. What suggestions to you have to improve these animations?

<i>Type comments here</i>

Appendix I: Assessment Survey Results

Assessment Survey






1. Would you recommend or use this animation in the future?			
		Response Percent	Response Count
Yes	<div><div></div></div>	100.0%	5
No		0.0%	0
answered question			5
skipped question			0

2. How would you rate this animation's ease of use?			
		Response Percent	Response Count
Very easy to use	<div><div></div></div>	60.0%	3
Somewhat easy to use	<div><div></div></div>	20.0%	1
Somewhat difficult to use	<div><div></div></div>	20.0%	1
Very difficult to use		0.0%	0
answered question			5
skipped question			0

3. Please explain:	
	Response Count
	3
answered question	3
skipped question	2




4. How useful were the animations in helping you understand the material?

		Response Percent	Response Count
Extremely useful		0.0%	0
Very useful		40.0%	2
Moderately useful		20.0%	1
Slightly useful		40.0%	2
Not at all useful		0.0%	0
answered question			5
skipped question			0



5. Please explain:




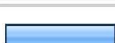

	Response Count
	4
answered question	4
skipped question	1

6. Was the content well organized?

		Response Percent	Response Count
Extremely organized		40.0%	2
Very organized		20.0%	1
Moderately organized		40.0%	2
Slightly organized		0.0%	0
Not at all organized		0.0%	0
answered question			5
skipped question			0

7. Qualify the pace of the animations:

		Response Percent	Response Count
Much too quickly		0.0%	0
Somewhat too quickly		20.0%	1
About the right speed		80.0%	4
Somewhat too slowly		0.0%	0
Much too slowly		0.0%	0
answered question			5
skipped question			0

8. How well did the animations meet your learning needs as a student?			
		Response Percent	Response Count
Extremely well		0.0%	0
Very well		0.0%	0
Moderately well		60.0%	3
Slightly well		20.0%	1
Not at all well		20.0%	1
answered question			5
skipped question			0

9. What are the weaknesses of these animations?		
		Response Count
		5
answered question		5
skipped question		0

10. What suggestions to you have to improve these animations?		
		Response Count
		5
answered question		5
skipped question		0

Q3. Please explain:		
1	The interface is very intuitive. The only thing I would suggest is changing the animation as you move the slider along the bar. It is a little annoying to have to move the slider to the position I want, press play, then press pause to study one point in time. Also, it would be nice if you could play the animation both backwards and forwards.	Apr 13, 2012 4:03 PM
2	Rotating the embryo was difficult. I could not get the embryo to look directly at me face-to-face. It would be better if there were designated axes (x,y,z) of the embryo and we would be able to rotate it about just one axis at a time to orient it properly.	Apr 13, 2012 11:20 AM
3	Interface is easy to catch onto. Some of the dates are wrong/go backwards at times. And it would be nice to have speed control.	Apr 13, 2012 9:54 AM

Q5. Please explain:		
1	Once labels are put in I'm sure it will be more useful, but at this point unless you know the material you would not be able to identify the structures. Also, perhaps the ability to click on a structure or name and bring up another window with relevant information would be useful.	Apr 13, 2012 4:03 PM
2	I think since there are no labels it makes it difficult to see and understand what is going on or what to be specifically looking for.	Apr 13, 2012 1:21 PM
3	You can follow the path of the nerve to the muscles which it innervates. It makes the anatomy a story that could be understood rather than just static pictures that have to be memorized.	Apr 13, 2012 11:20 AM
4	I thought this was great for putting things together. I don't think I ever TRULY understood what the arches meant and consisted of until this point.	Apr 13, 2012 9:54 AM

Q9. What are the weaknesses of these animations?		
1	As stated above. Also, I did not check in depth, but I noticed that there are structures missing for the vagus nerve; you have the pharyngeal constrictors and one more that I am assuming is for all the laryngeal muscles, but no palatoglossus or soft palate muscles.	Apr 13, 2012 4:03 PM
2	I think some of the weaknesses were that there were no labels and no explanations.	Apr 13, 2012 1:21 PM
3	Poor control in orienting the embryo Muscles not labeled Cannot view one arch and its nerve at a time	Apr 13, 2012 11:20 AM
4	I think the labels that you're going to add later would greatly improve the educational value of this animation.	Apr 13, 2012 10:13 AM
5	I think that this was a great thing to see once. It really did allow my brain to cling to a tangible and 3D image of a fetus for my learning purposes. However I can't imagine ever having to look at it more than once or how it could help me do better on an exam or boards. But perhaps I'm wrong.	Apr 13, 2012 9:54 AM

Q10. What suggestions to you have to improve these animations?		
1	Making them more interactive, so that you can play the animation forward and in reverse as well as rotate the fetus, would be tremendously helpful.	Apr 13, 2012 4:03 PM
2	I think by simply adding in some labels it will help a lot. I'm not sure what the animation is exactly meant for but I think a voice over explaining the process and what to be directing your attention to would also be very helpful.	Apr 13, 2012 1:21 PM
3	Allow rotate about a single axis at a time. Give zoom control. Label muscles . Allow viewing of just one arch at a time. I know the coloring can be changed but there is still a lot going on so it would be easier to see an arch and its nerve develop without the others in view. Show development of sensory branches.	Apr 13, 2012 11:20 AM
4	I guess it would be a lot of extra work, but if you could add the option of 3D rotation and zoom, it'd be ten times better!	Apr 13, 2012 10:13 AM
5	See above	Apr 13, 2012 9:54 AM

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