AN INVESTIGATION OF RELATIONSHIPS BETWEEN STUDENT ACCEPTANCE OF EVOLUTION, TREE-THINKING, AND EYE MOVEMENT AMONG DIFFERENT INSTRUCTIONAL INTERVENTIONS

by

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DEDICATION

I dedicate my thesis work to my family: my parents, Jay and Pam Leone, and my grandmother Barbara May, without their love and support this thesis would not have happened. To my siblings Tucker and Gracie Leone, who have continued to provide words of encouragement throughout this process. To my boyfriend, Matt Vu, for being a wonderful listener and for helping reduce my stress and anxiety throughout this process. I owe each of you so much thanks.

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I. INTRODUCTION

Evolution is the cornerstone upon which the field of biology is based. The field of biology helps drive the medical profession as new pathogens slowly become resistant to current medication (Davies & Davies, 2010), and also guides biological research, with entire departments at major research universities devoted to its study. Although a majority of scientific professionals accept evolution (Pew Research Center, 2009), 30% of the United States public still rejects the idea of evolution (Pew Research Center, 2013). In the United States specifically, 42% of the public believe in a creationist view of human evolution (Gallup, 2014), with humans created in their current form about 10,000 years ago. With a strong religious presence in the United States, these religious perspectives might be an important factor to consider when investigating evolution acceptance among college students and the public (Dagher & BouJaoude, 1997; Heddy & Nadelson, 2013). Also, introductory biology courses could be the first opportunity for many students to thoroughly learn the concept of evolution at a collegiate level. Learning evolutionary concepts helps all students build scientific literacy and these concepts will continue to follow science majors that pursue life science degrees, thus requiring scientific literacy of introductory level concepts. As a result, it is imperative that introductory biology students properly learn evolutionary concepts early in their academic career and into their profession.

One of the ways biologists represent evolution is through the use of phylogenetic trees. These tree diagrams are visual representations that convey hypothesized evolutionary relationships among other information such as speciation and lineage history of organisms (Baum, Smith, & Donovan, 2005). These relationships are essential for evolutionary biologists to understand as the relationships are working hypotheses upon which future studies are based. Phylogenetic trees are a common way scientists currently represent these hypothesized relationships among taxa is through phylogenetic trees (Baum & Smith, 2013). For example, most recently, scientists have released a phylogenetic tree of life including 2.3 million species (Hinchliff et al. 2015). Phylogenetic trees come in a variety of representational styles (Catley, Novick, & Shade, 2010; Matuk, 2007) (e.g., Figure 1). Although the tree styles in Figure 1 differ in visual arrangement, the evolutionary relationships they convey remain unchanged. Unfortunately, this physical change in tree style can prove difficult for students (Catley et al., 2010; Halverson, 2011). This challenge might act as a barrier to student success with

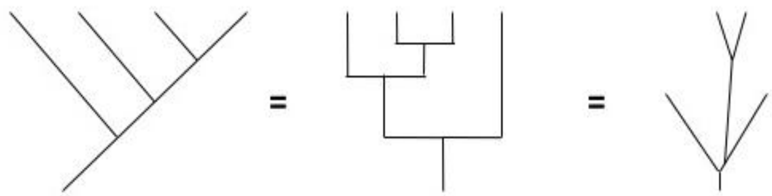


Figure 1. Illustration of the same phylogenetic relationship represented by different tree styles. From left to right: a diagonal tree, a squarish-corner tree, and a broom-like tree.

regards to successfully interpreting these tree diagrams.

The capacity to accurately interpret, use, and generate phylogenetic trees is referred to as *tree-thinking* (Halverson, Pires & Abell, 2011). Unfortunately, tree-thinking is a cognitively difficult task that many learners struggle to grasp (Baum et al., 2005). Some challenge with tree-thinking are associated with visual representation style (Catley et al., 2010; Halverson, 2011) and confusing the identifying informative features (Gregory, 2008; Halverson, 2011). For example, individuals have a tendency to add meaning to reading the tips of branches in a particular order (Gregory, 2008; Halverson, 2011). Because students have numerous alternative conceptions about the correct approach to interpreting these visual diagrams of evolution, students might also have challenges relating these trees to relevant concepts in evolution, resulting in a lower level of evolution acceptance.

Previous studies have investigated the relationship between tree-thinking and evolutionary acceptance while incorporating a single, integrated instruction method (Gibson & Hoefnagels, 2015; Walter, Halverson, & Boyce, 2013). But, the results from these studies were based on a tree-thinking questionnaire with limited reliability (Naegle, 2009). While informative, these studies do not accurately represent the potential relationship between evolution acceptance and student tree-thinking ability. Additionally, both studies measured student tree-thinking after only a single instructional method was used. An existing gap in the literature highlights the need for an investigation of tree-thinking learning with multiple tree-instructional methods and its possible relationship with evolution acceptance. It is expected that any type of instruction method is better than no instruction at all. However, we do not yet know what type of instructional approach yields tree-thinking learning gains. The purpose of my study was twofold. First, my goal was to identify the relationships between evolution acceptance, tree-thinking, and religiosity when students were exposed to different instructional interventions. Second, my goal was to explore how students visually access phylogenetic trees.

Review of literature

The relationship between understanding evolution and acceptance of evolution is a contested issue among science education researchers (Deniz, Donnelly, & Yilmaz, 2008). Some studies found no relationship between acceptance and understanding of evolution (Sinatra, Southerland, McConaughy & Demastes, 2003; Demastes-Southerland, Settlage, & Good, 1995; Bishop & Anderson, 1990) while others found a relationship between evolution acceptance and knowledge of macroevolution (Nadelson & Southerland, 2010). Research suggests that lack of acceptance might serve as a barrier to scientific understanding (Sinatra et al., 2003). However, Sinatra et al. (2003) also argue that a student might not accept a theory unless an understanding of the theory is developed. There is clearly no agreement in the literature about the relationship between acceptance and understanding. Deniz et al. (2008) found that, among multiple factors, scientific understanding only explained 3.3% of the variance in acceptance of evolution. Therefore, they caution not to exaggerate scientific understanding when measuring evolution acceptance among multiple factors. Instead, my study investigated how tree-thinking knowledge interplays with evolution acceptance and religiosity. Phylogenetic trees represent hypothetical evolutionary relationships. Thus, evolution acceptance might be able to explain how students learn about phylogenetic trees.

Few studies have focused on evolution acceptance and tree-thinking in introductory-level biology courses (Walter et al., 2013; Gibson & Hoefnagels, 2015). Walter et al. (2013) found no significant gain in evolution acceptance and little correlation between students' tree-thinking ability and evolution acceptance among non-science majors. However, Gibson and Hoefnagels (2015) found a significant relationship between tree-thinking and evolution acceptance among biology majors. Both studies used the original version of the Measure of Acceptance of the Theory of Evolution (MATE) (Rutledge & Warden, 1999) instrument to measure evolution acceptance, and each study used an altered version of the Tree Thinking Concept Inventory (TTCI) instrument to measure tree-thinking ability (Naegle, 2009). The altered TTCI used by Walter et al.

(2013) and Gibson and Hoefnagels (2015) was limited in reliability, as an overestimation of its reliability using Cronbach's Alpha. Cronbach's Alpha is appropriate for measuring reliability in instruments utilizing a Likert-scale. However, the TTCI is a dichotomous instrument. Dichotomous instruments consist of items that only have one correct answer, and one or more incorrect answers. Thus, reliability should have been measured by the Kuder-Richardson 20 (KR20), as this measure is more appropriate for dichotomous instruments where only one correct answer exists among multiple incorrect answers. Still, for comparison sake, each of these two studies used similar instruments to measure evolution acceptance and tree-thinking with introductory-level biology students, the results are limited in scope by participant sample size and limited instruments. Additionally, these studies only measure tree-thinking outcomes from one type of instructional intervention where phylogenetic trees were heavily integrated throughout the course. The different outcomes from these similar studies suggests that further studies are needed to investigate student tree-thinking competency using a more reliable tree-thinking instrument in multiple, different instructional interventions. Recently, a new instrument was developed to measure tree-thinking competency (Boyce, 2015). This instrument, the Basic Evolutionary Tree Thinking Skills Inventory (BETTSI), targets common tree-thinking misconceptions and has confirmed reliability ($\rho_{KR20} = 0.80$). The BETTSI was first used to measure tree-thinking among STEM majors in an introductory biology course for science majors (Boyce, 2015).

To supplement tree-thinking data obtained from the BETTSI, I incorporated the use of relatively new technology that measures eye-movement patterns in a process called eye-tracking. Eye-tracking is a process which quantitatively measures biometric data of pupil eye-movement from participants as they interact with images on a computer screen. This technology is commonly used in reading comprehension experiments (Rayner, 2009) and is now being applied across different disciplines (Duchowski, 2002). For example, using eye-movement technology can have potentially, positive applications in fields such as aviation to advertising (Duchowski, 2002). Few studies exist incorporating eye-movement technology and biology students (Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Novick, Stull, & Catley, 2012). Jarodzka et al. (2010) studied how biology expert and novice approaches compared when interacting with dynamic visual images and found that experts were better at perceiving and interpreting information within dynamic visualizations. Although phylogenetic trees are not dynamic visualizations, some studies investigated visual interactions with static images. Novick et al. (2012) investigated how upper-level biology students interacted with static visual images of phylogenetic trees and found that students had a strong bias to read from left to right and that the “backbone” line of diagonal tree styles guided their direction of visual processing. Both of these studies had very small sample sizes; 21 participants and 19 participants, respectively. The study by Novick et al. (2012) is the only preliminary study incorporating upper-division biology students, eye movement, and phylogenetic trees. My investigation builds and improves upon the study of Novick et al. (2012) by utilizing a larger sample size overall and students enrolled in introductory biology courses experiencing different instructional interventions.

It is important to note that students can approach material that they read with certain perspectives, and these perspectives can affect what students learn (Pichert & Anderson, 1977). Approaching a text from a certain perspective is also known as imposing a schema, and readers often fill empty gaps in their schema with the manner by which the reader considers important information (Pichert & Anderson, 1977). For example, Pichert and Anderson (1977) asked groups of students to read the same passage from two different perspectives, or schemas. One schema was that of a burglar and the other was that of a realtor. When using different schema on the same passage, students were more likely to notice words that fit their schema. Words like “expensive jewelry” or “unlocked home” fill the slots of the burglar schema while words like “leaky roof” fill the gaps of a realtor schema. Using this same idea, it is possible that students might approach tree-thinking with a certain perspective. As phylogenetic trees are visual representations of evolution and relatedness, a student might begin reading and interpreting these diagrams (tree-thinking) with preconceived schema, like evolution acceptance, that might affect learning outcomes in tree-thinking.

Science and religion are often seen as conflicting ideas and these conflicts can arise in the classroom (Meikle & Scott, 2010). In America, 59% of the public say that science and religion are incompatible (Pew Research Center, 2015). Examples like the Scope’s Trial in 1925 attest to the American attitude toward science content that conflicts with religious beliefs. Some of the participants for my investigation live within highly religious parts of the United States such as the Deep South. As a result, it is of interest to investigate the relationship between evolution acceptance and religiosity using two valid, reliable instruments, the MATE (Rutledge & Warden, 1999) and DUREL (Koenig & Bussing, 2010).

Religiosity is defined as the degree of expression of religious importance in one’s life (Heddy & Nadelson, 2013; Holdcroft, 2006). Research has shown a strong connection between religious affiliation and student position regarding the theory of evolution (Dagher & BouJaoude, 1997). Additional research shows strong negative relationships between religiosity and evolution acceptance (Heddy & Nadelson, 2013), especially in the United States (Heddy & Nadelson, 2012), but does not utilize a reliable religiosity test. My study incorporates a reliable, valid measure of religiosity: The Duke University Religion Index (DUREL) (Koenig & Büssing, 2010). Currently, there is no literature describing the relationship between religiosity, tree-thinking, and evolution acceptance. Deniz et al. (2008) suggest that future studies of evolution acceptance consider religion as an important factor of acceptance. Therefore, my investigation incorporates religiosity as a possible phenomenon that might explain student acceptance of evolution and learning outcomes.

Conceptual framework

My study is guided by two conceptual frameworks: learners' development of expertise and the interplay between student knowledge and belief. Experts in a domain can organize information based on similar components in an ability called "chunking" (Bransford, Brown, & Cocking, 2000). Although this "chunking" ability allows for faster memory recall in experts, Bransford et al. (2000) also argue that learners need not be experts to encode "chunked" information. It is possible that novices might "chunk" incorrect information, leading to misconceptions or incorrect problem solving abilities. As learners develop expertise in a subject, one might expect the novice to quickly recognize patterns of information, especially among the common representation of evolution in biology (Halverson et al., 2011). The combination of chunking accurate information for quick memory recall and recognizing meaningful patterns of information both visually and conceptually might help a student move from novice to expert with regards to tree-thinking. For example, expert level tree-thinkers chunk information about evolutionary time and relatedness among taxa to quickly interpret phylogenetic tree diagrams regardless of tree style (Halverson, 2009). Expert level tree-thinkers are professionals in the field of systematics, and although the students in this study are not professionals in this field, it is important to note the level of expertise of tree-thinking competency.

Several key principles define a barrier between an expert's knowledge of concepts and novice's knowledge (Bransford, et al., 2000). Of these key principles, an expert's ability to, "notice features and meaningful patterns of information that are not noticed by novices" (Bransford et al., 2000, p. 31) is most applicable to my study as student participants are engaging with representations of evolution that hold key features and meaningful patterns of information in a visual sense. While the development of expertise framework provides a lens through which to examine student learning outcomes, it does not incorporate how learners' personal beliefs might affect the development of core scientific concepts, for example, evolution.

As experts depend on deep conceptual knowledge, personal worldviews might affect learners' acquisition of knowledge (Smith, 1994). The discussion of evolution within the public is historically accompanied by religion as there are potential disagreements between the two domains regarding the history of life on earth. Smith (1994) cautions not to misuse the word *belief* as it has different meanings between science and non-science. For example, scientists do not use the word *belief.* Instead, the word *accept* is used as scientists can choose to accept or not accept evidence that supports, for example, a particular evolutionary based hypothesis. For non-scientists, the word *belief* does not require any supporting evidence of an idea or notion. For instance, if a non-scientist says, "I believe in the existence of a higher being," he or she likely does not require evidence to support the idea of a higher being existing. As the connotations for *belief* vary, it is important to define the use of the word in the context of my study: I will use the definition of belief described by Sinatra, Southerland, McConaughy, & Demastes (2003) as a subjective way of knowing. My study investigates student learning outcomes in tree-thinking, so *knowledge* is defined in the context of successful tree-thinking competency.

Eye-tracking has been used to study the relationships between eye-movement and cognitive processes in reading comprehension (Rayner, 2009). These relationships may exist when reading visual diagrams, such as phylogenetic trees. Thus, I want to record students' eye movements as they "read" trees. By capturing learner interactions along the novice-expert continuum, I can begin to identify informative patterns.

Research questions

1. What are the relationships among instructional intervention, tree-thinking, and evolution acceptance?

2. How does tree-thinking knowledge, acceptance, and belief compare across participants?

3. How do students visually interact with informative tree features when tree reading?

II. METHODOLOGY

Setting

For my investigation, I targeted undergraduate students enrolled in introductory biology courses at Texas State University and Southern Utah University. Texas State University offers a unique, diverse student population as a Hispanic serving institution where 33% of the population identify as Hispanic (Forbes, 2016). Southern Utah University is one of few institutions in the United States in which extensive tree-thinking approaches are incorporated during introductory biology courses. I used a quantitative approach to capture tree-thinking learning outcomes, level of acceptance of evolution, religiosity and biometric data to identify how students visually interact with informative tree features while tree reading.

Participants

With approval from the Texas State University Institutional Review Board (see Appendix A) I recruited a total of n = 884 (n = 294 majors, n = 590 majors) undergraduate students from Texas State University and Southern Utah University over the age of 18 in the spring and fall 2016 semesters. Specifically, I targeted students enrolled in introductory biology courses for biology majors and non-majors across 5 different instructional interventions (see Appendix B). It is critical to note that each instructional method had only one week of instruction time and no instructional method had more or less times than other methods. The 5 instructional interventions used in introductory biology for majors and non-majors are as follows: no instruction (None), implicit instruction (Implicit), video instruction (Video), manipulative model instruction (Model) and extensive instruction (Extensive) (Table 1). Students experiencing no instruction (n = 113 majors, n = 224 non-majors) did not receive any instruction on phylogenetic trees in any capacity. Students experiencing implicit instruction (n = 55 majors, n = 101 non-majors) received instruction about concepts such as evolution and biodiversity which incorporated trees, but these students were not explicitly taught how to interpret or understand them. They were simply exposed to trees. Video instruction treatment (n = 45 majors, n = 112 non-majors) used video evidence as the primary teaching evidence, which showed students how to correctly interpret trees and introduced students to the concept of tree style. The manipulative model instruction (n = 70 majors, n = 115 non-majors) involved students in a tactile, interactive learning experience where they manipulated 5 different colored pipe cleaners as teaching evidence of phylogenetics. Each color corresponded to a colored organism on a PowerPoint lecture with which the instructor led the activity. Finally, students experiencing extensive instruction (n = 11 majors, n = 38 non-majors) borrowed few strategies from the video and manipulative model approaches and combined them with very tree-intensive lectures.

Table 1

Sample sizes per instructional intervention across majors and non-majors

	Instructional Intervention					
	None	Implicit	Video	Model	Extensive	Total
Major	113	55	45	70	11	294
Non-Major	224	101	112	115	38	590
Total	337	156	157	185	49	n =884

Data sources

I used a total of four data sources to answer my research questions (Table 2). Three data sources were part of a larger questionnaire administered to students online via SNAP 11 survey software. Instructors administered the questionnaire link to consenting students both before (pretest) and after (posttest) the one week-long instruction time. The three instruments I used were the Basic Evolutionary Tree Thinking Skills Inventory (BETTSI) (Boyce, 2015), the Measure of Acceptance of the Theory of Evolution (MATE) (Rutledge & Warden, 1999), and the Duke University Religion Index (DUREL) (Koenig & Büssing, 2010). My fourth data source, eye movement, informed my third research question. I collected eye movement data after participants completed the week-long instructional intervention.

Table 2

Data matrix: Research questions by data sources

Research Questions	Data Sources			
	BETTSI	MATE	DUREL	Eye Movement Exercise
1. What are the relationships among instructional intervention, tree-thinking, and evolution acceptance?	X	X		
2. How does tree-thinking knowledge, acceptance, and belief compare across introductory students?	X	X	X	
3. How do students visually interact with informative tree features when tree-thinking?				X

Basic Evolutionary Tree Thinking Skills Inventory. The BETTSI (see Appendix C) is a reliable ($\rho_{KR20} = 0.80$) 11-item multiple-choice instrument that targets common tree-thinking misconceptions (Boyce, 2015). Each question has only one correct answer from five possible choices, with each correct answer worth one point value. Students can receive a score from 0 (poor tree-thinking ability) to 11 (excellent tree-thinking ability). Since this instrument was administered in a pre/posttest format, paired difference scores on the BETTSI can range from -11 to +11. Paired differences between BETTSI pre and posttest scores in my study represent tree-thinking changes, and BETTSI post scores represent tree-thinking learning outcomes.

Measure of Acceptance of the Theory of Evolution. The MATE (see Appendix D) is a reliable ($\alpha = 0.94$) 20-item, 5-point Likert scale instrument that measures evolution acceptance based on a 100 point scale (20 reject – 100 accept). I calculated a reliability of $\alpha = 0.93$ from my participant data. Questions focus on "fundamental concepts of evolution and science as a method of inquiry" (Rutledge and Sadler, 2007, p. 332). Originally constructed to assess high school biology teachers' overall acceptance of evolution, the MATE is widely used for many studies investigating evolution acceptance. In my study, I used the MATE to measure evolution acceptance among undergraduate students in introductory biology courses both before and after instruction (where appropriate) of phylogenetic trees. Student changes in pre/posttests can range from -80 to +80. Paired differences in MATE pre and posttest scores represent change in evolution acceptance, while MATE posttest scores represent the final level of evolution acceptance.

Duke University Religion Index. The DUREL (see Appendix E) is the Duke University Religion Index, a reliable ($\alpha = 0.78$-0.91) 5-item, 5-point Likert scale instrument that assesses religious involvement at three major dimensions previously described at the National Institute of Aging (Koenig & Büssing, 2010). I calculated the DUREL reliability in my study as $\alpha = 0.89$. It consists of three subscales that measure organized religious activity, non-organized religious activity, and intrinsic religiosity. I summed the three subscales allowing for a score from 5 to 27, with higher scores indicating higher religiosity. I used this instrument to determine how religious students view themselves in a university setting, before instruction (where appropriate), about phylogenetic trees.

Eye movement. I gathered biometric eye movement data from student volunteers (n = 212) at Texas State University and Southern Utah University using eye tracking infrared cameras and software from Tobii and SensoMotoric Instruments (SMI). These cameras capture focal points on a computer screen and do not record video of the participants. These cameras only gathered data about where participants are looking on the screen and for how long. This eye movement exercise included similar questions to those included on the BETTSI.

The camera monitors eye movement using a non-invasive infrared laser aimed at each participants' eyes. The infrared laser does not harm the student nor can the student see the laser coming from the camera. Because I used two different infrared cameras to capture student eye movement, I set each camera to record eye movement at 120 Hz to ensure each camera was functioning as similarly to each other as possible. The Tobii X120 camera is located underneath a desktop monitor to measure eye movement across images, in this case phylogenetic trees, on the screen. The SMI camera is small and magnetic, which allows for easy portability to laptops. I used the SMI camera, software, and laptop to gather data from students at Southern Utah University instead of the Tobii X120 and Tobii software because of its portability.

The eye movement exercise was composed of four tasks (see Appendix F) which related to concepts included in the BETTSI. Student volunteers signed up for the eye movement exercise which lasted about 10-15 minutes. Students were shown 4 separate slides, one slide per task. Each slide included a tree with an associated question and phylogenetic tree to help the student answer the question. Students were asked to answer each question to the best of their ability using the tree from the slide. After data collection, I drew areas of interest around structures of each tree using Tobii and SMI software.

An area of interest is designated space inside specified borders focused around explicit features of phylogenetic trees (see Appendix G). I defined areas of interest around the most informative parts of the phylogenetic trees for tasks 1, 2, and 3 including the written question, nodes, branches, and tips. For task 4 (Figure 2), I drew areas of interest around each lineage illustrated by the tree, with lineage C representing the informative lineage. I calculated how many times a student visited an area of interest (a time independent value). Visit duration/dwell time is defined as how many time a participant enters an area of interest. I also calculated visit duration/dwell time (a time dependent variable) for each participant for each area of interest on each task.

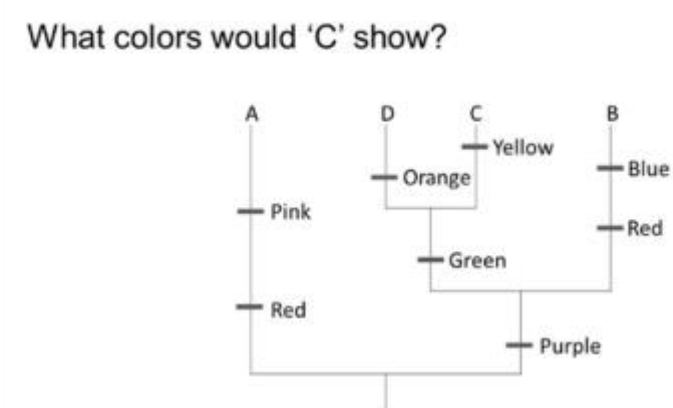


Figure 2. Task 4 of the eye-tracking exercise.

After selecting the Visit Duration metric in Tobii studio software and Dwell Time in SMI, I organized participant eye movement outputs by question, treatment group, and then question accuracy by assigning accurate responses a value of 1 and inaccurate responses a value of 0. I then calculated the total time spent on the tree by summing the duration in seconds of each area of interest and searched for patterns across treatment and by question accuracy. This portion of my study is exploratory in nature as we do not have biometric data on how students visually access squarish-corner tree diagrams.

Data analysis

Analyses for research question 1. To investigate the relationships among instructional intervention, tree-thinking, and evolution acceptance, I performed two multivariate analysis of variances (MANOVA) to compare changes on the BETTSI and MATE and post scores on the BETTSI and MATE across instructional interventions. The first MANOVA included instructional methods coded by major and non-major as the independent variable and the average paired difference of BETTSI scores and MATE scores as the continuous response variables. The independent variable remained the same in the second MANOVA, but included post BETTSI and post MATE scores as the continuous response variables.

After performing both MANOVAs, I performed multiple Pearson’s correlations to determine how related changes in tree-thinking and acceptance were and how related post measurements in tree thinking and evolution acceptance were to each other. I calculated a Pearson’s correlation coefficient between paired differences in the BETTSI and MATE for biology majors and non-majors. I then calculated a second Pearson’s correlation coefficient between post BETTSI and post MATE scores for biology majors and non-majors.

Lastly, I calculated four regressions with the BETTSI as the dependent variable and the MATE as the independent to explain the variance of tree-thinking changes and learning outcomes. Two regressions used paired differences of the BETTSI and MATE in biology majors and non-majors, and the other two regressions used post BETTSI and post MATE scores in biology majors and non-majors.

Analyses for research question 2. To investigate how tree-thinking knowledge, acceptance, and belief compare across introductory students, I used the two Scheffe's *post hoc* tests from each MANOVA performed for my first research question to compare biology majors and non-majors per treatment with regards to BETTSI paired differences, and post BETTSI scores. The two Scheffe's *post hoc* tests also compared biology majors and non-majors per instructional intervention with regards to MATE paired differences and post MATE scores. To compare religiosity between majors and non-majors per instructional intervention, I performed a one-way analysis of variance (ANOVA) on DUREL scores and performed a Scheffe's *post hoc* due to unequal sample sizes. I then performed a total of four regression analyses using the DUREL as my independent variable to determine how much variance in tree-thinking changes, tree-thinking learning outcomes, changes in evolution acceptance, and final levels of evolution acceptance could be explained by the DUREL.

Analyses for research question 3. To investigate how students visually interacted with informative tree features when tree reading, I selected the Visit Duration and Dwell Time metrics in the Tobii eye tracking software and SMI software, respectively, to calculate the number of times each participant visited each area of interest and how long participants spent within each area of interest. I separated the counts and the durations (measured in seconds) by instructional intervention and by question accuracy. I performed two, two-way MANOVAs and two, two-way ANOVAs for each task. The first two-way MANOVA examined instructional treatment and task accuracy as independent variables, and visitation counts within areas of interest on the tree as the dependent variable. For the second two-way MANOVA, I set times spent within areas of interest as the dependent variable. The first two-way ANOVA examined instructional treatment and task accuracy as independent variables, and visitation counts on the written question as the dependent variable. For the second two-way ANOVA, I set times spent on the written question as the dependent variable. I could have used a Bonferroni correction within task comparisons using an alpha level of 0.008 to address this issue. However, because this is an exploratory research question, I did not carry out any corrections for possible study-wide type I error.

III. RESULTS

The first MANOVA revealed a statistically significant difference in changes in tree thinking and MATE scores based on instructional treatment F (9, 874) = 22.552, $p <$ 0.001, Roy's Largest Root = 0.232, η^2 = 0.188. The second MANOVA revealed a statistically significant difference in outcomes in tree thinking and MATE scores based on instructional treatment F (9, 874) = 26.233, $p < 0.001$, Roy's Largest Root = 0.270, η^2 = 0.213. I performed a Scheffe's *post hoc* test to compare tree-thinking changes, tree-thinking learning outcomes, changes in evolution acceptance and final levels of evolution acceptance among the instructional treatments within biology majors and non-majors.

BETTSI changes in non-major biology students.

Students had positive gains in tree-thinking changes across all interventions (Table 3). Within non-majors, participants that experienced no instruction had statistically significant (p < 0.001) lower tree-thinking changes (M = 0.19, SD = 1.84) than participants experiencing the video intervention (M = 1.51, SD = 2.17), manipulative model intervention (M = 2.16, SD = 2.14), and extensive intervention (M = 3.42, SD = 2.75). Non-majors that experienced the implicit intervention (M = 0.18, SD = 1.88) had statistically significant (p < 0.001) lower tree-thinking changes than participants that experienced the manipulative model intervention (M = 2.16, SD = 2.14), and extensive intervention (M = 3.42, SD = 2.75). There was also a statistically significant difference (p = 0.007) between the implicit intervention and video intervention (M = 1.51, SD = 2.17). Lastly, I found a statistically significant difference (p = 0.003) between participants that experienced the video intervention (M = 1.51, SD = 2.17) and the extensive intervention (M = 3.42, SD = 2.75). There were no other significant differences in BETTSI changes between instructional interventions (Table 4).

Table 3

Averages of tree-thinking changes by intervention in non-majors

Intervention	Mean	CI
None	0.19	-0.50, 0.43
Implicit	0.18	-0.19, 0.55
Video	1.51	1.10, 1.92
Model	2.16	1.76, 2.55
Extensive	3.42	2.52, 4.32

Table 4

Significance of tree-thinking changes in non-majors across interventions

	Intervention				
	None	Implicit	Video	Model	Extensive
None	-				
Implicit	*	-			
Video	< 0.001	0.007	-		
Model	< 0.001	< 0.001	*	-	
Extensive	< 0.001	< 0.001	0.003	*	-

Note. Significance is noted at $p = 0.05$. Non-significant values are p-values are represented by *.

BETTSI changes in biology major students.

Students showed losses and gains in tree-thinking changes across interventions (Table 5). Within biology majors, the only statistically significant difference (p < 0.001) in BETTSI learning outcomes occurred between students that experienced no instruction (M = -.23, SD = 1.94) and the manipulative model intervention (M = 1.59, SD = 2.26). All other pairs of instructional interventions had no significant difference within biology majors (Table 6).

Table 5

Averages of tree-thinking changes by intervention in majors

Intervention	Mean	CI
None	-0.23	-0.59, 0.13
Implicit	0.49	-0.02, 1.00
Video	0.84	0.32, 1.37
Model	1.59	1.05, 2.12
Extensive	1.64	-0.22, 3.50

Table 6

Significance of tree-thinking changes in majors across interventions

	Intervention				
	None	Implicit	Video	Model	Extensive
None	-				
Implicit	*	-			
Video	*	*	-		
Model	< 0.001	*	*	-	
Extensive	*	*	*	*	-

Note. Significance is noted at $p = 0.05$. Non-significant values are p-values are represented by *.

BETTSI learning outcomes in non-major biology students.

Tree-thinking learning outcomes, represented by the post-scores, were all positive across interventions in non-major biology students (Table 7). Within non-majors, participants that experienced the extensive intervention had a statistically significant ($p < 0.001$) higher average ($M = 7.63$, $SD = 2.35$) in tree-thinking learning outcomes than participants that experienced no instruction ($M = 4.12$, $SD = 1.78$), the implicit intervention ($M = 4.37$, $SD = 1.81$), and the video intervention ($M = 5.42$, $SD = 2.35$). Participants that experienced the manipulative model had a statistically significant ($p < 0.001$) higher average ($M = 6.59$, $SD = 2.35$) in tree-thinking learning outcomes than participants that experienced no instruction (M = 4.12, SD = 1.78), and the implicit intervention (M = 4.37, SD = 1.81). Participants that experienced the manipulative model intervention (M = 6.59, SD = 2.35) also had a statistically significant (p = 0.033) higher average than participants that experienced the video intervention (5.42, SD = 2.35). Lastly, participants that experienced no instruction had a statistically significant (p = 0.001) lower average (M = 4.12, SD = 1.78) than participants that experienced the video intervention (5.42, SD = 2.35). There were no other significant differences in tree-thinking learning outcomes between instructional interventions (Table 8).

Table 7

Averages of tree-thinking learning outcomes by intervention in non-majors

Intervention	Mean
None	4.12
Implicit	4.33
Video	5.42
Model	6.59
Extensive	7.63

Table 8

Significance of tree-thinking learning outcomes in non-majors across interventions

	Intervention				
	None	Implicit	Video	Model	Extensive
None	-				
Implicit	*	-			
Video	0.001	*	-		
Model	< 0.001	< 0.001	0.033	-	
Extensive	< 0.001	< 0.001	< 0.001	*	-

Note. Significance is noted at *p* = 0.05. Non-significant values are p-values are represented by *.

BETTSI learning outcomes in biology major students.

Tree-thinking learning outcomes were all positive across interventions in major biology students (Table 9). Within biology majors, participants that experienced no instruction had a statistically significant ($p = 0.002$) lower average ($M = 4.60$, $SD = 1.94$) in tree-thinking learning outcomes than participants that experienced the manipulative model intervention ($M = 6.23$, $SD = 2.16$) and the extensive intervention ($M = 7.09$, $SD = 3.27$). All other instructional interventions had no significant difference within biology majors (Table 10).

Table 9

Averages of tree-thinking learning outcomes by intervention in majors

Intervention	Mean
None	4.60
Implicit	5.93
Video	6
Model	6.23
Extensive	7.09

Table 10

Significance of tree-thinking learning outcomes in non-majors across interventions

	Intervention				
	None	Implicit	Video	Model	Extensive
None	-				
Implicit	*	-			
Video	*	*	-		
Model	0.002	*	*	-	
Extensive	0.002	*	*	*	-

Note. Significance is noted at $p = 0.05$. Non-significant values are p-values are represented by *.

Changes in evolution acceptance in non-major biology students.

Changes in evolution acceptance evolution were both positive and negative in non-major biology students (Table 11). Within non-majors, I found no significant differences in changes in evolution acceptance between instructional interventions.

Table 11

Average change in MATE scores in non-majors across interventions

Intervention	Mean	CI
None	-0.50	-1.63, 0.62
Implicit	0.96	-0.67, 2.59
Video	1.38	-0.17, 2.94
Model	1.48	-0.27, 3.23
Extensive	3.37	0.44, 6.30

Changes in evolution acceptance in major biology students.

Changes in evolution acceptance evolution were both positive and negative in biology majors (Table 12). Within majors, I found no significant differences in changes in evolution acceptance between instructional interventions.

Table 12

Average change in MATE scores in majors across interventions

Intervention	Mean	CI
None	-0.94	-2.25, 0.37
Implicit	-0.16	-2.69, 2.36
Video	3.84	.40, 7.28
Model	1.04	-1.10, 3.19
Extensive	1.55	-5.23, 8.32

Final levels of evolution acceptance in non-major biology students.

Post MATE scores in non-major biology students ranged from 69.44 to 76.35 (Table 13). Within non-majors, there was a statistically significant difference (p = 0.019) in final levels of evolution acceptance between participants that experienced no instruction (M = 69.35, SD = 12.31) and the manipulative model intervention (M = 76.24, SD = 13.13). There was also a statistically significant difference (p = 0.017) in final levels of evolution acceptance between participants that experienced no instruction (M = 69.35, SD = 12.31) and the video intervention (M = 76.35, SD = 13.98). No other significant differences occurred in final levels of evolution acceptance between instructional interventions (Table 14).

Table 13

Average post MATE scores in non-majors across interventions

Intervention	Mean
None	69.348
Implicit	72.426
Video	76.348
Model	76.235
Extensive	74.579

Table 14

Significance of post MATE scores in non-majors across interventions

	Intervention				
	None	Implicit	Video	Model	Extensive
None	-				
Implicit	*	-			
Video	0.017	*	-		
Model	0.019	*	*	-	
Extensive	*	*	*	*	-

Note. Significance is noted at $p = 0.05$. Non-significant values are p-values are represented by *.

Final levels of evolution acceptance in major biology students.

Final levels of evolution acceptance in biology majors range from 72.65 to 80.42 (Tale 15). Within majors, there were no significant differences in final levels of evolution acceptance between instructional interventions.

Table 15

Average post MATE scores in majors across interventions

Intervention	Mean
None	72.65
Implicit	77.87
Video	80.42
Model	75.51
Extensive	76.55

Correlation and regression of tree-thinking and evolution acceptance.

In non-majors, participant tree-thinking changes are significantly but weakly correlated with change in evolution acceptance $r = 0.199$, $p = 0.004$. Additionally, participants' learning outcomes about trees is significantly weakly correlated with final acceptance of evolution in non-majors. $r = 0.342$, $p < 0.001$.

I calculated a simple linear progression to predict tree-thinking changes based on changes in evolution acceptance in non-majors. I found a significant regression ($F(1, 588) = 8.436$, $p = 0.004$), with an R^2 of .014. Regarding the variance, 1.4% of the variance in participant tree-thinking changes is explained by their change in evolution acceptance. I calculated another simple linear regression to predict participant learning outcomes about tree-thinking based on final level of acceptance of evolution in non-majors. I found a significant regression $F(1, 588) = 77.721$, $p < 0.001$), with an R^2 of

.117. Regarding the variance, 11.7% of the variance in participant tree-thinking learning outcomes is explained by their final level of evolution acceptance.

In biology majors, changes in tree-thinking are significantly but weakly correlated with change in evolution acceptance $r = 0.175$, $p = 0.003$. Additionally, students' learning outcomes about trees is significantly weakly correlated with final acceptance of evolution $r = 0.314$, $p < 0.001$.

I calculated simple linear regression to predict tree-thinking changes based on changes in evolution acceptance in biology majors. I found a significant regression ($F(1, 293) = 9.176$, $p = 0.003$), with an R^2 of .030. 3% of the variance in tree-thinking changes is explained by their change in evolution acceptance. I also calculated a simple linear regression predict participant tree-thinking learning outcomes based on final level of acceptance of evolution in biology majors. I found a significant regression ($F(1, 293) = 32.023$, $p < 0.001$) with an R^2 of .099. 9.9% of the variance in participant learning outcomes of tree-thinking is explained by their final level of acceptance of evolution.

Tree-thinking and evolution acceptance between majors and non-majors.

The two Scheffe's *post hoc* tests performed after each MANOVA in research question one also informed part of my second research question. I found no significant differences in tree-thinking changes between biology majors and non-majors across instructional interventions. However, biology majors that experienced the implicit intervention (M = 5.93, SD = 2.04) had a statistically significant (p = 0.012) higher average in tree-thinking learning outcomes than did biology non-majors under the same implicit intervention (M = 4.33, SD = 1.81).

Regarding changes in evolution acceptance and final levels of evolution acceptance, I found no significant difference between majors and non-majors across any instructional intervention.

Religiosity between majors and non-majors.

Average scores for religiosity in majors and non-majors across instructional interventions can be found in Table 16. To compare religiosity between majors and non-majors per instructional intervention, I performed a one-way ANOVA. Overall, there was a significant difference in religiosity between majors and non-majors per instructional intervention [F(9, 874) = 2.51, p = 0.008]. I ran a Scheffe's *post hoc* test to determine where the significance lies, but no significant difference was found across any instruction intervention.

Table 16

Average DUREL score in majors and non-majors across interventions

	Intervention				
	None	Implicit	Video	Model	Extensive
Major	14.51	15.20	15.60	15.84	21.36
Non-Major	16.98	15.51	16.04	15.46	15.87

Regression analysis of religiosity and tree-thinking

I performed a simple linear regression analysis to determine if participant religiosity could explain the variance in tree-thinking changes and tree-thinking learning outcomes, respectively. I found a non-significant regression between religiosity and tree-thinking learning outcomes ($F(1, 882) = 1.56$, $p = 0.212$), with an R^2 of 0.002. Religiosity explains 0.2% of the variance found in tree-thinking changes. I found a significant regression between religiosity and tree-thinking learning outcomes ($F(1, 882) = 5.19$, $p =$

0.023), with an R^2 value of 0.006. Religiosity explains 0.6% of the variance found in tree-thinking learning outcomes.

Regression analysis of religiosity and evolution acceptance.

I performed a simple linear regression analysis to determine if participant religiosity could explain the variance in changes in evolution acceptance and final levels of evolution acceptance, respectively. I found a non-significant regression between religiosity and changes in evolution acceptance ($F(1, 882) = 1.29$, $p = 0.257$), with an R^2 value of 0.001. Religiosity explains 0.1% of the variance found in changes in evolution acceptance. I found a significant regression between religiosity and final levels of evolution acceptance ($F(1, 882) = 207.34$, $p < 0.001$), with an R^2 value of 0.190. Religiosity explains 19% of the variance found in final levels of evolution acceptance.

Visual interactions with eye tracking task 1.

Participants that completed this task incorrectly regardless of instructional intervention looked at branches/corners, nodes, and tips more than participants that answered the question correctly. This trend holds true for duration counts as well. Participants that incorrectly completed the task spent more time looking at branches/corners, nodes, and tips that those that answered it correctly (Table 17 and Table 18).

I found a statistically significant interaction effect between task 1 accuracy and type of instructional method on the combined branch/corner, node, and tip grouping counts, $F(4, 202) = 2.95$, $p = 0.021$; Roy's Largest Root = 0.058. However, upon performing a Scheffe's *post hoc* test due to unequal sample sizes, I did not find a significant difference between instruction method and how many times looked at either branches/corners, nodes, or tips.

I did not find a statistically significant difference between instruction method and how long participants spent looking at groupings of branches/corner, nodes, or tips $F(4, 202) = 1.79$, $p = 0.133$; Roy's Largest Root = 0.035.

I did not find a statistically significant difference in the number of times participants looked at the question based on instruction method (p = 0.324), task 1 accuracy (p = 0.186) or the interaction between instruction method and task 1 accuracy (p = 0.642). There was also no significant difference in how long participants spent looking at question 1 based on instruction method (p = 0.592), task 1 accuracy (p = 0.163), or the interaction between instruction method and task 1 accuracy (p = 0.426).

Table 17

Fixation counts for task 1 by area of interest and intervention

			Counts				
Accuracy		n	Branches/Corners	Tips	Nodes	Question	Total counts
Correct	None	8	7.88	5.75	4.63	5.38	23.63
	Implicit	12	9.75	10.00	5.67	8.17	33.58
	Video	12	14.08	9.67	7.58	8.08	39.42
	Model	33	8.70	10.03	4.12	7.39	30.24
	Extensive	13	7.15	7.00	1.46	6.00	21.62
	Total	78	47.56	42.45	23.46	35.02	148.48
Incorrect	None	27	9.85	9.19	4.11	5.93	29.07
	Implicit	49	11.47	6.55	4.98	6.29	29.29
	Video	29	9.52	9.72	5.24	6.34	30.83
	Model	20	12.20	7.30	6.60	6.60	32.70
	Extensive	9	13.22	11.89	6.78	6.00	37.89
	Total	134	56.26	44.65	27.71	31.16	159.78

Table 18

Fixation durations for task 1 by area of interest and intervention

Accuracy		n	Duration (seconds) Branches/Corners	Tips	Nodes	Question	Total duration
Correct	None	8	2.36	2.63	2.32	5.87	13.18
	Implicit	12	3.44	3.61	2.68	7.10	16.82
	Video	12	4.79	3.52	3.10	8.16	19.58
	Model	33	3.28	3.76	1.89	8.33	17.26
	Extensive	13	2.62	2.77	0.50	6.27	12.17
	Total	78	16.49	16.28	10.49	35.74	79.01
Incorrect	None	27	3.38	3.39	1.52	7.05	15.33
	Implicit	49	4.30	2.52	2.10	6.00	14.92
	Video	29	3.45	4.33	2.61	5.92	16.31
	Model	20	4.22	2.08	2.45	6.59	15.35
	Extensive	9	5.06	4.40	2.54	6.03	18.03
	Total	134	20.42	16.72	11.21	31.59	79.94

Visual interactions with eye tracking task 2.

Only 18 of the 212 participants completed this task correctly. Zero participants from the no instruction or implicit intervention completed the correctly. Participants that completed the task incorrectly looked at the grouped features of branches/corners, nodes, and tips more times than those participants that completed the task correctly. However, participants that completed the task correctly spent more time looking at tips than participants that answered incorrectly (Table 19 and Table 20).

I found a statistically significant interaction effect between task 2 accuracy and type of instructional intervention on the combined branch/corner, node, and tip grouping counts $F(3, 203) = 4.591$, $p = 0.004$; Roy's Largest Root = 0.068. However, upon performing a Scheffe's *post hoc* test due to unequal sample sizes, I did not find a significant difference between instruction method and how many times participants looked at either branches/corners, nodes, or tips.

With regards to amount of time spent on combined groups, I found a statistically significant interaction effect between task 2 accuracy and type of instructional intervention $F(3, 203) = 3.57$, $p = 0.015$; Roy's Largest Root = 0.053. However, upon performing a Scheffe's *post hoc* test due to unequal sample sizes, I did not find a significant difference between instructional method and how long participants looked at either branches/corners, nodes, or tips.

I found statistical significance in the number of times a participant visited task 2 nodes based on their instructional intervention ($p = 0.030$), and task accuracy ($p = 0.013$). The Scheffe's *post hoc* test revealed that participants in the implicit intervention (M = 4.39, SD = 1.92) looked at the question significantly ($p= 0.006$) less than participants in the extensive intervention (M = 6.82, SD = 2.65). Participants in the extensive method (M = 6.82, SD = 2.65) also looked at the question significantly ($p = 0.016$) more times than participants that experienced no instruction (M = 4.40, SD = 2.85). With regards to time, I found that participants spent a significant amount of time ($p = 0.048$) looking at the question based on instruction method ($p = 0.048$) and question accuracy ($p = < 0.001$). After performing a Scheffe's *post hoc* test, no significance was found between time spent on the question among the instructional intervention.

Table 19

Fixation counts for task 2 by area of interest and intervention

Accuracy		n	Counts				
			Branches/Corners	Tips	Nodes	Question	Total counts
Correct	None	0	0.00	0.00	0.00	0.00	0.00
	Implicit	0	0.00	0.00	0.00	0.00	0.00
	Video	3	9.67	24.33	4.67	6.00	44.67
	Model	6	6.80	19.40	4.40	9.20	39.80
	Extensive	9	7.22	12.00	1.00	7.00	27.22
	Total	18	23.69	55.73	10.07	22.20	111.69
Incorrect	None	35	4.66	10.89	2.34	4.40	22.29
	Implicit	61	4.80	8.95	1.39	4.39	19.54
	Video	38	6.18	9.76	2.39	5.05	23.39
	Model	47	8.09	10.85	2.60	4.87	26.40
	Extensive	13	8.69	14.23	2.54	6.69	32.15
	Total	194	32.42	54.68	11.27	25.41	123.78

Table 20

Fixation durations for task 2 by area of interest and intervention

Accuracy		n	Duration (seconds)				
			Branches/Corners	Tips	Nodes	Question	Total duration
Correct	None	0	0.00	0.00	0.00	0.00	0.00
	Implicit	0	0.00	0.00	0.00	0.00	0.00
	Video	3	2.71	8.57	1.18	9.84	22.31
	Model	6	2.26	7.82	2.29	12.75	25.11
	Extensive	9	2.63	4.89	0.26	7.50	15.29
	Total	18	7.60	21.28	3.73	30.09	62.70
Incorrect	None	35	1.50	4.14	0.84	4.76	11.25
	Implicit	61	1.91	3.42	0.50	4.94	10.77
	Video	38	2.06	3.46	0.97	5.17	11.66
	Model	47	2.99	3.98	0.95	5.49	13.42
	Extensive	13	3.11	5.02	1.03	6.32	15.48
	Total	194	11.57	20.03	4.28	26.69	62.57

Visual interactions with eye tracking task 3.

Most (86.3%) eye-tracking participants completed the task correctly. Regarding counts, participants that completed the task correctly looked nearly the exact same number of times at the tips as they did the branches. However, participants that completed this task incorrectly looked at the tips much more frequently than either branches or nodes, even compared to participants that got the question correct. Regarding duration, participants that answered correctly spent the most time looking at tips of both trees compared to the branches and nodes of both trees. Participants that incorrectly completed the task also followed this pattern. Participants spent the least amount of time on nodes regardless of task accuracy (Table 21 and Table 22).

I found a statistically significant interaction effect between task 3 accuracy and type of instructional method on the combined branch/corner, node, and tip grouping counts, $F(4, 202) = 2.87$, $p = 0.024$; Roy's Largest Root = 0.057. I found statistical significance in the number of time participants frequented branches ($p = 0.037$) and nodes ($p = 0.004$) based on instructional intervention. Specifically, the Scheffe's *post hoc* revealed a statistically significant difference ($p = 0.003$) in the number of visits to branches on both trees between the implicit intervention (M = 12.56, SD = 6.74) and model intervention (M = 7.45, SD = 4.10). A statistically significant difference ($p = 0.024$) also exits in branch visits between the implicit intervention (M = 12.56, SD = 6.74) and the extensive intervention (M = 6.91, SD = 5.35). Regarding visits to nodes on both trees, I found a statistically significant ($p = 0.021$) difference between the model intervention (M = 4.21, SD = 2.99) and no instruction (M = 7.80 , SD = 6.57), between ($p = 0.018$) model intervention and the implicit intervention (M = 7.34, SD = 4.39), between

($p = 0.017$) no instruction ($M = 7.80$, $SD = 6.57$) and extensive intervention ($M = 3.23$, $SD = 2.86$), and between ($p = 0.020$) extensive intervention ($M = 3.23$ $SD = 2.86$) and implicit intervention ($M = 7.34$, $SD = 4.39$).

I also found a statistically significant interaction effect between task 3 accuracy and instruction method regarding how long participants spent on branches, nodes, and tips of both trees total $F(4, 202) = 3.61$, $p = 0.007$; Roy's Largest Root = 0.071. I found statistical significance ($p = 0.037$) in the amount of time participants fixated on branches of both trees and in the amount of time participants fixated on nodes of both trees ($p = 0.009$) based on instructional method. Specifically, the Scheffe's *post hoc* test revealed that a significance ($p = 0.003$) difference in branch total fixation time on both trees lies between model interventions ($M = 2.13$, $SD = 1.18$) and implicit interventions ($M = 3.84$, $SD = 2.36$); and between ($p = 0.047$) implicit interventions ($M = 3.84$, $SD = 2.36$) and extensive interventions ($M = 2.08$, $SD = 1.76$). The Scheffe's *post hoc* also revealed a statistically significant difference ($p = 0.032$) in total time spent on nodes between both trees between the model intervention ($M = 1.22$, $SD = 0.95$) and no instruction ($M = 2.45$, $SD = 2.53$); and between ($p = 0.013$) model intervention ($M = 1.22$, $SD = 0.94$) and implicit intervention ($M = 2.38$, $SD = 1.65$).

There is no significant difference in how frequently participants visit the question based on instructional intervention $F(4) = 0.995$, $p = 0.411$ nor task accuracy $F(1) = 0.19$, $p = 0.665$. There is also no significant difference in how much time participants spent fixating on the question based on instructional intervention $F(4) = 0.66$, $p = 0.622$ nor task accuracy $F(1) = 0.002$, $p = 0.961$.

Table 21

Fixation counts for task 3 by area of interest and intervention

			Counts									
			Tree 1			Tree 2			Both Trees			
Accuracy		n	Branch	Tip	Node	Branch	Tip	Node	Branch	Tip	Node	Question
Correct	None	25	4.00	7.44	2.72	6.32	5.80	4.16	10.32	13.24	6.88	3.36
	Implicit	49	5.82	4.94	3.29	7.08	3.53	4.33	12.90	8.47	7.61	2.86
	Video	37	4.62	4.59	3.49	6.00	3.95	4.24	10.62	8.54	7.73	2.89
	Model	52	3.02	4.44	1.87	4.48	3.44	2.40	7.50	7.88	4.27	2.87
	Extensive	20	2.90	5.10	1.30	4.40	4.90	2.25	7.30	10.00	3.55	3.40
	Total	183	20.36	26.52	12.66	28.28	21.62	17.38	48.64	48.13	30.04	15.37
Incorrect	None	10	5.90	6.20	3.70	7.10	7.40	6.40	13.00	13.60	10.10	4.00
	Implicit	12	4.17	9.42	2.42	7.00	7.58	3.83	11.17	17.00	6.25	3.42
	Video	4	2.00	6.25	1.50	4.25	4.25	1.25	6.25	10.50	2.75	2.50
	Model	1	1.00	2.00	0.00	4.00	4.00	1.00	5.00	6.00	1.00	4.00
	Extensive	2	1.00	5.50	0.00	2.00	9.00	0.00	3.00	14.50	0.00	2.50
	Total	29	14.07	29.37	7.62	24.35	32.23	12.48	38.42	61.60	20.10	16.42

Table 22

Fixation durations for task 3 by area of interest and intervention

			Duration (seconds)									
			Tree 1			Tree 2			Both Trees			
Accuracy		n	Branch	Tip	Node	Branch	Tip	Node	Branch	Tip	Node	Question
Correct	None	25	1.19	2.54	0.71	1.88	1.63	1.32	3.07	4.17	2.02	3.27
	Implicit	49	1.85	1.54	0.98	2.08	1.12	1.46	3.93	2.66	2.45	2.83
	Video	37	1.50	1.45	1.08	1.85	1.30	1.34	3.34	2.76	2.42	3.11
	Model	52	0.86	1.29	0.53	1.28	1.05	0.71	2.14	2.34	1.24	3.00
	Extensive	20	0.94	1.54	0.45	1.29	1.70	0.72	2.23	3.24	1.17	3.63
	Total	183	6.35	8.37	3.74	8.38	6.80	5.56	14.72	15.17	9.30	15.83
Incorrect	None	10	2.14	1.75	1.05	2.17	2.52	2.49	4.31	4.27	3.54	3.51
	Implicit	12	1.32	2.88	0.81	2.17	2.44	1.31	3.49	5.32	2.12	3.32
	Video	4	0.58	2.09	0.44	1.25	1.83	0.32	1.83	3.92	0.76	3.31
	Model	1	0.45	0.33	0.00	0.88	1.00	0.35	1.33	1.33	0.35	1.52
	Extensive	2	0.18	1.60	0.00	0.36	2.82	0.00	0.54	4.42	0.00	3.83
	Total	29	4.67	8.65	2.30	6.84	10.61	4.46	11.51	19.26	6.76	15.48

Visual interactions with eye tracking task 4.

A majority of eye-tracking participants (56.6%) completed task 4 correctly. Regardless of how participants answered, they visited the uninformative parts of the tree more than the informative parts. This also holds true for how long they fixated on parts of the tree. Regardless of how participants responded, they spent more time on uninformative parts of the tree than on informative parts. However, participants that correctly completed the task visited the informative parts less and fixated on the informative parts of the tree less than those that incorrectly completed the task (Table 23 and Table 24).

I found a significant interaction effect between task 4 accuracy and instructional intervention $F(4, 202) = 2.09$, $p = 0.084$; Roy's Largest Root = 0.041. There were no significant differences in visitation counts between informative and uninformative parts of the tree based on task accuracy $F(1) = 0.60$, p = 0.438 or instructional intervention $F(4) = 0.42$, p = 0.795.

Regarding time spent on informative and uninformative parts of the tree, I found no significant difference between informative and uninformative parts based on task accuracy $F(1) = 1.66$, p = 0.199 or instructional intervention $F(4) = 0.75$, p = 0.558.

When participants visited the question itself, there was a significant difference in visitations based on task accuracy $F(1) = 15.33$, p < 0.001. There was also a significant difference in how long participants fixated on the question itself based on task accuracy $F(1) = 50.76$, p = 0.004.

Table 23

Fixation counts for task 4 by area of interest and intervention

Accuracy		n	Counts			
			Informative	Uninformative	Question	Total counts
Correct	None	16	13.13	16.44	3.31	32.88
	Implicit	34	15.59	20.35	4.18	40.12
	Video	24	17.79	22.42	3.33	43.54
	Model	33	14.70	22.55	4.21	41.45
	Extensive	13	14.23	19.38	2.54	36.15
	Total	120	75.43	101.14	17.57	194.14
Incorrect	None	19	22.11	29.00	4.63	55.74
	Implicit	27	14.96	22.41	4.70	42.07
	Video	17	16.59	23.65	5.18	45.41
	Model	20	13.25	18.40	4.60	36.25
	Extensive	9	14.22	18.22	6.11	38.56
	Total	92	81.13	111.68	25.22	218.03

Table 24

Fixation durations for task 4 by area of interest and intervention

Accuracy		n	Duration (seconds)			
			Informative	Uninformative	Question	Total duration
Correct	None	16	4.78	6.16	2.89	13.83
	Implicit	34	6.23	7.78	3.08	17.08
	Video	24	6.72	8.17	2.59	17.49
	Model	33	5.48	8.36	3.12	16.95
	Extensive	13	5.51	8.42	2.38	16.31
	Total	120	28.71	38.89	14.05	81.66
Incorrect	None	19	8.39	11.14	3.45	22.98
	Implicit	27	6.79	10.31	3.69	20.80
	Video	17	7.21	9.11	4.10	20.42
	Model	20	5.54	7.72	4.07	17.33
	Extensive	9	5.39	6.38	4.02	15.79
	Total	92	33.31	44.66	19.34	97.31

IV. DISCUSSION

Relationships among interventions, tree-thinking and acceptance in non-majors.

Within non-majors, there was no significant difference in changes in evolution acceptance based on instructional intervention. However, students' final level of evolution acceptance did differ significantly when comparing scores from no instruction to scores from both the video intervention and the model intervention. According to the scale for evolution acceptance scores (Rutledge & Sadler, 2007), within non-majors students, all types of instruction had final, moderate levels of acceptance. Given that the video and model interventions included active tree-thinking instruction suggests that a students' final level of evolution acceptance might be related to active approaches. Using an active learning approach, specifically the model intervention, did convey a significant increase in tree-thinking changes and learning outcomes in non-majors. These results support the claim made by Walter et al. (2013) that using an active learning approach can help students with "difficult conventions of trees" (p. 6).

It is assumed that any kind of instruction is better than no instruction, and my findings suggest that regarding tree-thinking changes, students cannot simply be exposed to trees without instruction and expect to properly read and understand trees. Non-majors that experienced the extensive intervention showed greatest improvement in understanding phylogenetic trees. However, there was no significant difference in changes between non-majors that experience no instruction and non-majors experiencing implicit instruction. This suggests that courses should incorporate more active tree-thinking approaches to increase student learning outcomes. Students in an active tree-thinking intervention used in my study (video, model, and extensive) had significantly higher learning outcomes about tree thinking in non-majors. Students using the model and experiencing extensive interventions had significantly more learning outcomes than students experiencing the video intervention. These results continue to suggest, along with the literature (Freeman, et al., 2007) that introductory biology courses should incorporate more active tree-thinking approaches to increase student tree-thinking learning outcomes.

While statistically significant, my results suggest that the relationship between tree-thinking changes and changes in evolution acceptance, and the relationship between tree learning outcomes and final evolution acceptance, is relatively weak in non-majors regardless of instruction type. Walter et al. (2013) also found significantly low correlation effects between non-majors' final level of evolution acceptance and tree-thinking learning outcomes. When performing correlations, it is possible to receive significant results when incorporating a large sample size, however my findings and the findings in Walter et al. (2013) are both significant but weak. The weak relationship between non-majors tree-thinking and evolution acceptance is further supported by regression analyses. Changes in evolution acceptance only explain 9.4% of the variance found in tree-thinking changes, and final levels of evolution acceptance only explain 11.7% of the variance in tree-thinking learning outcomes. While both of these regression analyses show significance, the results suggest that evolution acceptance does not explain tree-thinking well and that other factors might explain how non-majors think about trees. Thus, future studies should move from investigating this relationship and attempt to find other variables that might share a relationship with tree-thinking.

Relationships among interventions, tree-thinking and evolution acceptance in majors.

Biology majors experiencing the model intervention had significantly different tree-thinking changes compared to majors experiencing no instruction. In fact, students experiencing no instruction had a net loss in tree-thinking changes, and was the only intervention to do so. All other interventions had positive changes, but the changes were not significant across interventions. The lack of difference in tree-thinking changes between students experiencing no instruction (which convey a net loss) and students experiencing the extensive approach is surprising. However, I think this lack of significance is due to the sample size of biology majors experiencing the extensive intervention. Only 11 biology majors experienced the extensive intervention, so comparing learning outcomes from those 11 students to learning outcomes of the 113 students experiencing no instruction is limited. When comparing tree-thinking learning outcomes in biology majors, students that experienced the model and extensive intervention show significant increases compared to students that experienced no instruction. However, there were no significant differences between the model and extensive interventions and the implicit intervention. Again, I expected the extensive intervention students to have higher learning outcomes but the lack of significance might also be due to sample size. These results suggest that within biology majors, there’s no best type of approach that course instructors should incorporate when teaching about phylogenetic trees.

Evolution acceptance in biology majors did not significantly change across all intervention types, nor was there a significant difference in final levels of evolution acceptance in biology majors across all interventions. This lack of significance across interventions suggest that biology majors' evolution acceptance remains steady and doesn't change. It makes sense that biology majors' acceptance of evolution is not affected by instruction type, because biology majors will continue to encounter the theory of evolution if they progress through their program.

Regardless of instructional intervention, there is a significant but weak relationship between tree-thinking learning changes and change in evolution acceptance in biology majors. Tree-thinking learning outcomes also had a significant but weak correlation with final evolution acceptance in biology majors. Gibson and Hoefnagels (2015) also found a significant but weak relationship between tree-thinking learning outcomes and final level of evolution acceptance. These weak relationships are supported by regression analyses, as only 3% of the variance in tree-thinking changes is explained by changes in evolution acceptance. Only 9.9% of the variance found in tree-thinking learning outcomes is explained by final levels of evolution acceptance. These finding suggest that future studies should not focus on the relationship between tree-thinking and evolution acceptance, as the relationship is relatively weak for biology majors.

Summary of tree-thinking and acceptance in biology majors and non-majors.

I found no significant difference when comparing tree-thinking changes and tree-thinking learning outcomes between biology majors and non-majors across interventions except after implicit instruction. Biology majors had significantly higher tree-thinking learning outcomes than non-majors when exposed to an implicit instructional intervention, which suggests that instructors for biology major introductory courses could possibly employ an implicit intervention during the course. However, instructors for introductory non-majors biology courses should not employ an implicit intervention and expect learning outcomes about trees to be equal to that of biology majors.

Although phylogenetic trees represent evolution, the way a student, regardless of their major, accepts evolution does not explain how they will think about trees. There is also a significant but weak relationship between how students accept evolution and how students think about trees. My findings suggests that the way students approach thinking about hypothesized evolutionary relationships as a skill is not dependent on whether a student accepts the theory of evolution.

Comparisons of tree-thinking, acceptance, and belief across students.

Religiosity is defined as the degree of expression of religious importance in one's life (Heddy & Nadelson, 2013; Holdcroft, 2006). Total scores on the DUREL can range from 5 to 27, although there is no published description of total score meaning. I interpreted low scores as a low expression of religious importance and high scores as high expression of religious importance. In non-majors, average scores across instructional interventions were in the middle range (15.51 to 16.98), suggesting that non-majors express religious importance somewhat in their life. In biology majors, average scores across interventions were also in the middle range (14.51 – 15.84) except for biology majors experiencing an extensive intervention (21.36). When I compared religiosity in biology majors to non-majors across interventions, I did not find any significant difference.

I only collected data from biology majors experiencing the extensive intervention in Utah. All other data came from the southwestern United States, specifically Texas. Because a large majority identify as religious, and because conflicting ideas between science and religion can arise in the classroom (Meikle & Scott, 2010), I was interested in how the expression of religious importance interacted with evolution acceptance and tree-thinking knowledge. The degree of religious conviction does have a strong correlation to the way in which teachers present evolution in the classroom (Trani, 2004), and other studies investigate what factors explain evolution acceptance in pre-service teachers abroad (Deniz et al. 2008), but in the United States, evolution acceptance and religiosity share a strong negative correlation (Heddy & Nadelson, 2013).

Regardless of major and instructional method, I found that 0.2% of the variance in student tree-thinking changes is explained by religiosity, and that variance in tree-thinking learning outcomes is significantly explained at 0.6%. This suggests that other factors can explain the variance in how students interact with representations of evolution. I expected religiosity to explain more tree-thinking variance, as these representations might represent ideas that conflict with student personal beliefs. It is important to note that I am not measuring how religious students are, I am measuring the degree to which importance of religion is expressed. How students express their religious importance does not explain how students think about phylogenetic trees. This suggests that students can express religious importance highly while still interacting with diagrams of evolution, which might contradict their belief system that is highly important to them. It also suggests that there is no interference between knowledge and belief in students, as students are easily separating their ability to apply knowledge about evolutionary diagram, which might differ from the explanation in their religious practice. Future studies should continue to investigate this relationship.

Religiosity also is not a strong predictor of change in evolution acceptance, as it only explains 0.1% of the variance. With literature supporting a strong negative correlation between religiosity and evolution acceptance (Heddy & Nadelson, 2012; Heddy & Nadelson, 2013), I expected religiosity to explain changes in evolution acceptance. It seems that the degree of importance of religion in someone's life hardly explains changes in evolution acceptance. However, religiosity does explain, significantly, 19% of students' final level of evolution acceptance. These findings suggest that nearly one-fifth of a student's final level of acceptance after an introductory biology class is explained by how important religion is to them. Deniz et al. (2008) were only able to explain 10.5% of the variance found in evolution acceptance with multiple factors, so my findings suggest that religiosity might have a stronger explanation for evolution acceptance than previously thought.

Visual interactions with tree diagrams.

As students approach tree-thinking expertise, I wanted to investigate how students visually interacted with tree diagrams. These participants completed four tree-thinking tasks in front of eye tracking technology so I could measure how often they looked at areas of interest on trees (fixation counts) and how long (duration) they spent within those areas of interest. As students move through the different levels of expertise with regard to tree-thinking (Halverson et al., 2011), they should not spend a lot of time interacting with the tree diagram. Therefore, I expected students that answered the questions correctly to spend less time interacting with the diagram. Additionally, I did not expect students to employ misconceptions that are common among students (Gregory, 2008), as properly interacting with tree diagrams is a step towards tree-thinking expertise.

Students that completed task 1 correctly (36.7%) spent less time interacting with the tree than students that answered incorrectly (63.3%), but this difference was not significant. There were more fixation counts on branches and corners than on any other part of the tree, thus students spent more time there than on any other part of the tree. The same tree was provided to students in task 2 with one difference: the tips were replaced with organism names. This was the only task that provided organism names at the end of the tips. All other tasks provided letters at the tips. When tips are changed from single letters to organism names, students spent more time, regardless of completing the task correctly, on the tips. This task was the hardest for students, only 8.5% completed it correctly. Students have difficulty completing tree-thinking tasks that require them to compare lineages within the same tree, as it is a task they feel is counterintuitive (Halverson et al., 2011). The task the students were to correctly complete was to answer "Is a bird more closely related to a bird or a crocodile?" My results suggest that when asked a question regarding content knowledge, students will spend more time looking at the tips for relatedness than at the informative features (nodes). However, the difficulty of this task might also be due the nature of the question itself. The correct answer to the question is that the lizard is equally related to the bird and crocodile. But, because this choice was not in the question, it might have led students to think that the answer was either only "bird" or "crocodile".

Within task 3, 86.3% of students correctly completed the task when I asked students to compare two trees that conveyed the same relationship and to state whether or not they thought the relationship was the same. I found significant differences between the fixation counts on branches and nodes and instructional intervention, as well as the amount of time spent on those features. Again, students spent more time looking at the tips than any other feature. This question only had letters at the tips, not organisms. Students that answered correctly spent more time on this question than students that answered incorrectly. My findings suggest that students are still incorrectly interacting with these diagrams, even when comparing them, as they are spending more time at the tips than any other feature. When students compare trees with the same relationship, they still unfortunately think that the diagrams contain two different meanings, and thus have approach the problem incorrectly (Novick & Cately, 2008a). The style of diagrams students compared in my study follow the squarish-corner tree, which is the easiest for students to read (Novick & Cately, 2008b) from the many styles of tree diagrams that exist (Matuk, 2007).

Within task 4, student used synapomorphies to answer the question. I grouped all informative areas of interest together and all other parts (excluding the question) together. Regardless of task accuracy, students spent more time on uninformative parts of the tree than informative parts. This tree had four lineages, so it is possible that students spent more time on uninformative parts simply because of the number of lineages present. Halverson (2010) created a multicolor pipe cleaner activity which allows the user to clearly identify each individual lineage as it ultimately reaches the root of the tree. I expected students that experienced the model intervention to spend less time looking at the tree, but I did not find any significant difference across interventions regarding time. However, there was a significant difference between task accuracy and how many times the students referred to the question and how long they spent at the question.

Overall, the eye tracking portion of my study is exploratory, but there are still some conclusions I can draw from the data. Students approached tree-thinking with common misconceptions (Gregory, 2008). These trees were squarish-corner trees and required multiple strategies to answer the questions including comparisons and following lineages. The only other study that incorporated eye tracking technology and phylogenetic trees had a small sample size (Novick et al., 2012). It also did not solely include students in undergraduate biology courses, as they included upper-division biology students as well. Novick et al. (2012) showed that when students interacted with a diagonal tree, they eyes were heavily drawn to its diagonal backbone. Their results also suggested that students read the tree from left to right, the same direction we read text, which is not always appropriate when interacting with a phylogenetic tree.

V. IMPLICATIONS AND FUTURE DIRECTIONS

Undergraduate students struggle with tree-thinking, and this issue needs to be addressed in introductory biology courses with the proper teaching approaches. I found that students in introductory biology courses for non-majors approach tree-thinking expertise significantly when instructors employ an active tree-thinking intervention. Non-major students also had significantly higher tree-thinking learning outcomes when instructors use an active tree-thinking intervention. Compared to biology majors, non-majors had significantly lower learning outcomes when both are taught using an implicit intervention. Biology majors also had significantly higher learning gains when using certain active tree-thinking instructional interventions, specifically the use of a manipulative model, such as pipe cleaners (Halverson, 2010). However, these tree-thinking changes do not correlate strongly with changes in evolution acceptance. My study is consistent with the literature for non-majors (Walter et al., 2013) and majors (Gibson & Hoefnagels, 2015) and suggests that future investigations of this relationship will likely yield the similar results.

Not only is there a weak correlation, but evolution acceptance is not a strong predictor of tree-thinking changes nor tree-thinking learning outcomes in both majors and non-majors. Future studies should investigate other predictors that might explain the variance found in tree-thinking learning outcomes and summative knowledge.

The degree to which students express their religious importance is also not a good predictor for tree-thinking changes or learning outcomes. Just because students struggle with understanding representations of evolution does not mean that religious importance in one’s life can explain how they learn about them. The relationship between religiosity and evolution acceptance is a popular area of investigation for researchers (Heddy & Nadelson, 2012; Heddy & Nadelson, 2013) and teaching controversial topics like these can shed light into future directions of teaching evolution (Trani, 2004). My study suggests that changes in evolution acceptance and religiosity are not well explained by each other, and that future studies should investigate multiple factors that might better explain more changes in evolution acceptance.

Lastly, students are still displaying misconceptions as they interact with tree diagrams. The laundry list of misconceptions presented by Gregory (2008) captures one of the most common misconceptions that participants in my study are employing: focusing on the tips. Students spend more time at tips than any other feature, especially when the tips have organism names instead of single letters. Instructors should continue to address these misconceptions in the classroom and in laboratory exercises (if applicable) to confront their students' misconceptions. Eye-tracking technology is still a relatively new field for biology education regarding representational competence, so future studies should investigate the relationship between how students interact with these tree diagrams and the level of evolution acceptance. As students enter reading activities with preconceived perspectives (Pichert & Anderson, 1977), there is an opportunity to investigate if students are selective in the parts of phylogenetic trees they interact with based on their level of evolution acceptance.

In all, incoming college students are not competent tree-thinkers, and this issue needs to be addressed appropriately with the proper instructional interventions. Instructors can no longer work under the assumption that using some kind of instruction is better than no instruction at all, because the way instructors teach phylogenetic trees to students actually matters. My goal is to continue working with instructors to incorporate better teaching interventions and to help students build their much needed tree-thinking skills.

APPENDIX SECTION

APPENDIX A: IRB APPROVAL

TEXAS STATE UNIVERSITY
SAN MARCOS
The rising STAR of Texas

Institutional Review Board Application

Certificate of Approval

Applicant: Edward Leone

Application Number : 2016Z3809

Project Title: An investigation of relationships between student acceptance of evolution, tree-thinking, and eye movement.

Date of Approval: 03/10/16 22:10:47

Expiration Date: 03/10/17

Assistant Vice President for Research and Federal Relations

Chair, Institutional Review Board

APPENDIX B: CONSENT FORM

You are being asked to be part of a research project. We're trying to learn more about introductory biology students' level of acceptance of evolution with regards to phylogenetic tree style. If you agree to be part of this research, we will ask you to complete two questionnaires: One questionnaire will be administered at the beginning of the semester and the second questionnaire at the end of the semester. It should take about 20 minutes to finish each questionnaire. These questionnaires will be taken online via SNAP Survey, an online survey tool. The link will be provided to you by your instructor via email. This research will be conducted by Edward Austin Leone of Texas State University, aleone@txstate.edu (817-201-7865).

This study does not pose any risk to you and you may choose not to answer any question(s) for any reason.

Your instructor has the option of allowing up to 5 points maximum (0.5%) for completion of both the pre and post questionnaire. The amount of points you are compensated is up to your instructor if he/she allows compensation for your participation in this research project, not to exceed 5 points (0.5%).
Your name and age will be collected in the survey. If you choose to volunteer for an in person interview, you will need to provide an email address so we may contact you. We will keep the surveys in a secure database under password-encrypted protection at Texas State University for the duration of the study. Only my supervising professor, Dr. Kristy Daniel, and I will have access to the surveys.

I understand that I may withdraw permission to participate from the above project at any time during the project with no repercussions.
This project IRB # 2016Z3809 was approved by the Texas State IRB on 3/10/16. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Jon Lasser (512-245-3413 - lasser@txstate.edu) and to Monica Gonzales, Director, Research Integrity & Compliance (512-245-2314 – meg201@txstate.edu).

Your participation is voluntary, and refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

A summary of the findings will be provided to participants upon completion of the study, if requested. To access results of the study, contact me at aleone@txstate.edu or (817-201-7865).

PRE/POST ASSESSMENT:

NAME: ____

COURSE: _______________ PROFESSOR: ______________________________

Please indicate whether you are participating in this study by circling one bullet indicating your choice, signing and then dating the consent form.

<u>ONLY SELECT ONE OF THE FOLLOWING</u>:

- **<u>I AGREE TO PARTICIPATE</u>**: Consent is hereby given to participate in this study. I understand that my participation is voluntary and that I may withdraw at any time without consequences to me. I understand that my professor will not see any of my work in relation to this project.

  _____________________ _____________________
  Signature Date

  ____________________________ ____________________________
  Email address Student ID number

- **<u>I DECLINE TO PARTICIPATE</u>**: I choose NOT TO participate in this study. I know that my decision has no bearing upon my course grade.

APPENDIX C: BASIC EVOLUTIONARY TREE THINKING SKILLS INVENTORY (BETTSI)

Biologists represent evolutionary relationships between organisms as phylogenies or "evolutionary trees." Evolutionary relationships are similar to genealogies, but evolutionary relationships are between groups rather than individuals and also typically represent vast amounts of time. As with all graphic representations of information, users need to understand how to "read" a tree. This assessment measures your ability to read a tree and apply the information to evolutionary problems. Questions about your experience include your entire biology education back through middle and high school.

1) What previous experience do you have with phylogenies?

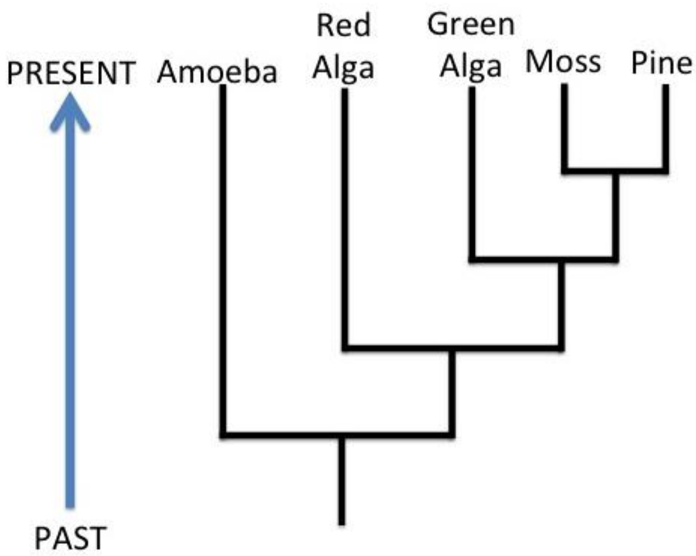
a) I have never seen a phylogeny.
b) I may have seen one or two phylogenies in a class or in my textbook.
c) I have seen several phylogenies in previous biology classes.
d) I have encountered phylogenies frequently and have used them to help understand biological examples.

2) Have you been taught how to interpret a phylogeny?

a) YES
b) NO

3) How comfortable are you with reading phylogenies?

a) Do not feel confident
b) Somewhat confident
c) Fairly confident
d) Confident
e) Dead sure of myself

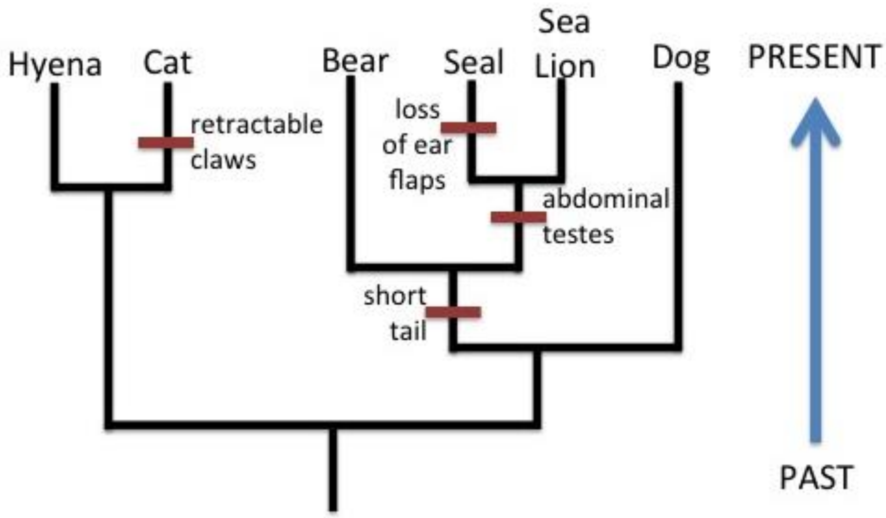


4) In reference to the tree above, which of the following is an accurate statement of relationships?

a) A green alga is more closely related to a red alga than to a moss
b) A green alga is more closely related to a moss than to a red alga
c) A green alga is equally related to a red alga and a moss
d) A green alga is related to a red alga, but is not related to a moss
e) None of these organisms are related.

5) Three students are arguing over the correct interpretation of the tree in Question 4 above**.** Which student is correct?

a) Student A insists that pine is the most highly evolved living species because it evolved most recently and is more complex than the other species.
b) Student B says the amoeba is the most highly evolved living species because it is older than the other species.
c) Student C says that no living species is more highly evolved than another because all living species have been evolving for the same amount of time from their common ancestor.
d) None of the students are correct.
e) I do not know how to interpret the tree.

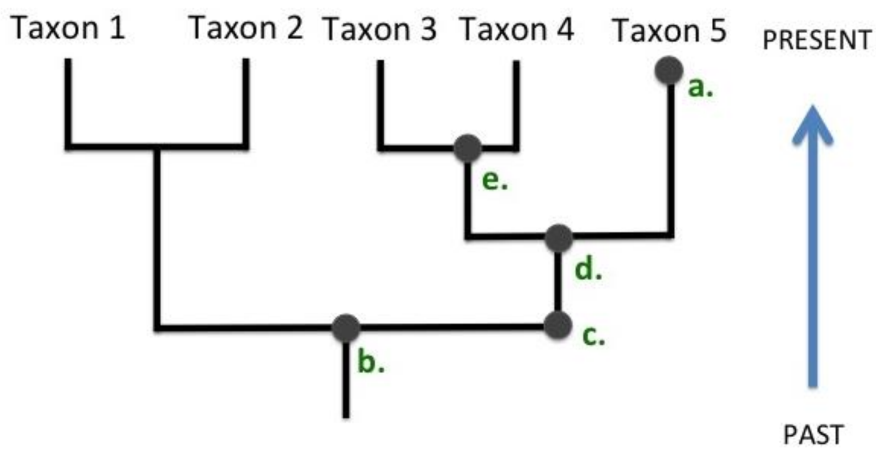


6) In the above tree, assume that the ancestor had a long tail, ear flaps, external testes, and fixed claws. Based on the tree and assuming that all evolutionary changes in these traits are shown, what traits does a sea lion have?

a) long tail, ear flaps, external testes, and fixed claws
b) short tail, no ear flaps, external testes, and fixed claws
c) short tail, no ear flaps, abdominal testes, and fixed claws
d) short tail, ear flaps, abdominal testes, and fixed claws
e) long tail, ear flaps, abdominal testes, and retractable claws

7) Looking at the tree above in Question 6, two students are discussing the evolutionary relationship between sea lions, seals and dogs. Which student do you think is correct?

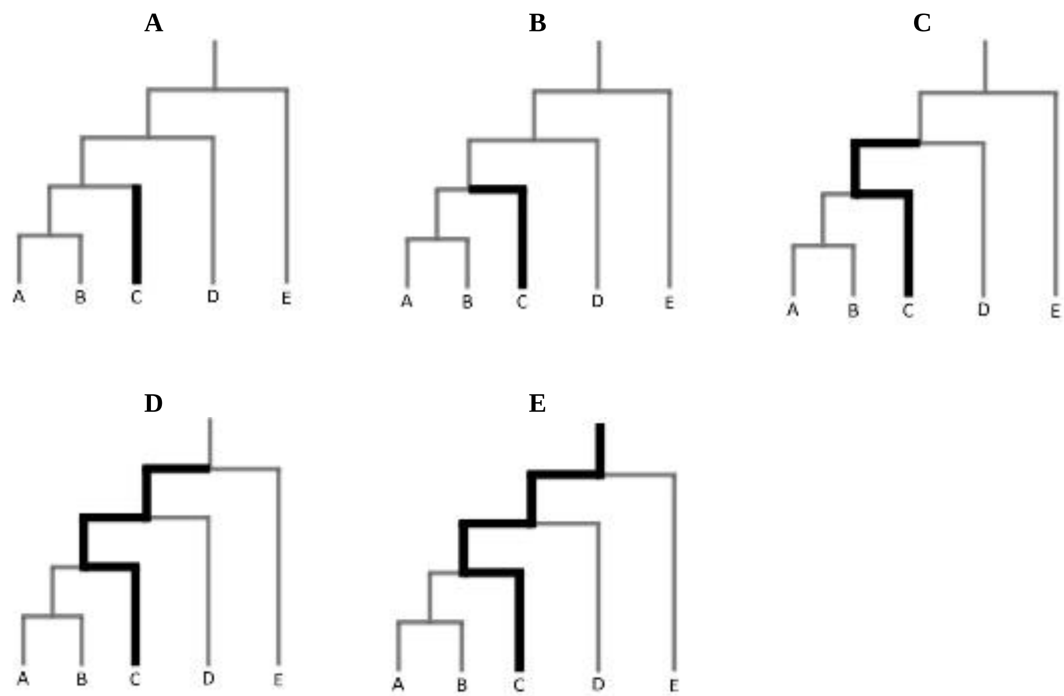
a) Student A says seals and sea lions are equally related to dogs because the lineages of seals and sea lions share the same common ancestor with dogs.
b) Student B says that sea lions are more closely related to dogs than seals are because there are fewer trait differences between sea lions and dogs, and sea lions are next to dogs in the diagram.
c) Neither student is correct.
d) I do not know how to interpret the tree.



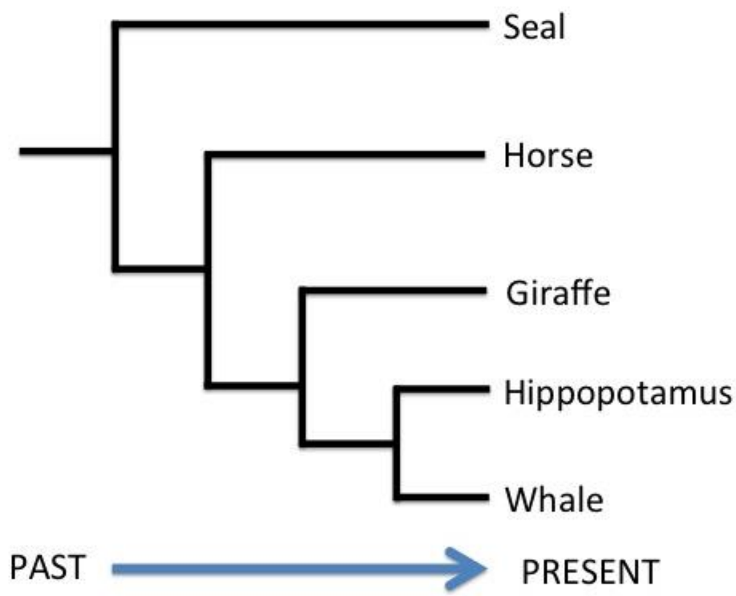
8) Which of the five marks on the tree above corresponds to the most recent common ancestor of taxon 3 and taxon 5?

a. A
b. B
c. C
d. D
e. E

9) A lineage refers to the entire evolutionary history of a species or taxon. Using this definition, which image tree below has correctly traced the Taxon C lineage, as indicated by the bolded thick black line.



10) Using the tree below, which of the following is an accurate statement?



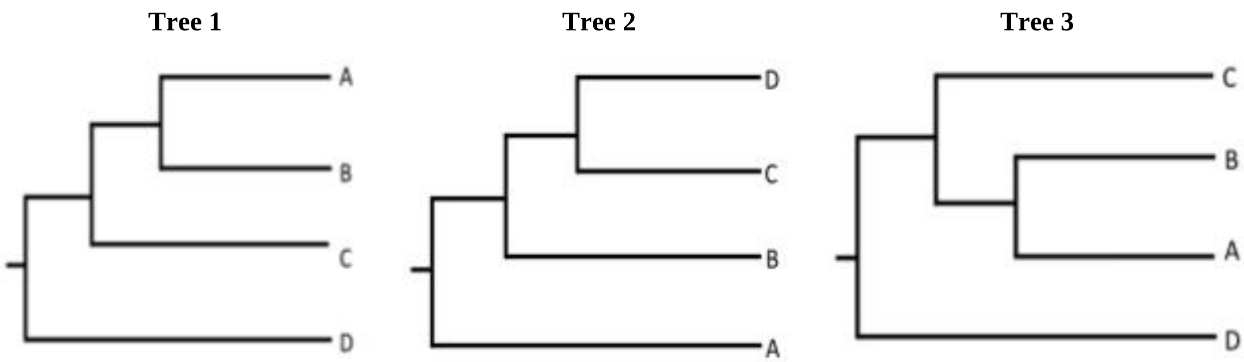
a) A seal is more closely related to a horse than to a whale
b) A seal is more closely related to a whale than to a horse
c) A seal is equally related to a horse and a whale
d) A seal is related to a whale, but is not related to a horse
e) None of these organisms are related

11) Imagine you could travel backwards through time and examine the last common ancestor of a giraffe and a hippo. What would it be?

a) A giraffe
b) A hippo
c) A horse
d) A species that cannot be classified as any of the above.
e) There is no common ancestor between a giraffe and a hippo.

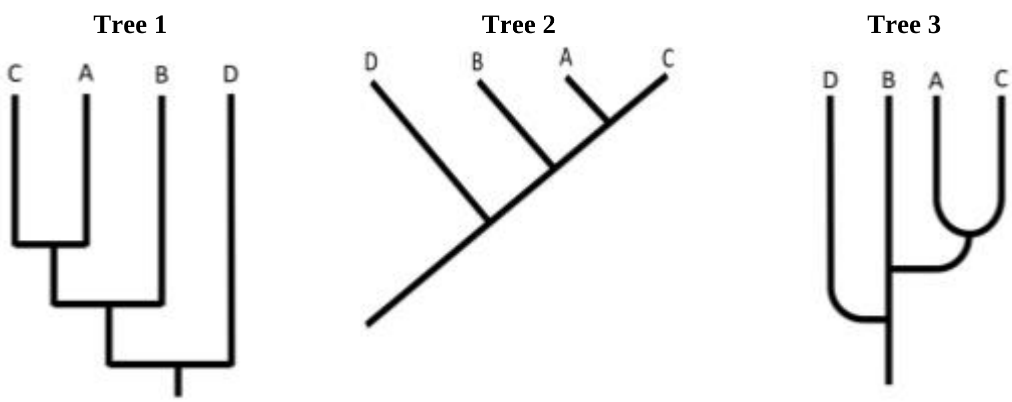
12) Which of the following trees provides different information about the evolutionary relationships among the groups?

a. Tree 1
b. Tree 2
c. Tree 3
d. They are all the same.
e. They are all different



13) Which of the following trees provides different information about the evolutionary relationships among the groups?

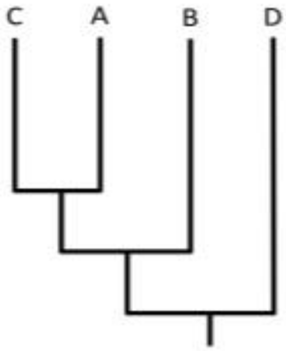
a. Tree 1
b. Tree 2
c. Tree 3
d. All trees are the same.
e. All trees are different.



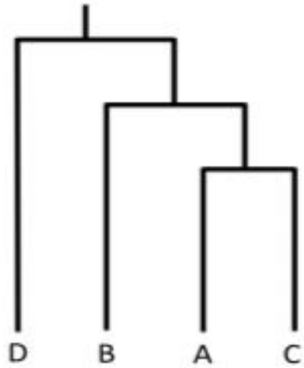
14. Which of the following trees provides different information about the evolutionary relationships among the groups?

a. Tree 1
b. Tree 2
c. Tree 3
d. They are all the same.
e. They are all different

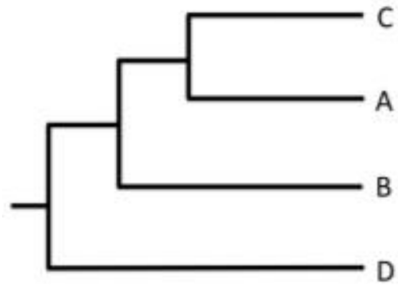
Tree 1



Tree 2



Tree 3



APPENDIX D: THE MEASURE OF ACCEPTANCE OF THE THEORY OF EVOLUTION (MATE)

For the following items, please indicate your agreement/disagreement with the given statements using the following scale.

A	B	C	D	E
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

1. Organisms existing today are the result of evolutionary processes that have occurred over millions of years.

2. The theory of evolution is incapable of being scientifically tested.

3. Modem humans are the product of evolutionary processes which have occurred over millions of years.

4. The theory of evolution is based on speculation and not valid scientific observation and testing.

5. Most scientists accept evolutionary theory to be a scientifically valid theory.

6. The available data are ambiguous as to whether evolution actually occurs.

7. The age of the earth is less than 20,000 years.

8. There is a significant body of data which supports evolutionary theory.

9. Organisms exist today in essentially the same form in which they always have.

10. Evolution is not a scientifically valid theory.

11. The age of the earth is at least 4 billion years.

12. Current evolutionary theory is the result of sound scientific research and methodology.

13. Evolutionary theory generates testable predictions with respect to the characteristics of life.

14. The theory of evolution cannot be correct since it disagrees with the Biblical account of creation.

15. Humans exist today in essentially the same form in which they always have.

16. Evolutionary theory is supported by factual, historical, and laboratory data.

17. Much of the scientific community doubts if evolution occurs.

18. The theory of evolution brings meaning to the diverse characteristics and behaviors observed in living forms.

19. With few exceptions, organisms on earth came into existence at about the same time.

20. Evolution is a scientifically valid theory.

APPENDIX E: DUKE UNIVERSITY RELIGION INDEX (DUREL)

1. How often do you attend church or other religious meetings?

A	B	C	D	E	F
Never	Once a Year or Less	A Few Times a Year	A Few Times a Month	Once a Week	More than Once a Week

2. How often do you spend time in private religious activities, such as prayer, meditation or Bible study?

A	B	C	D	E	F
Rarely or Never	A few times a month	Once a Week	Two or more times a week	Daily	More than Once a Day

The following section contains 3 statements about religious belief or experience. Please mark the extent to which each statement is true or not true for you.

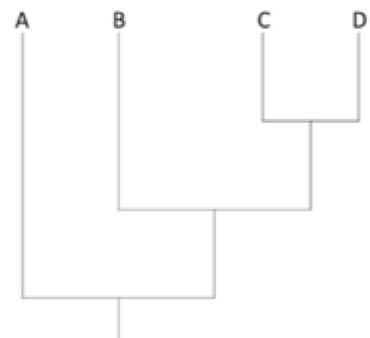
A	B	C	D	E
Definitely Not True	Tends Not to be True	Unsure	Tends to be True	Definitely True

3. In my life, I experience the presence of the Divine (i.e., God)
4. My religious beliefs are what really lie behind my whole approach to life
5. I try hard to carry my religion over into all other dealings in life

APPENDIX F: EYE MOVEMENT TASKS WITHOUT AREAS OF INTEREST

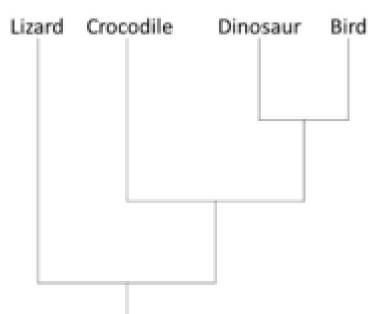
Question 1:

Is ‘B’ more closely related to ‘D’ or ‘A’?



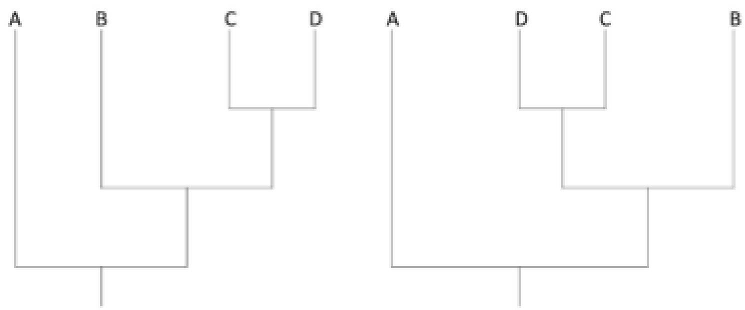
Question 2:

Is a lizard more closely related to a Bird or a Crocodile?



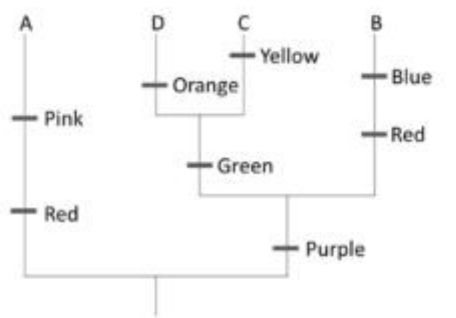
Question 3:

Do these trees show the same relationships?



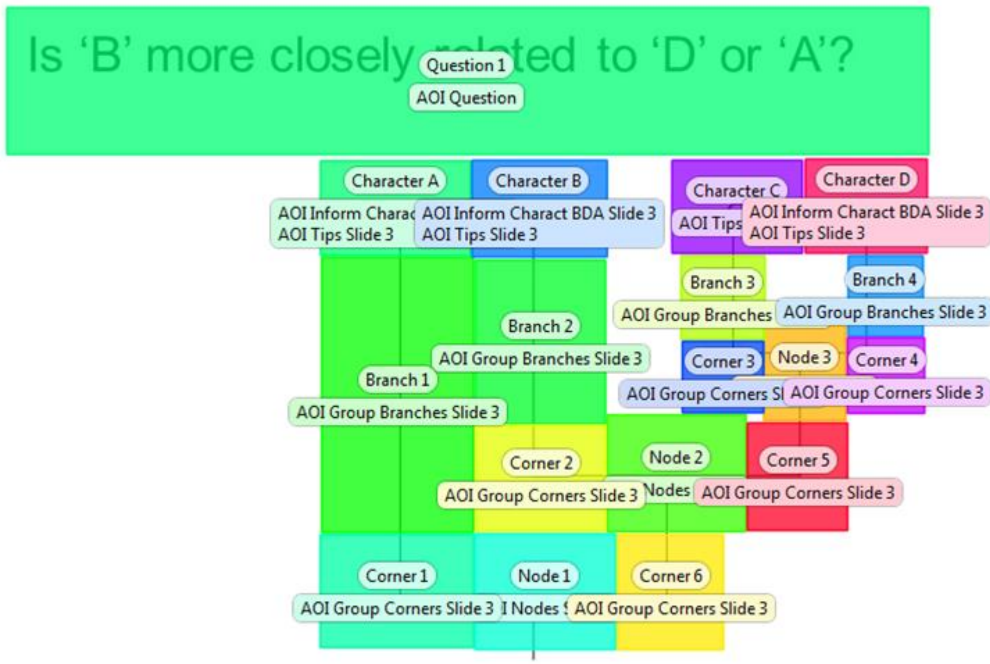
Question 4:

What colors would 'C' show?

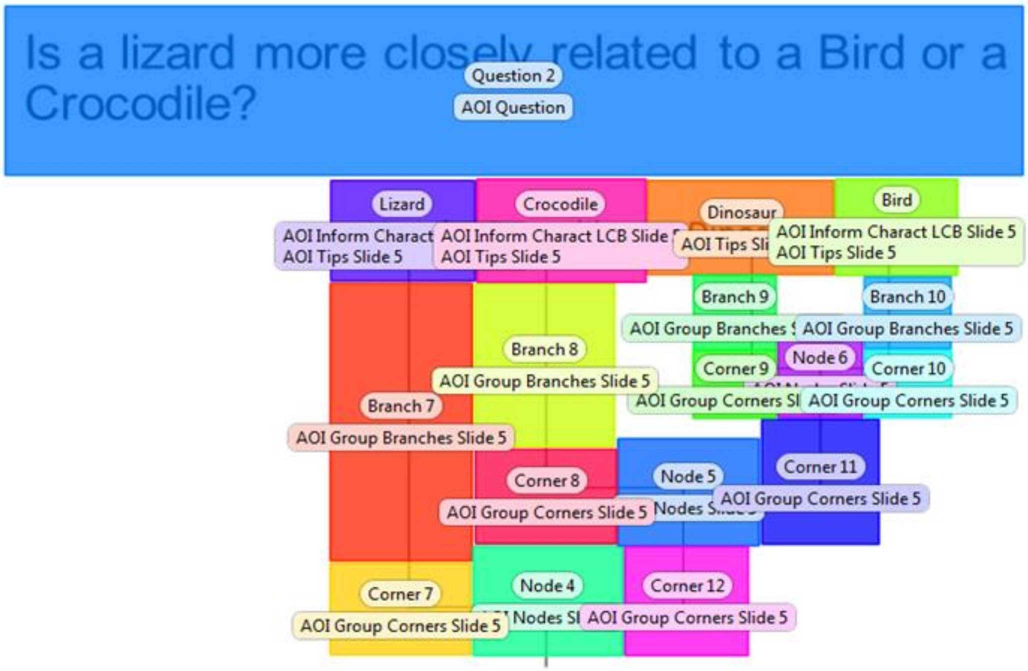


APPENDIX G: EYE MOVEMENT TASKS WITH AREAS OF INTEREST

Question 1:

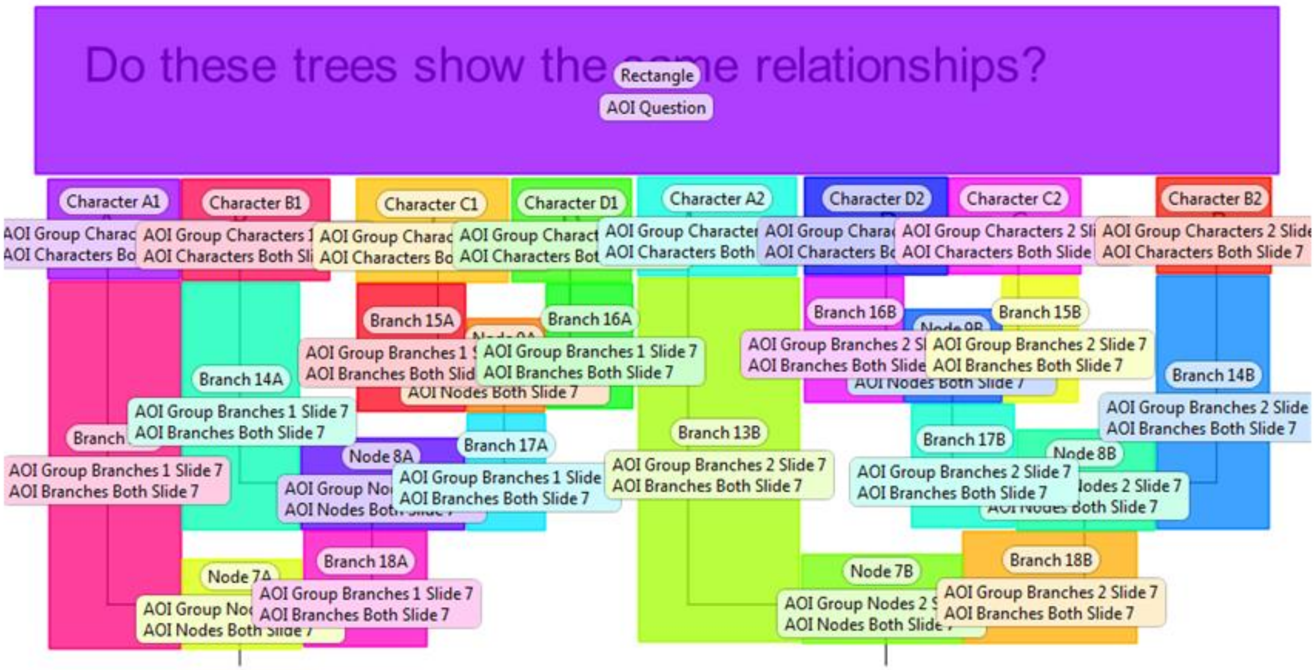


Question 2:

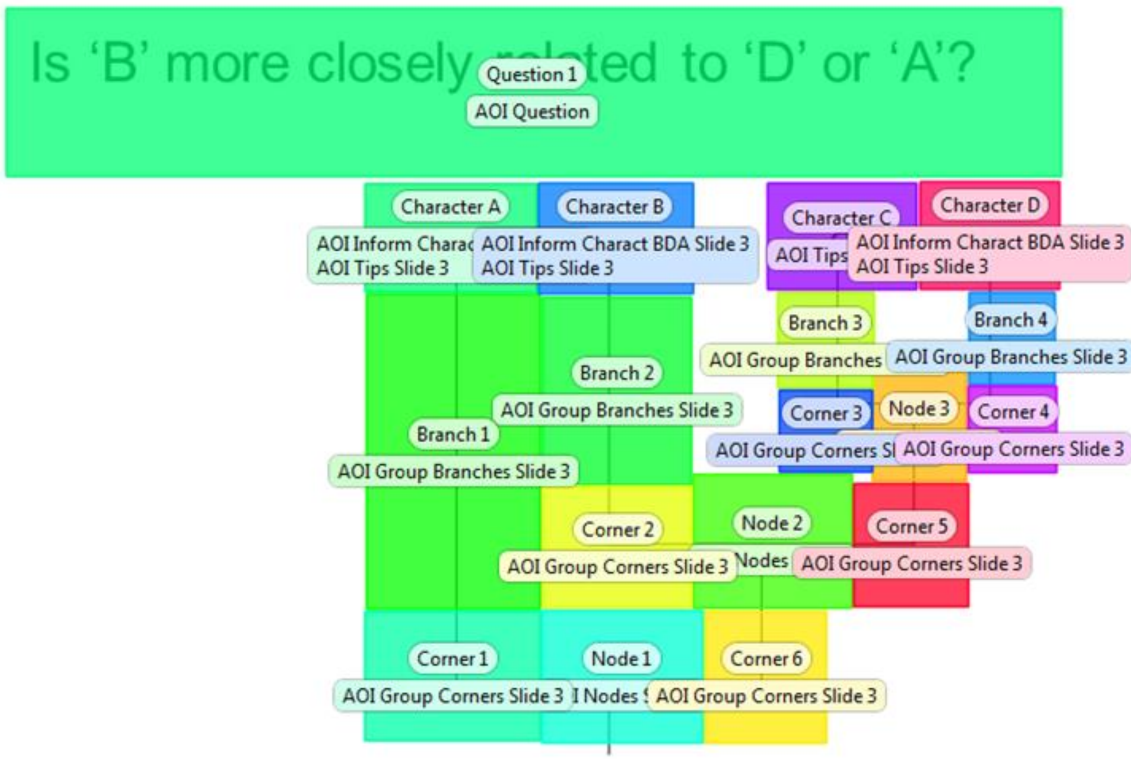


Is a lizard more closely related to a Bird or a Crocodile?
Question 2
AOI Question
Lizard
Crocodile
Dinosaur
Bird
AOI Inform Charact
AOI Tips Slide 5
AOI Inform Charact LCB Slide
AOI Tips Slide 5
AOI Tips Sli
AOI Inform Charact LCB Slide 5
AOI Tips Slide 5
Branch 9
Branch 10
AOI Group Branches
AOI Group Branches Slide 5
Branch 8
Node 6
Corner 9
Corner 10
AOI Group Branches Slide 5
AOI Group Corners Sl
AOI Group Corners Slide 5
Branch 7
AOI Group Branches Slide 5
Corner 11
Node 5
Corner 8
AOI Group Corners Slide 5
AOI Group Corners Slide 5
Nodes
Node 4
Corner 12
Corner 7
Nodes Sl
AOI Group Corners Slide 5
AOI Group Corners Slide 5

Question 3:


Do these trees show the same relationships?
Rectangle
AOI Question
Character A1
Character B1
Character C1
Character D1
Character A2
Character D2
Character C2
Character B2
Branch 15A
Branch 16A
Branch 14A
Branch 17A
Branch 18A
Node 8A
Node 7A
Branch 16B
Branch 15B
Branch 14B
Branch 13B
Branch 17B
Node 8B
Node 7B
Branch 18B
AOI Group Branches 1 Slide 7
AOI Branches Both Slide 7
AOI Group Branches 2 Slide 7
AOI Characters Both Slide 7
AOI Nodes Both Slide 7

Question 4:



Is 'B' more closely related to 'D' or 'A'?
Question 1
AOI Question
Character A
Character B
Character C
Character D
AOI Inform Charac
AOI Tips Slide 3
AOI Inform Charact BDA Slide 3
AOI Tips Slide 3
AOI Tips
AOI Inform Charact BDA Slide 3
AOI Tips Slide 3
Branch 3
Branch 4
AOI Group Branches
AOI Group Branches Slide 3
Branch 2
AOI Group Branches Slide 3
Corner 3
Node 3
Corner 4
Branch 1
AOI Group Branches Slide 3
AOI Group Corners Sl
AOI Group Corners Slide 3
Corner 2
Node 2
Corner 5
AOI Group Corners Slide 3
Nodes
AOI Group Corners Slide 3
Corner 1
Node 1
Corner 6
AOI Group Corners Slide 3
I Nodes
AOI Group Corners Slide 3

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