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# Decision Making in the Sciences: Understanding Heuristic Use by Students in Problem Solving

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# DECISION MAKING IN THE SCIENCES: UNDERSTANDING HEURISTIC USE BY STUDENTS IN PROBLEM SOLVING

by

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**ABSTRACT**

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The purpose of this study was to examine the use of heuristics by students and gain insight into the thought process behind their problem-solving skills. The study used an adaptive narrative as the information delivery medium. An adaptive narrative was chosen because it could be designed to simulate decision making processes encountered in real world situations. Students enrolled in an introductory biology major class were chosen for the study because their fields of interest all require complex problem solving and decision-making skills. It was of interest to investigate what decisions were made when heuristics were given and how that may influence their rationale in the decision-making process. The results of this study indicate that: heuristics can enable students to make correct decisions when the heuristics are based on already familiar concepts; although students self-reported low cognitive load challenges in the NASA TLX, most of the explanations were deemed poor when graded by rubrics; students had difficulty transferring information learned in the narrative and synthesizing a complete and complex explanation past three data points. This study provides evidence that greater practice in the transfer of information to novel settings is important in education in order for students to become proficient in complex decision-making.

This dissertation is dedicated to everyone who helped me along the way. The saying that "no man is an island" is never more true than in the completion of a dissertation. I could not have done it without the support and encouragement of others. Much thanks to my parents who always were there for me along the journey. Much thanks to my wife, whose love and encouragement made all the early mornings and long work nights possible. To my friends and colleagues who were my cheerleaders and sympathetic ears along the way, thank you for helping with the stress and anxiety. And while they will never understand this, a huge thanks to my dogs whose unconditional love was a wonderful comfort when I doubted myself. And finally, my awesome advisor Dr. Stefaniak, thank you for being an amazing graduate advisor and having patience with me as I worked through this dissertation!

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# CHAPTER I

## INTRODUCTION

A goal of biology education is to promote problem solving skills in students. Undergraduate students enrolled in a degree-required biology class, or one that serves as a prerequisite for a science based profession, will be required to solve ill-structured problems in authentic settings using information that they have learned. This is an important goal since common tasks in biology careers involve the making of decisions based on the diagnoses of ill-structured problems and the construction of solutions.

Studies have shown that one of the major problems in communicating scientific information to students is the use of methodology and strategies that place the material out of cognitive reach resulting in a high intrinsic cognitive load (Avraamidou & Osborne, 2009; Brownell, Price, & Steinman, 2013; Bubela et al., 2009; Dahlstrom, 2014). One technique to compensate for a lack of understanding is the rote memorization of facts. Unfortunately, memorization of individual facts isolates understanding and hampers the transfer of knowledge to novel situations (González, Palencia, Umaña, Galindo, & Villafrade M, 2008; Plomer, Jessen, Rangelov, & Meyer, 2010) thereby impairing the ability to construct solutions to authentic complex problems. Novel situations or problems are defined here as ones that have not yet been encountered.

One method used to reduce cognitive load is the use of heuristics to simplify complex decision making. Heuristics are defined as easily remembered domain specific strategies used to solve task specific problems (McClary & Talanquer, 2011). Heuristics may be based on a variety of traditions (e.g. scientific study, religion, cultural norms, family values). Studies have shown that the use of heuristics in making decisions about complex problems have similar if not better success rates than complex statistical analysis (Gigerenzer & Gaissmaier, 2011). Other benefits of heuristic use include the speed with which decisions may be made and the decrease in the intrinsic cognitive load necessary to make decisions (Gigerenzer & Gaissmaier, 2011; Hutchinson & Gigerenzer, 2005; McClary & Talanquer, 2011; Todd & Gigerenzer, 2000). These factors make heuristic use in the allied health fields very attractive since decisions concerning a patient's wellbeing often need to be made accurately and quickly.

The development of problem solving skills is important since, in real life, people are not exposed to neatly bundled packages of data waiting to be run through a statistics program. While there have been calls for shifts in biology education techniques recently (American Association for the Advancement of Science, 2011; Knight & Wood, 2005; Tanner & Allen, 2005), most classes and laboratory activities are often designed around well-structured problems. Well-structured problems are ones that have fairly prescribed sequence of events that need to be completed to achieve a single correct answer. While well-structured problems may be used to reinforce a concept described in lecture, very few real-world situations offer themselves with such clear-cut solutions.

Storytelling or narratives may be able to solve the gap in communication between scientists and non-scientists (Avraamidou & Osborne, 2009; Brownell et al., 2013; Bubela et al., 2009; Dahlstrom, 2014; Fischhoff & Scheufele, 2014; Herman, 2007; Hopfer, 2012; Illes et al., 2010; Kerski, 2015; Kreuter et al., 2007) and bridge the gap between well-structured and ill-structured problems (Jonassen & Hernandez-Serrano, 2002). More specifically, because much of the science that is being communicated has very little resemblance to everyday experiences and the information is often communicated in a way that is foreign or devoid of superfluous descriptive detail, the non-scientist has a difficult time constructing the necessary mental models or schemata to incorporate the information. Therefore, information is either misunderstood or dismissed leading to poor decision-making skills.

For the development of good problem solving skills, it is important that students are given the opportunity to explore complex situations and learn from their experiences. By presenting students with more of a constructivist approach to scientific information, storytelling may help students understand that science is not a clear linear progression toward a goal but rather an endeavor fraught with mistakes and dead ends. It may inspire students to persevere in courses that they find difficult if they knew that success depended on an iterative approach and that overcoming challenges was simply part of science (Jonassen & Hernandez-Serrano, 2002). Additionally, stories in the form of adaptive narratives, allow a level of complexity and realism by allowing for different scenarios that are influenced by decisions made within the narrative. Most studies using adaptive narratives focus on their use in progressing a story line (e.g. writing adaptive scenarios for video games). Their use as a tool to assess and assist learning has largely been uninvestigated.

Therefore, in order to create better instruction to improve problem solving skills, it is important to understand instructional strategies that will help with knowledge transfer and development of problem solving skills (Avraamidou & Osborne, 2009; Jonassen & Hernandez-Serrano, 2002; van Merriënboer, 2013). To improve instructional strategies that promote the use of scientific facts, it is important to explore techniques that aid in decision making when confronted with a high intrinsic load and ill-structured problems. This study will give insight into the use of heuristics by students when confronted with ill-structured problems. In turn, this understanding will allow for the development of better instruction. Furthermore, the study will explore the efficacy of adaptive narratives in presenting ill-structured problems and the efficacy of using adaptive narratives in assessing decision making using heuristics. Adaptive narratives are predominantly studied in the design of immersive video games but not as potential models for instruction and will therefore add to the knowledge base.

**Definition of Terms**

*Adaptive narrative:* A story that has occasional points in the story during which the reader must make a decision (Gaeta et al., 2014). The decisions will often have differing consequences.

*Authentic*: Events or situations that in some way resemble those found in real life (Pender, Marcotte, Sto Domingo, & Maton, 2010). For example, an authentic problem may be one that has been adapted from an actual case study. Another example would be a problem whose setting is fictitious yet requires analysis and problem-solving skills used in real life.

*Course-based undergraduate research experience:* The teaching method that employs scientific methods to engage students in authentic and relevant research (Auchincloss et al., 2014; Ballen et al., 2017; Brownell et al., 2013).

*Heuristics:* Easily remembered, domain specific, strategies used to solve task specific problems (McClary & Talanquer, 2011).

*Ill-structured problems:* Problems having multiple goals, different possible means of arriving at an answer, or different criteria to solve them (Marra, Jonassen, Palmer, & Luft, 2014).

*Intrinsic cognitive load:* The cognitive burden placed on memory systems due to the complex nature of the information presented (Bannert, 2002; Seel, 2007).

*Research experiences for undergraduates:* Internships or apprenticeships that pair an undergraduate student with a faculty mentor for a semester or longer in a research project (Auchincloss et al., 2014).

*Storytelling and narrative*: These terms are used interchangeably to mean oral or written literature that includes an introduction, conflict, denouement, and conclusion, an overarching theme, and one or more characters (Avraamidou & Osborne, 2009).

## Literature Review

To investigate problem solving and heuristic use by undergraduate biology students and the use of adaptive narratives as an instructional design strategy, it is important to examine academic literature concerning biology instruction methods, problem solving, heuristics and decision-making, the use of storytelling in education and the use of adaptive narratives. To locate the relevant literature, the following search terms were used: ill-structured problems, problem solving, storytelling, narratives, choose your own adventure, adaptive narratives, biology education, reasoning, critical thinking, and heuristics.

### Common Methods in Biology Instruction

Some of the key goals of biology instruction are: to impart information about the biological parts of the world; to inform about the mechanisms and physiology behind biological interactions; and to promote critical thinking and evidence-based decision making (American Association for the Advancement of Science, 2011; Auchincloss et al., 2014; Ballen et al., 2017). Typically, biology instruction, at the college level, is taught via: lectures, labs, and/or undergraduate research. See Table 1 for a summary of instructional methods.

Table 1

*Summary Information About Biology Instruction Methods*

| Method | Summary | Benefits | Detriments |
|---|---|---|---|
| Lecture | Expository instructional format whereby a subject matter expert addresses a large | Instructional material may be presented to a large number of students at the same time | Not shown to be most effective means of engaging students or conveying information |

| | | | |
|---|---|---|---|
| | number of students on a topic | | or eliciting the transfer of information |
| Lab | Instructional method using hands-on well-structured activities to reinforce concepts | Students can definitively investigate scientific principles<br><br>Can be done with large numbers of students | Real-life scientific inquiry is rarely well-structured, therefore labs do not give authentic representations of the scientific method. |
| Undergraduate Research | Similar to labs, however, the activities are ill-structured aimed at reinforcing the scientific process and promoting problem solving | Have been shown to promote problem solving skills as well as persistence in the sciences in undergraduate students, women, and minorities | Limited to small numbers of students at a time. |

**Biology lecture.** Most everyone is familiar with the lecture format of teaching. The typical scenario is that of an instructor in the front of a large room filled with students conveying information by either writing on a board or presenting a PowerPoint. Students passively learn by listening to the instructor and by taking notes for later review. The persistence of this format of education is based in the belief that interactive teaching methods compromise the amount of information being delivered and require a disproportionate investment on the part of faculty with little educational return (Knight & Wood, 2005). While efficient in presenting large volumes of information, this lecture format has not proven to be the most effective means of engaging students or conveying information (Knight & Wood, 2005; Mayer et al., 2009; Tanner & Allen, 2005). One study using upper-division developmental biology students showed that learning could be increased by actually decreasing lecture time in large lecture halls (Knight & Wood, 2005). Specifically, the study examined the inclusion of group activities in the lecture and accompanying lab classes on students understanding of concepts.

In fact, in recent years there has been a move away from the focus of science education being the amount of information conveyed and a move toward the development of understanding and the application of information in authentic situations (Knight & Wood, 2005; Smith et al., 2005; Tanner & Allen, 2005). This move is due to the lack of understanding and the inability to use information that has been memorized (Knight & Wood, 2005). Again, there is a cognitive gap between knowledge and understanding and information must be understood in order for it to be applied to solve problems.

Therefore, instructors have adapted teaching methods more often used in smaller classes for use in large lecture hall classes. For example, asking students questions in a large lecture hall is awkward; however, using technology such as clickers allows the instructor to ask questions and poll the entire class for their response. This promotes a greater level of engagement as some interaction is required by students (Cotner, Fall, Wick, Walker, & Baepler, 2008; Knight & Wood, 2005; Mayer et al., 2009). In a study examining upper-division developmental biology students, clicker responses were used to promote group discussions (Knight & Wood, 2005). Specifically, if a question received ambiguous responses (i.e. no clear consensus for the correct answer) the lecture hall students were asked to work in groups to come to a conclusion (Knight & Wood, 2005). Student attitudes during the study also changed with students asking instructors more questions about topics. Interestingly, the students that gained the greatest benefits were the "A" and "B" students; the reason for this was unknown. Nevertheless, while there was evidence that the use of clickers and discussion activities promoted understanding of the material, many students perceived the activity as unhelpful. It was postulated that students held a deep belief that learning can only be achieved when the instructor is lecturing despite evidence to the contrary (Knight & Wood, 2005). In any case, there is corroborating evidence that the use of clickers in large lecture halls can improve performance on exams. In another study using college students and clicker use, the use of clickers increased exam scores by over a third of a grade point. This benefit was seen when compared to simply asking students questions in lecture or inquiring whether or not students had any questions (Mayer et al., 2009).

Stories may also be used in large lecture halls to promote engagement. For example, to reinforce the scientific method and Darwinian theories on evolution, Krupa (2014) used the case of the ivory-billed woodpecker. Using the story of an extinct bird, that has been allegedly sited in remote areas of the American South, not only engaged students but elicited an emotional response and promoted discussion (Krupa, 2014). Further uses of storytelling are examined in later sections.

**Biology labs and undergraduate research.** Often, close student-instructor interactions are relegated to laboratory or recitation sections where students learn and interact by completing well-structured lab projects. A well-structured project is defined as a classroom based activity that has a known or highly predictable outcome as well as a highly prescribed sequence of events that must be completed to solve the problem (Jonassen, 1997). An undergraduate research project is defined as an ill-structured activity. The term ill-structured does not mean bad instructional design; rather ill-structured undergraduate research projects offer instructional scaffolding and mentoring but may have many possible outcomes based on the choices made by the student (Jonassen, 1997).

Undergraduate research is seen as a way to engage students in the scientific method and promote scientific literacy (American Association for the Advancement of Science, 2011; Ballen et al., 2017). In general, undergraduate research is seen as a superior model in promoting scientific literacy since standard laboratory activities are often highly structured which does not give appropriate experience into the scientific method. By engaging in undergraduate research, students are exposed to realistic situations, analysis, methods, and decisions employed by scientists.

Undergraduate research traditionally consists of an apprenticeship with a professor in a specific lab (American Association for the Advancement of Science, 2011; Ballen et al., 2017). This opportunity allows students to participate in research, become part of the lab culture, receive mentoring, and engage with scientists at various points in their career (e.g. graduate students and post-docs). Undergraduate students who have participated in this type of research overwhelmingly report an increase in their understanding of science, the scientific method, laboratory techniques as well as other areas of research (American Association for the Advancement of Science, 2011). Indeed, these research experiences are particularly important to women and minorities who have traditionally shown lower persistence rates in the sciences than males (Barlow & Villarejo, 2004; Gregerman et al., 1998; Pender et al., 2010). A study with biology students has shown that early exposure to undergraduate research (beginning the freshman year) has increased persistence in math and sciences including persistence into graduate school (Barlow & Villarejo, 2004). To facilitate success, the undergraduate research program was supplemented with additional instruction in General Chemistry, Calculus and Introductory Biology, and advising (both personal and academic). Additionally, another program explored the importance of participation in undergraduate research beginning in the freshman and sophomore level and found positive trends between undergraduate research participation and retention (Gregerman et al., 1998). In this program, undergraduates were given tasks such as conducting literature reviews, formulating hypotheses, and conducting studies and analyses. Students met with either their faculty sponsor and/or with the laboratory group at team meetings. A third study examined the benefits of summer research opportunities by focusing on STEM Ph.D. program matriculation and found a significant positive correlation between participation in summer research and matriculation into a doctoral program (Pender et al., 2010). This study examined the overall effects of summer research opportunities on continuing on to a STEM Ph.D. program and did not discuss the individual interventions that students received.

While this individualized laboratory research experience increases scientific awareness in students, it is limited in the number of students that may be reached. In recognition of the benefits of undergraduate research, another model has been developed. Course-based undergraduate research experience expands the exposure to research to an entire class of students. course-based undergraduate research experiences are defined as having 5 distinct characteristics: they use scientific practices; the problems are ill-structured with multiple possible outcomes requiring students to analyze information and make decisions; the work must be broadly relevant or important; the work must be collaborative and done in groups; and the work is iterative (Auchincloss et al., 2014).

While the first two traits are self-evident, others require greater description. The stipulation that the work must be broadly relevant or important is significant. This tenant requires that the work being completed by students somehow contributes to a broader knowledge base and does not simply repeat well-documented phenomenon. This prevents projects from becoming scripted. Collaboration and teamwork is also important since modern scientific experiments are often the result of work done by multiple groups or labs (Smith et al., 2005). Working with others is an important skill to learn early on. Finally, the iterative nature is also important because it instills good practice in students to verify their work as well as the work of others (Auchincloss et al., 2014).

The benefit of course-based undergraduate research experiences is that it exposes a larger group of students to the scientific method. This is particularly important since scientific literacy has been shown to be low in the American public (Funk et al., 2015). Course-based undergraduate research experiences also particularly benefit minorities and women who often lack the resources and/or encouragement to pursue scientific careers (Barlow & Villarejo, 2004; Gregerman et al., 1998).

While course-based undergraduate research experiences have clear benefits to learning, they are difficult to incorporate into all science classes. Often course-based undergraduate research classes are a special class that students may choose to take. Since many classes at colleges (particularly community colleges) are taught by adjuncts, redesigning entire curriculum may not be practical, especially since there is often a turnover of adjunct instructors. Additionally, students often only want to take courses that are necessary for their degree program and/or ones that will transfer to other institutions. While the skills learned in a course-based undergraduate research class will transfer, the credits may not. Therefore, a course-based undergraduate research class not be attractive to students. To promote problem solving, a more easily integrated method may be necessary.

**Problem Solving in Biology**

Problem solving is an important key-stone activity in the sciences. Individuals who enter a science profession are required to analyze data and situations and use the information to solve problems. Indeed, instilling good scientific analysis of medical conditions with the goal of solving problems and making good decisions is a goal of allied health education. Often these situations are complex and unique, requiring the individual to make decisions whose outcome, while predicted, is unknown. Before applying to an allied health program, students must complete a number of prerequisite courses in the sciences, particularly biology. Unfortunately, there has been a lack of improvement in the problem-solving skills attained by nursing students before entering the workplace (McCallum, Ness, & Price, 2011).

**Theoretical foundations of problem solving.** Problem solving and learning based in problem solving is founded in constructivist ideas about knowledge, meaning making, and learning (Cunningham & Duffy, 1996; Hung, Jonassen, & Liu, 2008; Marra et al., 2014). In the constructivist view, knowledge varies from individual to individual and is based on the interactions between individuals and between individuals and the environment. Through these interactions, new experiences are gathered and incorporated into existing schemata. Therefore, even though two individuals may experience the same event, the schema constructed around the details of the event may differ greatly. For example, individuals with relatively little experience concerning a problem tend to make slow, error prone decisions while individuals with comparatively greater experience make quick, automatic and error free decisions (Sarsfield, 2014). Not surprisingly, greater interaction with problems, allows individuals to incorporate their experiences into the necessary schema to make better decisions.

Following from this, because individuals perceive things differently, exposure to the insight of others can shape the knowledge that is constructed. In other words, after discussion, the views of an individual may change about a certain event. For example, an individual may dislike practicing a certain medical procedure and believes it to be flawed. After discussion with colleagues, information is exchanged and new insight into the medical procedure is gained.

There may be a revelation on how to perform the medical procedure more effectively thereby improving its perceived value.

Another key factor is the emphasis on context. One of constructivism's goals is to maximize the transfer of information acquired to novel settings and argues that skills acquired in a natural setting will have more meaning and transferability than information presented in traditional expository formats (Marra et al., 2014). The use of narratives is one way to achieve this goal since they may be based in actual events; represent realistic scenarios; make the material relevant to the learner; offer insight into events, actions, situations, and solutions; offer the opportunity for reflection by the reader; and connect inexperienced learners to experiences in a safe setting (Jonassen & Hernandez-Serrano, 2002).

**Problem solving strategies.** Problem-based learning is an educational method in which individuals learn material by solving problems based in realistic situations. This is in contrast to traditional views on education that promote the exposure to the material first, followed by examples and problems to solve. Problem-based learning reverses the order and promotes learning of the material while solving the problem. However, since students are learning information for the first time, it is important to have the proper scaffolding designed into the instruction. Scaffolds aide and direct students in their thought processes and, specifically in the case of problem-based learning, scaffolding helps direct cognitive process to solve problems. Common scaffolds include argumentation, analogical encoding, causal reasoning, and questioning (Jonassen, 2011). See Table 2 for a summary.

Table 2

*Problem Solving Strategies*

| Method | Summary |
| --- | --- |

| | |
|---|---|
| Argumentation | The constructing and refuting of arguments as well as the comparing of different views on a topic |
| Analogical encoding | Comparing and contrasting of two different situations or scenarios (i.e. analogues) |
| Causal reasoning | Examining the relationship between factors involved in a scenario or situation in order to make predictions |
| Questioning | Use of questions to guide students on discovering a solution to a problem |

Argumentation consists of constructing and refuting arguments as well as comparing different views on a topic (Jonassen & Kim, 2010; Oh & Jonassen, 2007; Tawfik & Jonassen, 2013). By constructing arguments, learners must recognize the strengths and the weaknesses of the topic in question and thereby learn multiple viewpoints about the topic. Analogical encoding involves the comparing and contrasting of two different situations or scenarios (i.e. analogues). By comparing and contrasting two analogues, the learner can determine similarities and patterns used to solve problems. Causal reasoning requires the learner to understand the relationship between the factors involved in the scenario so that predictions may be made. A prime example of causal reasoning is found in the medical field when a doctor attempts to make predictions about a treatment based on observed signs and symptoms. Questioning may also help direct learner thinking. By asking well timed and thought out questions, students may be guided in their journey and discussion to finding a solution to a problem (Jonassen & Ionas, 2008).

**Problem solving and heuristics.** The need to provide well developed scaffolds when solving problems is particularly important when dealing with inexperienced learners. Because solving a novel problem requires that the individual have some insight into the problem, it is not surprising that when an individual first encounters a type of problem, it often takes them an extended period of time to solve it. The strategy selected to solve the problem may be hardwired, based on what has been formally learned, based on social and cultural processes and norms, and determined by the conditions surrounding the problem (Gigerenzer & Gaissmaier, 2011).

Typically, the process using heuristics to solve a problem is: an individual compares the problem with similar situations experienced or recalls information from existing schema and compares the problem to prior knowledge. The more experience an individual has, the greater the complexity of the schema that is built and the easier and quicker it is to solve the problem (Jonassen, 1997). An extrapolation of this is that experts will rely more heavily on heuristics built by practical and relevant experience to make decisions; whereas, novices will rely more heavily on heuristics founded in social and cultural norms. In other words, experts will rely more on logical processes and novices will rely more on intuition or emotion to solve problems (Sarsfield, 2014).

Some have argued that the use of fewer cues when solving problems has the same if not better outcomes than when using complex algorithms to solve problems (Gigerenzer & Gaissmaier, 2011). In an inverse-U-shaped curve, the volume of information provided actually hinders decision making. This is the premise of the less-is-more heuristic.

**Heuristics and Decision Making**

There are various ways in which the term “heuristics” is defined. Mostly, this divergence resulted from the way in which heuristics are developed. For example, heuristics may be defined as mental shortcuts that reduce the cognitive load needed to solve complex problems. While useful, heuristics are not always based in logic or founded on domain specific information and their use may lead to incorrect solutions to problems (Tversky & Kahneman, 1974). For example, heuristics, to scientific professionals, may be defined as easily remembered domain specific strategies used to solve task specific problems (McClary & Talanquer, 2011). However, heuristics to students may be based on cultural or societal norms and strategies used to solve problems. Indeed, heuristics has also been defined as “cognitive processes, conscious or unconscious, that ignore part of the information” (Gigerenzer & Gaissmaier, 2011, p. 451). Nevertheless, there is evidence suggesting that not all decisions require complex algorithms in order to be correct (Gigerenzer & Gaissmaier, 2011). Therefore, the use of heuristics may be a time and effort efficient strategy to use when making decisions.

**Cognitive load and the creation of heuristics.** Cognitive load may be due to three factors: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Bannert, 2002). Intrinsic cognitive load is due to the complex nature of the material needing to be learned and the lack of assimilation by the learner of the necessary schemata; extrinsic cognitive load is due to poorly designed instructional material which reduces memory capacity; germane cognitive load is due to the processing, construction and automation of schemata.

Studies have indicated that one of the major problems with lack of scientific understanding is the use of material that is out of the cognitive reach of the non-scientist (Avraamidou & Osborne, 2009; Brownell et al., 2013; Bubela et al., 2009; Dahlstrom, 2014; Fischhoff & Scheufele, 2014; Herman, 2007; Hopfer, 2012; Illes et al., 2010; Kerski, 2015; Kreuter et al., 2007). For example, a study examined the use of narratives in cancer prevention (e.g. influence of lifestyle behaviors, importance of routine screenings) and control efforts (e.g. addressing emotional and existential concerns) found that narratives were more effective at communicating information than statistical information (Kreuter et al., 2007). In other words, because much of the science that is being communicated has very little resemblance to everyday experiences, the non-scientist has a difficult time constructing the necessary schemata to incorporate the information. Therefore, information is either misunderstood or dismissed since it does not fit existing schemata.

Furthermore, science material is often presented as a string of facts, again, with little thought to how it can be incorporated into the everyday lives of non-scientists. Therefore, due to the poorly designed mode of instruction, extrinsic cognitive load is also elevated. Finally, motivation is a key factor increasing germane cognitive load. Since science material is often presented in a way that non-scientists find non-motivating, the necessary germane cognitive load may not be reached (Avraamidou & Osborne, 2009; Brownell et al., 2013; Bubela et al., 2009; Dahlstrom, 2014; Fischhoff & Scheufele, 2014; Herman, 2007; Hopfer, 2012; Illes et al., 2010; Kerski, 2015; Kreuter et al., 2007).

Because scientific information is often out of the cognitive reach of students, in order to solve classroom problems, students do not have the existing schema necessary to solve the problem and rather, rely on mental shortcuts or heuristics to make decisions and develop answers. As mentioned earlier, heuristics may take on different forms and are not always correct; therefore, the heuristics used by students may not always be based on domain specific information or rational processes and may lead to incorrect conclusions and decisions (Tversky & Kahneman, 1974).

This may be why studies examining decision making between novices and experts define the two groups based on the speed and accuracy of their decision making. More specifically, novices are defined as individuals who make slow, error-prone decisions while problem solving (Sarsfield, 2014). Experts are defined as individuals who makes quick, automatic and error free problem solving (Sarsfield, 2014). As an extension of this, when asked to explain decisions made in solving problems, experts tend to give more detailed and specific solutions to problems, whereas novices tend to give general and superficial responses (Sarsfield, 2014).

**Storytelling in Education**

One of the oldest forms of communication known to mankind, storytelling is part of the oral tradition of passing information from generation to generation in narrative form that predates written language (Abrahamson, 1998) and has been called the fundamental unit of communication between people (Avraamidou & Osborne, 2009; Kreuter et al., 2007). The common story format follows a three-part structure: an introduction where backgrounds of the characters and setting is provided; the conflict where a situation or catalyst forces the characters to interact with one another and the setting to confront the problem; and the resolution where the problem is confronted and resolved. This format is naturally constructed to provide rich scenarios to promote problem solving and decision making. Additionally, stories have other benefits such as low cognitive load, engagement, and rich audience analysis.

**Storytelling and science communication.** As mentioned earlier, studies have shown that one of the major problems in communicating scientific information to students is the use of methodology that places the material out of cognitive reach resulting in a high intrinsic cognitive load (Avraamidou & Osborne, 2009; Brownell et al., 2013; Bubela et al., 2009; Dahlstrom, 2014). Because students have a difficult time constructing the necessary schemata to incorporate the information, information is either misunderstood or dismissed since it does not fit existing schemata (e.g. the difficulty students have understanding evolution because it does not fit into a religious world view). Although students may rely on the rote memorization of facts, this isolates understanding and hampers the transfer of knowledge to novel situations (González et al., 2008; Novak, 2002; Plomer et al., 2010). In the example of physics being taught to medical students, the medical students had a difficult time understanding the relevance of the physics lesson to biological physiology (Plomer et al., 2010). Additionally, when the same physics lesson was taught including biologically relevant information and examples, students scored better on exams, were able to transfer the information from physics to physiology relevant settings, and were more aware of the implications to medicine (Plomer et al., 2010).

Storytelling has been explored as a way to bridge the gap between facts and understanding. Many of the empirical research exploring comprehension and storytelling in the sciences has looked at the use of narratives in public health campaigns (Betsch, Ulshöfer, Renkewitz, & Betsch, 2011; Hopfer, 2012; Mazor et al., 2007). Typically, scientists communicate their findings to students and the public the same way that they communicate their findings with their peers: data and statistics. While data driven decision making may be the norm in academia and business, there is evidence that among educated individuals (i.e. non-scientists) the presentation of statistical information is found confusing (Dahlstrom, 2014). In fact, studies have shown that the use of narratives is more persuasive than the presentation of statistical facts (Betsch et al., 2011; Hopfer, 2012; Mazor et al., 2007), and narratives may counteract the information given in statistical form (Betsch et al., 2011). More specifically, when subjects were presented with information about the benefits of vaccinations and narratives about possible side effects, subjects favored the information presented in narrative form even if it contradicted statistical information (Betsch et al., 2011). Furthemore, a longitudinal study examining the use of narratives on increasing the vaccination for human papillomavirus among college women, showed that narratives nearly doubled the vaccination rate compared to control (Hopfer, 2012). Finally, similar results were found in a study examining the use of narratives in educating patients about warfarin (blood thinner) use (Mazor et al., 2007). In other words, information presented in narrative form is more compelling and believable than statistical evidence.

Unfortunately, storytelling is understudied and underutilized in higher education particularly in the sciences (Kokkotas, Rizaki, & Malamitsa, 2010; Krupa, 2014; Olson, 2015). One reason may be that storytelling is not seen as a scientifically rigorous topic or methodology to present information. For example, the aforementioned studies examining storytelling in public health campaigns use the terms "narratives" and "narration" instead of stories. Methodologies and teaching habits also tend to become embedded in disciplines. For example, it is not uncommon to hear otherwise highly educated individuals state that the way they present material is based on the tenant *this is simply how it is done* (Halpern & Hakel, 2003; Olson, 2015). The sciences may suffer from methodological inertia, resisting change. While not necessarily a weakness, one limitation in the literature is that most studies in storytelling are qualitative, and do not show a clear relationship to learning and retention. Furthermore, the studies that do try to quantify their results suffer from weak designs and very small sample sizes (Bower & Clark, 2013; Campbell & Hlusek, 2015; Kotluk & Kocakaya, 2015). Considering the inherent culture of experimental rigor in the sciences, this may be another reason for the unwillingness to adopt storytelling into the curriculum.

Storytelling has many benefits that allow listeners to effortlessly absorb information and incorporate it into their existing schemata. The use of storytelling or narratives has shown promise in public health campaigns (Betsch et al., 2011; Hopfer, 2012; Kreuter et al., 2007; Mazor et al., 2007) as well as learning language skills (Campbell & Hlusek, 2015; Hung, Hwang, & Huang, 2011; Hwang et al., 2016; Lee & Tseng, 2012; Mokhtar, Halim, & Kamarulzaman, 2011; Sadik, 2008; Tan, Lee, & Hung, 2014). For example, in a study with entry level English students in Malaysia, using stories to learn English resulted in enhanced vocabulary, comprehension, sequencing, and story recall (Mokhtar et al., 2011). While the results were mixed in a similar study with students in Egypt, students showed greater engagement and enjoyment of the lessons (Sadik, 2008). It is important to examine the benefits of storytelling in the development of schema which may then be used to develop domain specific heuristics.

**Other strengths of storytelling.** Even today, storytelling is a popular and powerful way to communicate ideas, information, and emotions as evidenced by the multitude of media using stories including books, movies, television programs, and internet channels. There are three fundamental components of stories that contribute to their popularity: resolution of conflict, high level of audience engagement, and extensive audience analysis (McDonald, 2009).

***Conflict.*** Conflict may take an overt form, as in the case of a paradoxical statement, but it may also be covert, like the internal struggle that an individual experiences when trying to relate new information to existing schemata (Olson, 2015). In the case of a story, conflict plays a pivotal role, without which, all that is being presented is a series of facts. Paradoxical stories (i.e. ones that have seemingly conflicting basis) may be used to pique individuals' curiosity and elicit deep discussion on a topic (Krupa, 2014). The goal of the discussion would be to elicit a greater understanding of the material and to help the learner incorporate the information into existing schemata.

For example, in the case of a biology lesson, the instructor may present the class with a paradoxical situation based on the information recently presented and ask for a resolution. A more specific example would be asking students to explain how cows are able to build so much muscle eating nothing but grass. This is paradoxical because the building blocks of proteins necessary for building muscle are amino acids and grass is predominantly made of sugar and fiber. Therefore, cows should not be able to build the muscle mass based on their diet (body builders eat large quantities of protein, not salads).

Students would be encouraged to work in small groups to come up with resolutions to the problem and then report back to the entire class. The merits of their solutions could then be further debated as a whole group. These debates would expose misunderstandings as well as thought processes that the instructor could then correct or encourage. Through the use of stories and discussion students may increase comprehension of the information and therefore better incorporate the information into exiting schemata. It may even give insight into how the presentation of the information is perceived by the audience. This, in turn, would allow instructors to revamp instruction to better communicate the concepts.

***Engagement.*** Engagement is positively correlated with learning and information retention (Krupa, 2014; McDonald, 2009; Olson, 2015). Additionally, emotional engagement (i.e. eliciting an emotional response) has also been shown increase retention of the information (Lencioni, 2004; McDonald, 2009; Steidl, Razik, & Anderson, 2011). Stories are intended to engage the audience as well as elicit an emotional response. Therefore, students can benefit from stories being used in courses not only to increase the above mentioned contextual comprehension of the material, but to also increase their engagement with the material and thereby increasing their learning and retention of the information (Lencioni, 2004; McDonald, 2009; Olson, 2015; Tan et al., 2014). This engagement may even promote learning outside the classroom as students are inspired to continue their understanding of a topic.

***Audience analysis.*** A fundamental principle of storytelling is to know your audience. Stories are often adapted to reflect the backgrounds, beliefs, and expectations of specific audiences. This is not unlike creating an audience analysis or developing personas in instructional design. Nevertheless, the audience analysis completed for storytelling is often more in depth than that in instructional design. Specifically, audience analysis for storytelling may exceed traditional analysis because often a goal of stories is to elicit an emotional response and therefore the audience analysis may even be described as having a level of empathy (McDonald, 2009; Parrish, 2006).

Furthermore, one of the goals of storytelling is to make the listener feel as though they are being spoken directly to and feel as though they are one of a larger group of people. In the case of instructional storytelling, if done well, the story may help the learner to better visualize the material and to envision connections between the material being presented and prior knowledge. If students feel as though they are part of the narrative, they may feel greater ownership of their knowledge and feel more comfortable experimenting with and extrapolating the information to novel areas and topics. Additionally, if the learner feels connected and invested in the material, they may be more willing to independently pursue supplemental information outside of the classroom (American Association for the Advancement of Science, 2011; Auchincloss et al., 2014; Ballen et al., 2017).

**Storytelling as an instructional strategy.** Currently, the use of storytelling in education may be divided into two overarching categories. Storytelling is either used to assess student knowledge or it is used to deliver content particularly in public health campaigns. The benefit of using storytelling to assess knowledge is that the learner is required to take the information given and put it into their own words thereby requiring the learner to engage in higher levels of learning according to Bloom’s taxonomy (i.e. creating materials versus simply understanding content). When done correctly, storytelling is a good tool to assess the transfer the knowledge

(Campbell, 2012; Hung et al., 2011; Mokhtar et al., 2011; Sarıca & Usluel, 2016). It may be used as an extension of the constructivist ideal of the individual making their own meaning of a topic.

Most of the recently published studies on storytelling in education discuss the use digital storytelling to assess knowledge with very few publications examining the use of storytelling as a means of content delivery. As described in following paragraphs, much of the use of stories in the sciences has been in public information campaigns. One notable exception is a study conducted on college students in a biology classroom (Krupa, 2014). It is a notable exception not only because it uses storytelling to deliver content, but it also is one of the few studies that examine storytelling in the sciences in higher education. Further examination into their utility as an instructional strategy is important. Because stories are relatable, they may be a useful tool for knowledge transfer particularly when explaining complex issues. Additionally, storytelling may be used a scaffold, overlaying complex scientific information onto relatable stories and thereby facilitating schema development.

The majority of empirical research exploring comprehension and storytelling in the sciences has looked at the use of narratives in public health campaigns (Betsch et al., 2011; Hopfer, 2012; Kreuter et al., 2007; Mazor et al., 2007). It is typical for scientists to communicate their findings to students and the public in the form of data and statistics. While efficient, there is evidence that among non-scientists, using statistics to communicate information is found confusing (Betsch et al., 2011; Dahlstrom, 2014; Hopfer, 2012; Mazor et al., 2007) and that information given in narrative form may counteract the information given in statistical form (Betsch et al., 2011). When information is presented in statistical versus narrative formats, individuals will preferentially trust the narrative rather than compelling statistical evidence. It is possible that narratives are seen as more truthful than statistical evidence because anecdotal information is easier to relate to on a personal level (Dahlstrom, 2010).

**Benefits of storytelling as an instructional strategy.** One may think that the use of narrative, with superfluous details and imagery would increase extrinsic load and thereby decrease learning. However counterintuitive, there is evidence to suggest that use of narrative improves memory for instructional material (Dahlstrom, 2010). While the exact mechanism for the findings is unknown, it is possible that the improvement is due to the ability of stories to evoke vivid imagery which is easier to remember than individual facts. In fact, it has been shown that individuals are able to learn new facts from stories without prior exposure via traditional means with a similar degree of success as learning through traditional lecture methods (Marsh, 2003). More specifically, the study investigated the ability of individuals to separate factual information from fiction stories (Marsh, 2003). Not only were individuals able to separate factual information from the fiction but many also incorporated the information so seamlessly into existing schemata, that they no longer recalled where they heard the information from (Marsh, 2003). This suggests that stories may be used as the primary means of delivering instruction and not simply as supplemental instructional material when teaching.

Furthermore, there is evidence that digital storytelling helps students improve their communication skills, increases their motivation as well as creates a social bond through shared experience (Campbell, 2012; de Lima et al., 2014; Hwang et al., 2016; Kilic, 2014; Mokhtar et al., 2011; Morais, 2015; Sadik, 2008). More specifically, the use of storytelling increased engagement in chemistry class in 8-10 year olds and, while not quantified, is hoped to prevent “chemophobia” or the fear of chemistry class (Morais, 2015). The influence of storytelling on engagement cannot be unequivocally known since many of these studies are qualitative and did not use control groups (Campbell, 2012; de Lima et al., 2014; Hwang et al., 2016; Kilic, 2014; Mokhtar et al., 2011; Morais, 2015; Sadik, 2008).

**Adaptive Narratives**

In 1979, Random House, Inc., released a series of books in its Choose Your Own Adventure series (Vicary & Fraley, 2007). These books, now belonging to the interactive fiction literature genre, allowed the reader to influence the story based on their choices made in response to the passages read. One benefit to researchers is that this narrative style gives insight into the value system of the reader. For example, if confronted with adversity (e.g. zombie horde) the reader may choose to either fight or flee. The decision made gives insight into the thought process and values that the reader holds (e.g. safety is a greater priority than heroism). Another benefit is that it gives insight into the thought processes of the reader. By writing a passage on a medical condition with multiple treatment options, for example, the instructor can gain insight into which of the symptoms the reader is focused on or possibly which side effect the reader finds to be an acceptable compromise. Insight into the value system and focus of readings of students is valuable in order to design and develop better instruction. Interestingly, few studies outside of literature writing and game design use these types of narratives to investigate decision making by students.

**Purpose of the Study**

Undergraduate students enrolled in a major's class, or one that serves as a prerequisite for a science based profession, will be required to solve problems using information that they have learned in new and authentic situations and settings. This is an important goal since common tasks in science careers involve the diagnoses of problems, the construction of solutions, and the making of decisions. It is important to examine the use of heuristics by students to gain greater understanding into their problem-solving skills.

Prior studies mostly focus on improvements in motivation and self-reports to support the use of storytelling in the classroom and most studies using adaptive narratives focus on their use in progressing a story line (e.g. writing adaptive scenarios for video games) (Campbell, 2012; de Lima et al., 2014; Göbel, Wendel, Ritter, & Steinmetz, 2010; Sadik, 2008; Steiner & Tomkins, 2004). The purpose of this mixed-methods study was to provide insight into the use of heuristics by students when solving ill-structured problems, to gather evidence supporting the use of storytelling in instruction, and to investigate the efficacy of adaptive narratives in assessing problem solving skills in college students. This understanding will allow for more effective instruction design in the sciences promoting learning and the transfer of information. In order to advance instruction in the sciences that promotes the transfer of knowledge to authentic situations, examining alternative instruction methods such as adaptive narratives are vital.

## Research Questions

The following research questions guided this study:

1. To what extent are students able to use information presented in a story to make decisions?
2. When heuristics are presented in an adaptive narrative, how do they affect decision making?
3. To what extent does the introduction of heuristics reduce cognitive load as measured by the NASA Task Load Index?

## Summary

To give background information on problem solving and heuristic use by undergraduate students and to provide a basis for the use of adaptive narratives as an instructional design strategy, the topics of biology instruction methods, problem solving, heuristics and decision-making, storytelling in education, and the use of adaptive narratives were explored in academic literature. The literature review showed that common instructional methods are: lectures, labs, and undergraduate research projects. While large lecture classes are the norm, studies indicate that they are not the most efficient means of engaging students or conveying information (Knight & Wood, 2005; Mayer et al., 2009; Tanner & Allen, 2005). The typical lab activity consists of well-structured problems that students must complete during the lab period. While they may be convenient from a scheduling perspective, well-structured labs do not accurately reflect real-life experiences. Conversely, undergraduate research is seen as a way to replicate the experience of working on research projects while providing the instructional scaffolding necessary to transfer knowledge and skills. Unfortunately, undergraduate research is limited in the number of students that can participate at a time. Therefore, there is a need for the development of instruction that can replicate the complex, ill-structured nature of most scientific endeavors while still reaching a large number of students at a time.

Two of the skills that are necessary to be successful in the sciences are being able to problem solve and make good decisions. Typically, the situations encountered in the sciences and health related fields are complex and unique with multiple interrelated factors. Often, the decision that are made have outcomes that may be predicted but not guaranteed, resulting in the reexamination of information and the decisions made. Again, it is important to introduce good instructional and learning strategies that promote the development of the necessary schema that underlay problem solving and decision making. Two instructional strategies that show promise are storytelling and heuristics.

Because of the universal appeal of storytelling, it may be a way to engage learners and introduce information within familiar settings. By introducing information in a way that facilitates the connection of individual facts to personal or relatable experiences, schema development may be promoted in the novice learner. Ergo, as more correct domain specific schema are developed, the individual is able to solve problems more quickly and with greater accuracy (Sarsfield, 2014). Adaptive narratives have a unique potential to develop problem solving and decision-making skills since outcomes and storylines change based on choices made by the reader.

Heuristics that reduce cognitive load and thereby facilitate problem solving and decision making would have obvious benefits. There is evidence to suggest that one of the factors limiting scientific understanding is a high intrinsic cognitive load (Brownell et al., 2013; Bubela et al., 2009; Dahlstrom, 2014; Fischhoff & Scheufele, 2014; Illes et al., 2010). Introducing novice learners to domain specific heuristics may reduce cognitive load and improve problem solving and decision-making skills.

Therefore, it is the purpose of this study to provide insight into the use of heuristics by students when solving ill-structured problems, to gather evidence supporting the use of storytelling in instruction, and to investigate the efficacy of adaptive narratives in assessing problem solving skills in college students.

# CHAPTER II

# METHODOLOGY

This chapter describes the research design, methodology, and procedures for this mixed-methods study. This chapter is organized as follows: a) research design; b) participants; c) instrumentation; d) data collection procedures; e) data analysis; f) delimitations; and h) conclusion.

## Research Design

The purpose of this study was to provide insight into the use of heuristics by students when solving ill-structured problems, to gather evidence supporting the use of storytelling in instruction, and to provide a basis for the use of adaptive narratives as an instructional design strategy. This mixed-methods study was influenced by grounded theory. Grounded theory was chosen because information gained from the study will contribute to the fields of instructional design by suggesting a framework for incorporating storytelling in biology instruction (Hays & Singh, 2011; Strauss & Corbin, 1994). The study examined the choices and responses of students in an introductory biology class to an adaptive narrative. Students were divided into an experimental group (received supplemental heuristics related to biological information within the story) and a control group (no supplemental heuristics were given).

## Participants

Four sections of introductory biology classes for biology majors from a two-year community college in the southwestern United States were asked to participate in the study (with 100 students participating in the study; see Table 3). Two of the classes were capped at an enrollment of 24 students and two classes were capped at an enrollment of 48 students. One of the 24 student sections, was taught hybrid with face-to-face labs and online lecture. The other three sections were taught face-to-face. The four sections had different instructors. All classes were of mixed gender and students ranged in age and experience. Some students had recently graduated high school while others were non-traditional students returning to school looking to change careers. Since the survey was anonymous, there was no exclusion criteria.

Of the students enrolled, 100 consented to participate in the study (52 in the control group and 48 in the experimental group). Instructors teaching the sections with 24 students randomly assigned students into one of the two groups. Instructors teaching the sections with 48 students divided students into either the control or experimental group based on lab section. Each 48-student class was evenly divided into two lab sections.

Introductory biology for majors is a gateway course for students entering biology as well as a number of applied health fields (e.g. nursing). Unfortunately, the success rate, measured as the percentage of students completing the course, is often as low as 50%. This is one of the lowest success rates for any biology course. Since this course is the first step to a number of other courses, it is important to investigate reasons behind the success and failure of students.

The demographics of community college students tend to differ from university students. Please see Table 4 for a summary of demographic information about participants from the community college's Institutional Effectiveness Office. Demographic information for the local university (Arizona State University) was not as readily available nor as descriptive. Nevertheless, of the information that could be obtained from the university's Institutional Effectiveness Office, numbers that differed were: full-time students (91.5% of university compared to only 1.3% of students at the community college); gender distribution (females accounted for 47% of the students at the university compared to 54% at the community college); Asian/Pacific Islander students (0.2% at the university compared to 7.1% at the community college); Hispanic students (22.8% at the university compared to 31.4% at the community college); and American Indian students (1.3%. at the university compared to 3.5% at the community college). In summary, the community college consists of a higher percentage of minority students and significantly fewer full-time students.

Table 3

*Summary Information About Participants*

| Groups | Age Range | Declared Majors | Number of Participants |
|---|---|---|---|
| Introduction to biology students – majors course | High school graduates to non-traditional adult learners | Nursing, General Studies, Biology, Dental Hygiene, Business, Associate of Arts, Biotechnology, Administration for Justice Studies, Undecided | 100 |

Table 4

*Community College Student Demographic Information (Summer 2018)*

| Race/ Ethnicity | Age Range | Gender | Prior Education | First Generation | Student Intent | Enrollment Intensity | Primary Time Attending |
|---|---|---|---|---|---|---|---|
| 43% White<br>31.4% Hispanic<br>7.1% Asian & Pacific Islander<br>5.8% Black<br>5.4% Not Specified<br>3.9% Two or More<br>3.5% American Indian | Under 18 – 12.8%<br>18-19 – 20.3%<br>20-24 – 33.3%<br>25-29 – 14.9%<br>30-39 – 11.2%<br>40-49 – 3.5%<br>50+ - 3.9% | Female – 54%<br>Male – 44%<br>Other and Unknown – 1.9% | No college – 31%<br>Some college, no degree – 36.9%<br>College while in HS – 4.3%<br>Associates – 4.5%<br>Bachelors – 5.6%<br>Masters or Higher 2.7%<br>Unknown – 15% | First Generation – 51%<br>Not First Generation – 44.3%<br>Unknown – 4.3% | College Transfer – 70.8%<br>Career or Job Skills – 19.6%<br>Credits while in HS – 15%<br>Meet University Requirement – 8.3%<br>Personal Interest – 6.9% | Full Time – 1.3%<br>¾ Time – 6.2%<br>Half Time – 32.1%<br>Less Than Half Time – 60.4% | Day – 70.8%<br>Evening – 22.6%<br>Non-Traditional – 6.1%<br>Unknown – 0.5% |

## Instrumentation

To explore the use of heuristics by introductory biology students an adaptive narrative was created in Google Forms. Google Forms is a cloud-based application that is accessible through a Gmail account. Numerous types of questions may be written (e.g. multiple-choice, short answer) and subsequent questions may be determined by responses. Additionally, short explanations or scenarios including pictures may be associated with each question. In this way, Google Forms was used to create an adaptive narrative that varied based on responses.

Students were given a scenario introducing the protagonist of the narrative, the setting, as well as the conflict which drove the narrative and created the problems that needed to be solved. As students progressed through the narrative they were asked to make decisions and explain certain decisions based on the information that they were given. Both the decisions and explanations were required by the Google Forms so students could not skip them or leave the answers blank. The length of the answers was not metered by Google Forms; therefore, answers could range from a few words to multiple paragraphs.

Once the final question of the adaptive narrative was answered, students were asked to give consent to have their responses used in this study. They were given the IRB form and if they agreed to consent, they continued on to complete the NASA Task Load Index (NASA TLX). If they did not consent, they were taken to the final screen where they could submit their responses.

**Adaptive narrative.** The adaptive narrative followed a three-part linear narrative structure of introduction, conflict, and resolution; was written with a specific target audience (i.e. introductory biology students); and was written to promote engagement (see Table 5). While there are many views on what constitutes a good narrative, three common components are:

conflict, audience analysis, and engagement (Bubela et al., 2009; Dahlstrom, 2014; Göbel et al., 2010; Kreps Frisch & Saunders, 2008; Tan et al., 2014).

Table 5

*Summary Information About the Adaptive Narrative Structure*

| Adaptive Narrative Element | Explanation | Example |
|---|---|---|
| Introduction | Introduces the characters and series of events that lead up to the conflict | The protagonist of “Bahb” was introduced as well as the setting in which the narrative takes place. Other minor characters were also introduced as was the conflict that she had to resolve. |
| Conflict | Problems arise and the protagonist has to learn new skills to solve the problem | “Bahb” was required to solve a series of anatomy and physiology related problems and had to gain the skills necessary to recognize certain pathologies. |
| Resolution | Problem reaches its climax and is solved | “Bahb” was confronted by a minor character and had to give an explanation for what she witnessed. |
| Audience Analysis | Examination of the background and composition of the intended reader (e.g. education level, reading level, experience level) to deliver a relevant story | The story was written using everyday vernacular. In instances where scientific information was presented the definitions were either provided or explained. Additionally, most individuals were familiar with police drama television programs and were therefore familiar with the setting of the story. |
| Engagement | The individual reading the story is invested, often emotionally, in the narrative | Visually, the narrative was punctuated by images (often humorous) making it more appealing. Pacing was optimized |

| | |
|---|---|
| | by breaking the narrative into multiple sections making each easy to read. Additionally, by giving the reader choices throughout the narrative, the reader is invested as part of the story. |

**NASA TLX.** The NASA TLX is a survey that may be taken in paper format or online. It is a subjective survey investigating the perceived workload of an assignment or task. The survey is divided into six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. The subscales are measured from 0 to 100 with 5 point increments. The following questions are asked in the survey ("TLX @ NASA Ames - NASA TLX Paper/Pencil Version," n.d.):

- How mentally demanding was the task?
- How physically demanding was the task?
- How hurried or rushed was the pace of the task?
- How successful were you in accomplishing what you were asked to do?
- How hard did you have to work to accomplish your level of performance?
- How insecure, discouraged, irritated, stressed, and annoyed were you?

Only after submitting responses was form archived in a cloud database accessible by the creator of the document and individuals with whom the document was shared.

**Adaptive Narrative Review**

Before administering the adaptive narrative to students, it was tested by three subject matter experts and two students. The subject matter experts included two faculty who have taught introductory biology classes at a community college and a practicing medical doctor. These subject matter experts were chosen because they could give feedback on level of information being presented, how the narrative would be perceived by faculty, and whether or not the information was factually correct.

The students were chosen because they had taken introductory biology within the last year and were familiar with the course and the material. They were also able to give feedback on how the narrative was perceived and make suggestions on improvements to the storyline, the progression through the narrative, and the ending.

**Data Collection Procedures**

Upon IRB approval (MCCCD IRB 2018-04-616, ODU IRB 18-083), the instructors for the four sections of introductory biology were given information about the experiment. They were asked to share the experiment with their students for the opportunity to earn credit. Two of the four instructors introduced the narrative in their lecture class and posted the link on the course LMS, while the other two instructors introduced it to their class via email. Of the two instructors who introduced the narrative in class, one gave the narrative as an outside-of-class assignment while the other made it an in-lab assignment. Of the two instructors who introduced it via email, they both made it an outside-of-class assignment.

The adaptive narrative was created online in Google Forms, and once participants logged into the site, they were given directions on how to progress through the adaptive narrative. They were asked to give as detailed explanations as possible and not to backtrack during the story. Finally, participants were instructed to take a screen shot of the submission screen and email it to their instructor as proof of completion.

Students were selected into the control or treatment group by their instructor. Methods of splitting classes varied. In two sections that had 48 students, they were divided into the control or treatment group based on the lab section that they were in. In the two sections that had 24 students, they were randomly assigned either the control or treatment group by the instructor.

The narrative was followed by the consent form. If the student consented to have their information used in the study, they were then taken to the NASA Task Load Index to complete. If consent was not given, the student was asked to submit their responses.

Within the narrative, students were given multiple passage to read. Some of the passages required that the students make a decision based on the information given. At three key decision points, students were asked to give a short explanation for their decision.

An adaptive narrative was proposed in this experiment because: by its structure, decisions need to be made; the decisions lead to consequences much like in real-life situations; it allowed multiple decisions to be made on a related scenario versus separate case studies; and the medium was engaging and hopefully promoted participation. The adaptive narrative presented information about basic biology concepts that the reader needed to analyze to make a decision. The adaptive narrative was split into the experimental group version and the control group version. The narratives were identical with the exception of two key points where the experimental group received visual heuristics in addition to information presented in narrative form. After completing the narrative (and once giving consent) students were asked six questions based on the NASA Task Force Index to assess perceived difficulty of the adaptive narrative (see Figure 1).

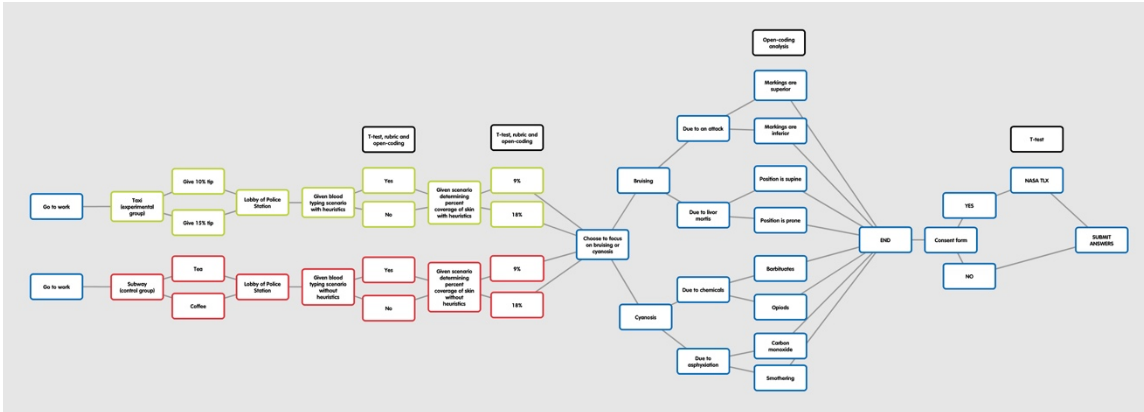


*Figure 1* – Mind map of the proposed adaptive scenario. An initial scenario including practice for low cost decisions and question determining experimental (green) versus control (red) group will be given; afterwards, a series of scenarios will require decisions to be made and explained. Blue indicates common pathway and the black boxes indicate decision points that will be analyzed.

To provide practice for the participants, the first two choices were low-cost choices, meaning that there were no adverse consequences to making them and neither choice were used in statistical analysis. The purpose was to introduce participants to the structure of the choose-your-own adventure. Afterwards, a series of scenarios were presented, each requiring a decision to be made based on the information given. Some decisions affected the progression through the remainder of the narrative (see Figure 1 or Appendix B for larger view). The three decision points that required an explanation were: blood typing, body percent, and overall explanation.

To collect the explanations for each decision, the participant had to progress through the narrative until they hit the submit option in the Google Forms (see Figure 1 or Appendix B for larger view). It was deemed more likely that the participant would backtrack if they made a decision with negative results despite instructions to the contrary. Therefore, no decision caused the narrative to come to an abrupt end. Again, the goal of the exercise was to gain insight into the heuristics used by students when solving ill-structured problems, how the heuristics are used, and decision-making processes that students use when responding to ill-structured problems. By minimizing the likelihood of backtracking and second-guessing answers and explanations, the responses are more likely to reflect the thought processes and not what students hope the right answer is.

The adaptive narrative was created using Google forms and therefore students' responses were collected using Google Forms. Google Forms collated the information into data tables and charts that were downloaded for analysis. Participants completed the adaptive narrative within the first four-weeks of the first summer session. This time in the semester was chosen because it is a fairly stable point in enrollment. More specifically, no new students were be enrolled in the course and dropouts were minimal. Students were given access to the Google Form via their instructors.

To summarize the storyline, the setting of the story was a police station in Boston, Massachusetts. The participant began the story as a temporary custodial worker who, on her first day on the job, is mistaken for a forensic scientist specially brought in on a highly secretive and ethically questionable murder investigation. It quickly becomes clear that the participant must perform an autopsy to determine the cause of death. If the individual failed to correctly identify the cause of death, they themselves will be protagonist in their own murder. The scenario interwove plot along with scientific information that the individual should have used to make decisions. See Appendix A.

The Google Forms results had no personally identifiable data. The investigator was not able to determine the identity of any participant. Responses were kept online in a secure Google Drive, and any printed material was kept in a locked cabinet in a locked office.  Access to databases generated under the project will be available for educational, research and non-profit purposes.  Such access will be provided using web-based applications, as appropriate. Digital materials generated under the project will be disseminated in accordance with University/Participating institutional and NSF policies. Depending on such policies, materials may be transferred to others under the terms of a material transfer agreement. Publication of data shall occur during the project, if appropriate, or at the end of the project, consistent with normal scientific practices. Digital research data which documents, supports and validates research findings will be made available after the main findings from the final research data set have been accepted for publication.

**Data Analysis**

This study investigated the performance of students in an adaptive narrative. More specifically, the adaptive narrative focused on biology based scenarios and required students to make decisions at different points along the storyline. The narrative progressed identically with the exception that the experimental group received information in the form of a visual or verbal heuristic in addition to an explanation. Dependent variables included the decisions that students made, the reasons given for the decisions, and the responses to the NASA TLX. Reasons given for decisions were analyzed both quantitatively and qualitatively. The purpose of the quantitative analysis was to assess the degree of correctness of the answer (i.e. will there be a difference between the control and experimental group in using the information presented to correctly explain their decisions). The purpose of the qualitative analysis was to determine how affective adaptive narratives are in assessing decision making and heuristic use.

**Quantitative analysis.** Reasons given for the blood typing and body percent decision points were examined using rubrics (see Tables 6 and 7). To increase validity, a second scorer familiar with the topics in biology was used. The second scorer was trained on the rubrics and the adaptive narrative. Scores were aligned so points would be similar between the two individuals. Scores were averaged and the rubric scores were analyzed using the independent t-test.

An independent t-test was conducted to compare the means between the experimental and control groups at the blood typing and body percent decision points as well as the responses to the NASA TLX.

Table 6

*Rubric for Blood Typing Question*

| | **0** | **1** | **2** | **3** |
|---|---|---|---|---|
| Yes | Incorrect answer and no real explanation | Incorrect answer but some mention of antigens and/or antibodies | Incorrect answer but clear mention of antigens and antibodies | Incorrect answer but extensive explanation of antigens and antibody interactions |
| No | Correct answer and no real explanation | Correct answer and some mention of antigens and/or antibodies | Correct answer but clear mention of antigens and antibodies | Correct answer but extensive explanation of antigens and antibody interactions |

Table 7

*Rubric for Body Area Estimate*

| Answer choice | **0** | **1** | **2** | **3** |
|---|---|---|---|---|
| 21% | Incorrect answer and no real explanation | Incorrect answer but some explanation | Incorrect answer but clear reason for answer | Incorrect answer but extensive explanation of answer |
| 18% | Correct answer and no real explanation | Correct answer and some explanation | Correct answer and clear correct reason for answer | Correct answer and extensive correct explanation answer |

**Qualitative analysis.** To examine the utility of the adaptive narrative, the reasons given for the decision points at blood typing, body percent, and overall analysis were analyzed via the open-coding method and codes were organized into themes using theoretical coding. The reason for this second analysis was to determine whether or not the adaptive narrative is a useful tool in gaining greater insight into the decision-making process. The open-coding method is also known as “initial coding”. As described in Saldaña (2016), open-coding is commonly used in studies based in grounded theory. The intent of open-coding is to remain open to all possible explanations that data interpretation may present (Saldaña, 2016). Theoretical coding is also known as “deductive coding” (Braun & Clarke, 2006). Theoretical coding is guided by the research hypothesis and the researcher’s past experience with the topic. The goal is the creation of a framework giving insight into the phenomenon being investigated (Braun & Clarke, 2006; Saldaña, 2016).

Data was collected and responses were analyzed after all of the data were collected. To ensure credibility, a second coder was used to create the codes and evaluate student responses. The second coder was trained in the coding process and was familiar with the biological topics covered in the adaptive narrative. An initial codebook was created as a starting point, the codes were explained to the second coder, and subsequent codes were generated by both coders. As suggested in Saldaña (2016), the lead researcher was assigned the duty of “codebook editor” responsible for the maintenance and update of the codebook.

As suggested in the use of open-coding (Saldaña, 2016), both coders were already familiar with the students’ responses since the same responses were examined via quantitative analysis of scores based on a rubric. Based on the tenant of constant comparison and in holding with the open-coding process (Saldaña, 2016), responses were analyzed based on the initial codebook and the codebook was revised based on subsequent responses. Basically, during the iterative process, the concepts and definitions in the codebook were refined. An analytic memo was also kept as documentation of the process. To ensure intercoder agreement, both coders were attentive to assigning the appropriate codes to similar responses and any discrepancies between codes were discussed until either different codes were assigned, new codes were created, or multiple codes were collapsed. Each coder ensured consistency within the codes by constantly comparing codes given to similar responses.

Codes were created based on general patterns observed in the data. At times, key phrases or terms used by the respondents were used to create the codes. In other cases, a code summarizing the response was used. Afterwards, theoretical coding methods were used to merge codes into categories based on themes (Saldaña, 2016). While the coding process was iterative, the end of the process was known when no new information could be gleaned from the responses.

In summary (see Table 8), students' decisions and responses were analyzed using the independent t-test and open and theoretical coding methods were used to gain further insight into responses with the goal of establishing a theoretical framework.

Table 8

*Data Analysis Summary*

| **Research Question** | **Data Source** | **Analysis** |
|---|---|---|
| To what extent are students able to use information presented in a story to make decisions? | Choices and responses given by students | Analysis of rubric created using independent t-test and open and deductive coding |
| To what extend does the introduction of heuristics reduce cognitive load as measured by the NASA Task Load Index? | NASA Task Load Index | Independent t-test |

| | | |
|---|---|---|
| When heuristics are presented in an adaptive narrative, how do they affect decision making? | Choices made by students at two decision points | Independent t-test |

# CHAPTER III

# RESULTS

## Decision Making Based on Information Presented in a Narrative

The rubrics for blood typing and body percent were analyzed using the independent t-test. Possible rubric scores ranged from 0 to 3. As shown in Table 9, neither the control nor the experimental group scored highly in the blood typing decision. Students given a heuristic ($M$=0.50, $SE$=0.094) were able to give detailed explanations at the same level as students who were not given a heuristic ($M$=0.33, $SE$=0.090). The difference was not significant $t(98)=-1.330$; $p=0.187$ and the effect size was small, $r=0.13$.

Conversely, in the body percent decision, students given a heuristic ($M$=1.39, $SE$=0.130) were able to give more detailed explanations than students who were not given a heuristic ($M$=0.82, $SE$=0.114). The difference was significant $t(98)=-3.297$; $p=0.001$ and the effect size was medium, $r=0.32$. Table 9 summarizes the quantitative analysis.

Table 9

*Rubric Score Statistic Summary*

| | **No Heuristic** | | **Heuristic** | | | |
|---|---|---|---|---|---|---|
| | **M** | **SE** | **M** | **SE** | ***t*-test** | ***r*** |
| Blood Typing | 0.33 | 0.090 | 0.50 | 0.094 | -1.33 | 0.13 |
| Body Percent | 0.82 | 0.114 | 1.39 | 0.130 | -3.297* | 0.32 |

***p<0.05**
**Note: M=Mean; SE=Standard error**

## Heuristics Use and Perceived Workload

On average, students given a heuristic found the adaptive narrative as mentally demanding ($M$=5.75, $SE$=0.29), as those who were not given a heuristic ($M$=5.90, $SE$=0.32). Although the average score for the control group was slightly higher than that of the experimental group, this difference was not significant $t(98)=0.349$, $p=0.728$; and the effect size was small, $r=0.04$.

Not surprisingly, the physical demand of the adaptive narrative was low in both students given a heuristic ($M=2.46$, $SE=0.32$), and those who were not given a heuristic ($M=2.15$, $SE=0.29$). Again, the value for the control group was slightly higher but the difference was not significant $t(98)=-0.709$, $p=0.480$; and the effect size was small, $r=0.07$.

Neither the group given the heuristics ($M=3.58$, $SE=0.383$), nor the control group ($M=4.23$, $SE=0.348$) felt particularly rushed in completing the task. Although the control group reported higher numbers, this difference was not significant $t(98)=1.253$, $p=0.213$; and the effect size was small, $r=0.13$.

Both the heuristic group ($M=7.15$, $SE=0.368$) and the control group ($M=7.06$, $SE=0.338$) felt fairly successful in completing the adaptive narrative with the experimental group having slightly higher values. This difference was not significant $t(98)=-0.177$, $p=0.860$; and the effect size was small, $r=0.02$.

Both the heuristic group ($M=5.67$, $SE=0.273$) and the control group ($M=5.38$, $SE=0.273$) felt that they worked equally hard to complete the adaptive narrative with the heuristic group reporting slightly higher values. This difference was not significant $t(98)=-0.728$, $p=0.468$; and the effect size was small, $r=0.07$.

Finally, both the heuristic group ($M=3.73$, $SE=0.433$) reported similar values than and the control group ($M=3.75$, $SE=0.378$) when asked about how insecure, discouraged, irritated, stressed, and annoyed they felt when completing the adaptive narrative. This difference was not significant $t(98)=-0.036$, $p=0.971$; and the effect size was small, $r=0.00$. Results are summarized in Table 10.

Table 10

*Perceived Workload Statistic Summary*

| | No Heuristic | | Heuristic | | | |
|---|---|---|---|---|---|---|
| | **M** | **SE** | **M** | **SE** | ***t*-test** | ***r*** |
| Mental demand | 5.90 | 0.320 | 5.75 | 0.290 | 0.349 | 0.04 |
| Physical demand | 2.15 | 0.290 | 2.46 | 0.320 | -0.709 | 0.07 |
| Feeling rushed | 4.23 | 0.348 | 3.58 | 0.383 | 1.253 | 0.13 |
| Feeling successful | 7.06 | 0.338 | 7.15 | 0.368 | -0.177 | 0.02 |
| Feeling worked hard | 5.38 | 0.273 | 5.67 | 0.273 | -0.728 | 0.07 |
| Insecure, discouraged etc. | 3.75 | 0.378 | 3.73 | 0.433 | -0.036 | 0.00 |

***p<0.05**
**Note: M=Mean; SE=Standard error; range for values were from 1 to 10**

**Effect of Heuristics on Decision Making**

Whether students simply made the correct or incorrect decision for blood typing and body percent were analyzed using the independent t-test. In the blood typing decision, students given a heuristic (*M*=0.50, *SE*=0.073) made the correct decision at the same rate as students who were not given a heuristic (*M*=0.42, *SE*=0.069). See Table 11 for numbers. As shown in Table 13, the difference was not significant $t(98)=-0.766$; $p=0.446$ and the effect size was small, $r=0.08$.

Table 11

*Blood Type Results Summary*

| Answer | Control Group | Experimental Group |
|---|---|---|
| No | 21 | 24 |
| Yes | 31 | 24 |

As shown in Table 13, in the body percent decision, students given a heuristic (*M*=0.96, *SE*=0.029) made the correct decision more often than as students who were not given a heuristic (*M*=0.37, *SE*=0.067). The difference was significant $t(98)=-7.846$; $p=0.000$ and the effect size was large, $r=0.62$. See Table 12 for numbers.

Table 12

*Body Percent Results Summary*

| **Answer** | **Control Group** | **Experimental Group** |
|---|---|---|
| 18% | 19 | 46 |
| 21% | 33 | 2 |

Table 13

*Effects of Heuristics on Decision Making Statistic Summary*

| | **No Heuristic** | | **Heuristic** | | | |
|---|---|---|---|---|---|---|
| | **M** | **SE** | **M** | **SE** | ***t*-test** | ***r*** |
| Blood Typing | 0.42 | 0.069 | 0.50 | 0.073 | -0.766 | 0.08 |
| Body Percent | 0.37 | 0.067 | 0.96 | 0.029 | -7.846* | 0.62 |

***p<0.05**
**Note: M=Mean; SE=Standard error**

**Qualitative Assessment of Heuristic and Information Use**

In addition to answering the question correctly, the reasoning behind the decision was also analyzed. The questions asked were: 1) Could the mystery person have donated blood to the body (when alive) in real life; and 2) What would you estimate the percent of the body that is bruised? Reasons were analyzed using an initial coding process followed by a focused methodology. Table 14 shows the codes generated and a brief explanation of each code.

Table 14

*Summary of Codes Used for Blood Typing and Body Percent Responses*

| Code | Explanation | Quotes from Blood Typing Responses | Quotes from Body Percent Responses |
|---|---|---|---|
| Detailed correct | The explanation uses information presented in the narrative and is correct. It is not a simple restatement of fact from the narrative. | Type O blood has type A antibodies and type B antibodies that would cause rejection of the B+ blood. | None |
| Limited detail correct | More than a simple statement but less information is given than a detailed correct explanation. Information given must be correct. | the body is 0-,and the two other blood are B+ which couldn't have work for a transfusion. | It would make more sense for the number to be even if it includes two surface areas that are roughly the same size. |
| Detailed incorrect | Information from the narrative is used however, it is applied incorrectly. | Because I remember B+ can be donated to O- body. O- body containing characteristic of B+blood | your back is relatively large in comparison to the whole body. If back and front are both roughly 21% then that would be 42% which is almost half your body. |
| Limited detail incorrect | More than a simple statement but less information is given than a full explanation. Information given must be incorrect. | Yes because type O blood can receive any type of blood in case they need it. | if is covering upper  and lower back with bruising ,is almost 1/2 of the body |
| Detailed heuristic | Heuristic is either used or stated in the response. Information from the narrative must also be given with specific details. | The mystery person has B + type, this means that they have a B antigen and Rh antigen. The body has 0- blood which means that they do not have Rh antigens. The diagram on the right suggests that people with Rh+ cannot give blood to people with Rh-,therefore making the two people incompatible. Furthermore, the diagram on the left suggests that the person who died | In order to calculate the extent of the burned area as accurately as possible, the use the rule called rule of 9. This rule assigns various parts of the body a percentage multiple of 9 to identify the extent of the bruise areas. The text specifies that the extent of the burn is on the upper and lower back. Thus,  the percentage following |

| | | | |
|---|---|---|---|
| | | could have donated blood to the mystery person on the right, as they also have A antigens as the person with the B+ blood would have. The mystery person could not have donated to an O- person as the arrows imply. | the rule of 3s are respectively 9% and 9%. this made a total of 18%. |
| Limited detail heuristic | Heuristic is either used or stated in the response in a manner but lacks the level of detail found in the detailed heuristic response. | No examples | Because he upper and lower back are each 9%. |
| Extrapolation explanation | The explanation is based on an extrapolation of a possibility not mentioned in the scenario | The man sounds like he is trying to cover up a murder and would like a certain type of blood to frame someone else. People donate blood all of the time and do not know where their donated blood goes to. If every donator did this scenario, there would be a lot of people fleeing the country and paying $10,000. | No examples |
| I don't know | This code is meant to be used for responses where the individual does not try to give an explanation. | things happen in mysterious ways | I don't know i don't know if you do an estimation, by adding. |
| Incoherent sentence | A sentence or statement is given however the meaning is not decipherable | Rare and Less Likely | Closer to 20% so 1/5 is possible |
| Not answering question | An explanation is given; however, it does not address the question. Rather it may discuss some other aspect of the story. | Yes to cover their tracks or to guarantee good work or to get the job done more efficiently. | There could have been a struggle. Or it was said it was the son of a politician. He could have been a wrestler, or a gymnast, or any other contact sport participant. |

| | | | |
|---|---|---|---|
| Restated | The reason given is simply a restatement of the question or facts given in the story. No new information is given nor is any given information synthesized. | O- was involved | The statement of "almost the entire upper and lower back is bruised" |
| Statement | A statement given addressing the topic that may be an incomplete sentence and not an explanation. | O- is able to donate to all blood types. | the upper and lower back make up more than 10% of the body |
| Detailed guess | Information from the adaptive narrative is given as reasoning, however, the answer is still a guess. | No examples | They indicated almost the entire upper and lower back, but did not say that it was entirely bruised, so 18% seemed like a better guess |
| Limited detail guess | Very little to no information is given and the answer is a guess | I don't know much about it but I feel that B+ dose not work with a person with O- | 18% seems like a reasonable amount |

**Blood typing.** Explanations given by students ranged from a few words (e.g. "Not possible") to several sentences. An example of a detailed response from a student follows:

> The mystery person has B + type, this means that they have a B antigen and Rh antigen. The body has 0- blood which means that they do not have Rh antigens.  The diagram on the right suggests that people with Rh+ cannot give blood to people with Rh-, therefore making the two people incompatible. Furthermore, the diagram on the left suggests that the person who died could have donated blood to the mystery person on the right, as they also have A antigens as the person with the B+ blood would have. The mystery person could not have donated to an O- person as the arrows imply.

Table 15 lists the codes that resulted from the iterative examination of the responses and the number of responses in each. From Table 15, a few differences become noticeable. While it is not surprising that the control group did not use the given heuristic in their response (0 detailed heuristic and 0 limited detail heuristic), neither did the experimental group (1 detailed heuristic and 0 limited detail heuristic).

Table 15

*Blood Type Code Summary*

| **Code** | **Control Group (n=52)** | **Experimental Group (n=48)** |
|---|---|---|
| Detailed correct | 1 | 1 |
| Limited detail correct | 4 | 7 |
| Detailed incorrect | 5 | 3 |
| Limited detail incorrect | 11 | 6 |
| Detailed heuristic | 0 | 1 |
| Limited detail heuristic | 0 | 0 |
| Extrapolation explanation | 5 | 3 |
| Detailed guess | 0 | 0 |
| Limited detail guess | 1 | 1 |
| I don't know | 2 | 3 |
| Incoherent sentence | 4 | 1 |
| Not answering question | 7 | 9 |

| | | |
|---|---|---|
| Restated | 4 | 2 |
| Statement | 8 | 11 |

**Body percent.** As indicated by the independent t-test, responses varied between the control and experimental groups. While the control group gave detailed explanations, they were incorrect or were guesses. Conversely, the experimental group overwhelmingly gave detailed correct answers while guessing very rarely.

Table 16 lists the codes that resulted from the iterative examination of the responses and the number of responses in each. As Table 16 shows, the experimental group used heuristics at a much higher frequency (21 instances of a detailed heuristic and 14 instances of a limited detail heuristic) than the control group (1 instance of both a detailed heuristic and limited detail heuristic). The control group also gave more incorrect explanations (n=15) compared to the experimental group (n=4). The range of response codes also differed between the two groups. The control group had more responses dispersed throughout the codes than the experimental group. Responses from the experimental group were predominantly in the detailed heuristic and limited detail heuristic categories.

Table 16

*Body Percent Code Summary*

| **Code** | **Control Group** | **Experimental Group** |
|---|---|---|
| Detailed correct | 0 | 0 |
| Limited detail correct | 3 | 2 |
| Detailed incorrect | 9 | 0 |
| Limited detail incorrect | 6 | 4 |
| Detailed heuristic | 1 | 21 |
| Limited detail heuristic | 1 | 14 |
| Extrapolation explanation | 0 | 0 |
| Detailed guess | 2 | 0 |
| Limited detail guess | 10 | 2 |

| | | |
|---|---|---|
| I don't know | 0 | 2 |
| Incoherent sentence | 4 | 1 |
| Not answering question | 4 | 1 |
| Restated | 4 | 1 |
| Statement | 8 | 0 |

Once the responses were examined iteratively, three themes emerged: detailed, limited detail, and non-answers. The codes were then grouped into three themes outlined in Table 17. For the blood typing response, the control and experimental groups gave similar numbers of detailed responses (11 and 8 respectively), similar numbers of limited detail responses (16 and 14 respectively), and similar numbers of non-answers (25 and 26 respectively). For the body percent response, the experimental group gave a larger number of detailed responses than the control group (21 and 12 respectively); similar number of limited detail responses (22 and 20 respectively); and fewer non-answers (5 and 20 respectively).

Table 17

*Themes for the Codes Used in Blood Typing and Body Percent Responses*

| **Detailed** | **Limited Detail** | **Non-Answers** |
|---|---|---|
| Detailed correct | Limited detail correct | I don't know |
| Detailed incorrect | Limited detail incorrect | Incoherent |
| Detailed heuristic | Limited detail heuristic | Restated |
| Detailed guess | Limited detail guess | Statement |
| Extrapolation explanation | | Not answering question |

**Overall explanation.** The generation of codes for the overall explanation followed the same process as the codes for blood typing and body percentage. A new set of codes was necessary since answers no longer represented a single decision point, but rather the synthesis of decisions and information presented throughout the narrative. As such, many explanations were awarded more than one code. Table 18 lists the codes generated, their description and an example of each.

Table 18

*Summary Codes for the Overall Explanation*

| Code | Detailed description | Example |
|---|---|---|
| 5 point synthesis | Information from 5 decision points is used | I say that the cause of the death was due to asphyxia from being intentionally suffocated to death perhaps by a pillow or other object that would leave no mark or evidence. And he was not strangled since there is not evidence of that around the neck. The bluish tint on the body is from cyanosis from inadequate oxygenation of the blood in the body. His body is bruised by 18 percent and there was a different blood type that was B positive meaning there was another person involved. The guy was the son of a very important man and someone wanted him gone or he got himself involved in somewhere that got him in trouble. He is too young to have suffered from any heart problems and you can’t rule out the bruising on his body or the other blood type found and for that a drug overdose doesn’t make sense. |
| 4 point synthesis | Information from 4 decision points is used | The deceased appears to have been a victim of strangulation due to the visible cyanosis. This is corroborated by the extensive bruising covering the man's back, possibly the result of an assault on his person preceding the strangulation. Also, the presence of blood other than his own implies that he was attacked. |
| 3 point synthesis | Information from 3 decision points is used | If there are no marks on the patient's neck then the blue tint was caused by carbon monoxide poisoning purposefully caused by someone who wanted to kill him. He became dizzy, fainted and fell onto his back which explains the bruises on his upper and lower back. |
| 2 point synthesis | Information from 2 decision points is used | There was a struggle, he died of asfixiation he was strangled. |
| 1 point synthesis | Information from 1 decision points is used | The man passed away due to trauma to over 18% of the body |
| Detailed resolution | A detailed description is given. It may include information from 5 of the decision points but is not required to. | I say that the cause of the death was due to asphyxia from being intentionally suffocated to death perhaps by a pillow or other object that would leave no mark or evidence. And he was not strangled since there is not evidence of that around the neck. The bluish tint on the body is from cyanosis from inadequate oxygenation of the blood in the body. His body is bruised by 18 percent and there was a different blood type that was B positive meaning there was another person involved. The guy was the son of a very important man and someone wanted him gone or he got himself involved in somewhere that got him in trouble. He is too young to have suffered from any heart problems and you can’t rule out the bruising on his body or the other blood type found and for that a drug overdose doesn’t make sense. |
| Creative resolution | A creative description is given. It differs from detailed in that there is | This person has a blood type of O- but the sample of blood found was identified as B so this means that there was someone else there that engaged the body, when alive, to defend themselves. I saw a lot of bruises on the back but none on the neck, which means he wasn't strangled but clearly had the chance to |

| | | |
|---|---|---|
| | an element of creativity and not just detailed information. | fight back and suffered quite a few attacks. I also saw a blueish tint on the bodies feet and ruled that to be due to asphyxiation with carbon monoxide. This is because it means the body suffered from lack of oxygen and since there are no signs of strangulation, it had to be carbon monoxide. So overall, I would say the attack was planned by someone that is trusted to protect the body from behind and so when the attack began, the body might have been pushed down and beaten to surrender. Then as the body was unconscious, the person with blood type B flipped the body over and checked if they were truly unconscious to begin setting up their getaway plan. They may have left the body on it's back to go find a way to make the death seem like a planned suicide and decided to have the body in an enclosed space with a way to have carbon monoxide released into the room and asphyxiate him. Since the body was left on it's back as he was unconscious, the attack from behind started to define themselves more and look like bruises. Then the attacker moved the body in a upright position in the enclosed room so that they may suffer from carbon monoxide poisoning. The body dies due to unconsciousness and the body not being able to alert the fight or flight response. The feet were so blue because it stop getting oxygen, the blood stops pumping through, and due to the upright position, the body started naturally decaying and having all the blood flow to the ground level. |
| Plausible | The explanation given is believable and would likely result in Barb being free to go | The man died from an attack, evidenced by the bruises obvservable on the anterior side of the body on the superior portion of the torso. The body had blood type O- however there were also samples of B+ blood type collected, a possible indication that this man had had an interaction with another person, as in he attacker, before his death. |
| Implausible | The explanation given is unbelievable and would likely result in Barb being killed | The bluish tint is due to carbon monoxide poisoning |
| Logical | The explanation could actually happen in real life | The man has died due to carbon monoxide poisoning which would explain the bluish tint on his body. It is also possible someone had forcibly held him down causing him to inhale the carbon monoxide explaining the bruises |
| Illogical | The explanation could not happen in real life or does not make sense. | I give him the person died from carbon monoxide. With the weather, he did not have enough water or oxygen. |
| Unsubstantiated statement | The explanation is entirely based on information that was not given in the narrative | That the guy was murdered by strangulation after they attempted to burn him alive |

| | | |
|---|---|---|
| Unsubstantiated component | A portion of the explanation is actually information that was not given in the narrative | The man has overdosed on barbiturates and the bluish tint and bruises come from the blood oxidizing. |
| Restatement | The explanation simply restates information given in the narrative with no synthesis | At this point I can determine that the body was found in the supine position with bruising to the upper and lower back. |
| Statement | A logical statement that does not explain anything | The victim was beaten and then strangled to death |
| Not answering question | Completely irrelevant statement | sometimes people die, it really do be like that though |

Once the responses were examined iteratively, three themes emerged: synthesis, non-answers/non-explanation, and unsound synthesis. The three themes are outlined in Table 19. There were similar numbers of responses coded for each of the themes for both the control and experimental groups.

Table 19

*Themes for the Codes Used in the Overall Explanations*

| **Synthesis (Control =78; Experimental = 69)** | **Non-Answer/Non-Explanation (Control = 17; Experimental = 19)** | **Unsound Synthesis (Control = 72; Experimental = 70)** |
|---|---|---|
| 5 point synthesis | Not answering question | Improbable |
| 4 point synthesis | Statement | Implausible |
| 3 point synthesis | Restatement | Unsubstantiated statement |
| 2 point synthesis | | Unsubstantiated component |
| 1 point synthesis | | Illogical |
| Detailed resolution | | |
| Creative resolution | | |
| Plausible | | |
| Logical | | |

Table 20 lists the codes that resulted from the iterative examination of the responses and the number of responses in each. As shown in Table 20, most of the reasons given by both the control group and the experimental group referred back to information given at 2 to 3 decision points (coded as 2 point synthesis and 3 point synthesis respectively). Very few reasons used information given at 4 or all 5 decision points (coded as 4 point synthesis and 5 point synthesis respectively). The reasons given by both groups were predominantly implausible meaning that they were not believable.

Table 20

*Overall Explanation Code Summary*

| **Code** | **Control Group (n=52)** | **Experimental Group (n=48)** |
|---|---|---|

| | | |
|---|---|---|
| 5 point synthesis | 1 | 1 |
| 4 point synthesis | 1 | 2 |
| 3 point synthesis | 15 | 9 |
| 2 point synthesis | 12 | 11 |
| 1 point synthesis | 4 | 5 |
| Non-Answer/Non-Explanation | 2 | 1 |
| Unsubstantiated statement | 2 | 5 |
| Unsubstantiated component | 4 | 2 |
| Statement | 11 | 16 |
| Restatement | 4 | 2 |
| Detailed resolution | 2 | 2 |
| Creative resolution | 7 | 7 |
| Plausible | 2 | 4 |
| Implausible | 50 | 44 |
| Logical | 34 | 28 |
| Illogical | 16 | 19 |

**Summary**

Students in an introductory biology class were given an adaptive narrative to read and were divided into an experimental group (received heuristics during the narrative) and a control group (no heuristics were provided). Independent t-tests were used to analyze the differences between the two groups and responses were examined using open and deductive coding qualitative analysis.

Results indicated that both the experimental and control groups responded similarly in both quantitative and qualitative analysis on two of the decision points (blood typing and summary) and the NASA TLX. They differed in their ability to correctly respond to the body typing question with the experimental group answering the question correctly with greater frequency.

The following section seeks to interpret these results and give: possible explanation for the findings, detail the implications, and provide examples of potential future research.

# CHAPTER IV

# DISCUSSION

The purpose of this mixed-methods study was to provide insight into the use of heuristics by students when solving ill-structured problems, to gather evidence supporting the use of storytelling in instruction, and to investigate the efficacy of adaptive narratives in assessing problem solving skills in college students. Three main decision points in the adaptive narrative were examined using quantitative and qualitative analysis: blood typing, body percent, and the overall explanation. Because explanations were given immediately after making a decision, the blood typing and body percent decision points represented the proximal use of information learned with or without a heuristic present. Since information given throughout the adaptive narrative needed to be synthesized, the overall explanation represented the transfer of information to a novel complex explanation.

## Proximal Use of Heuristics

Studies have shown multiple benefits to learners when heuristics are presented in a lesson. Some of the benefits include an increased speed with which decisions may be made and the decrease in the intrinsic cognitive load necessary to make decisions (Gigerenzer & Gaissmaier, 2011; Hutchinson & Gigerenzer, 2005; McClary & Talanquer, 2011; Todd & Gigerenzer, 2000); therefore, it was expected that the experimental group receiving heuristics would be able to make correct decisions more often and would be able to give better and more detailed explanations than the control group. The prediction was true for the body percent responses; however, it did not hold true for the blood typing responses. This difference in heuristic use may be due to the lack of necessary schema in the novice learner (D. H. Jonassen, 1997; Sarsfield, 2014).

In the body percent question, the experimental group was able to use the heuristic in clear explanations; however, the same group was not able to use the heuristic to explain their decisions in the blood typing question. The body percent heuristic shown would be familiar to most people. The image consisted of a man with portions of the body highlighted in different colors and the percent body area that the color represented correspondingly written (see Appendix A). This was a simple heuristic that could easily activate existing schema in the novice learner. Therefore, students in the experimental group were successful at answering the question correctly and even used the heuristic to explain their answers.

Conversely, while the concept of blood types may not be new to novice students, the antigens that create the different blood types and the antibodies involved in cross-type reactions would be. Information regarding antigens and antibodies would not be found in existing schema and therefore, the given heuristic was not helpful in making decisions. This finding reflects the literature about schema development in novice learners. Studies show that the better developed the schema is, the faster and more accurately an individual may make decisions (Jonassen, 1997). Much like Vygotsky's zone of proximal development, the learning aid must be given when students are ready to receive it. In this case, novice students likely would have benefitted more from scaffolding techniques that would have helped develop the appropriate schema necessary to use the heuristic (Belland, 2014; Jonassen, 1997). Since the information was presented in story form, analogical encoding could have been easily incorporated as a scaffolding technique. For example, different scenarios where blood typing was matched and mismatched could have been given to reinforce the concept (Jonassen, 1997). Another scaffolding technique that could have been introduced into the adaptive narrative is causal reasoning (Jonassen, 2011; Jonassen, 1997). Causal reasoning requires the understanding of the relationship between the factors so that predictions may be made. Since the story was presented as an adaptive narrative, one or more questions could have been presented with their appropriate consequences thereby reinforcing correct responses.

When examining the responses using qualitative analysis, it was clear that the experimental group was better able to explain their answers concerning the body percent question than when they were given the blood-typing heuristic. It may be that cognitive load for the task is already much lower since the necessary schema already existed for the body percent question. It is also possible that the explanation was simpler for the body percentage compared to the blood typing question. To show heuristic use for the body-type explanation, students could use a simple equation with a few words: “the upper back is 9% and lower is 9% in total 18%”. However, in the blood typing explanation, more complex sentences were necessary to covey the same level of correct information: “Type O blood has type A antibodies and type B antibodies that would cause rejection of the B+ blood”.

Again, this is in keeping with research that shows that when asked to explain decisions, novices gave superficial responses compared to the detailed and specific responses given by experts (Sarsfield, 2014). It is possible that students in an introductory biology class not only do not have an adequate domain knowledge but also do not have the appropriate knowledge structure to explain their answers (Xun & Land, 2004). Anecdotally, this is observed in the even when students are given the answer to the question ahead of time. It is highly likely that classroom instruction needs to focus more on scaffolding and schema development if the desired outcome is an explanation synthesizing information (Belland, 2014; Jonassen, 2011).

Some of the answers given in the responses indicated a more emotional response behind the decision than the logic driven rationale used by experts (Sarsfield, 2014). At times, responses included possibilities not given in the narrative to explain the reasoning behind decisions. The following two examples are typical of this type of response.

> *"There could be a possibility however blood banks contain thousands and thousands of blood bags, there a very small chance. O- is also the universal donor."*
>
> *"The man sounds like he is trying to cover up a murder and would like a certain type of blood to frame someone else. People donate blood all of the time and do not know where their donated blood goes to. If every donator[sic] did this scenario, there would be a lot of people fleeing the country and paying $10,000."*

Rather than use the information given in a logical manner, both students relied on fabrication to change the reality of the question. Again anecdotally, this is also seen on exams where novice students "read into" questions. This strategy is an attempt to make the question fit existing schema instead of constructing new schema to fit the information.

**Transfer of Information**

The findings suggest that novice students have difficulty transferring the information learned in the narrative into a novel setting. There were five points of information that students could have used to construct their explanation of events that occurred (see Figure 1). However, most students only incorporated two or three points of evidence and many of those neglected to include mention of blood type and body percentage. The responses indicated that even the experimental group, who was overwhelmingly able to correctly answer the body percent question, did not transfer the knowledge to the overall explanation.

As Sweller (1994) said, “If, as in some areas, interactions between many elements must be learned, then intrinsic cognitive load will be high.” It is possible that novice learners can only use up to three separate pieces of information in working memory at one time. This is in keeping with research that showed novices utilizing more linear thinking and having a less complex knowledge base than experts (Sarsfield, 2014). This is an important factor to consider when creating instruction. While the learning of individual facts is important, the goal of education is to facilitate the use of the information in real life situations. If students cannot use the information that they have learned, they are more likely to make error prone decisions which can have serious negative outcomes leading to the development of negative perceptions about their work and burnout (Hoonakker et al., 2011; King-Okoye & Arber, 2014; Sarsfield, 2014; Simmons, Lanuza, Fonteyn, Hicks, & Holm, 2003).

Expecting novices to comprehend the interactions between five separate pieces of information without introducing instructional scaffolding may not be possible. As mentioned previously, it is possible that the necessary schema was not developed and thus students were unable to use multiple factors to explain events. Since scaffolds help direct cognitive process they can help build the necessary schema to solve problems (Belland, 2014; Jonassen, 1997). Different scaffolding techniques such as analogical encoding and causal reasoning could have been used in the adaptive narrative before presenting the heuristics. Another scaffolding technique that may have worked well in the adaptive narrative is questioning (Jonassen, 2011; Jonassen & Ionas, 2008; Knight & Wood, 2005; Mayer et al., 2009; Xun & Land, 2004). By asking well thought out questions, the story may have been able to guide understanding toward the correct answer. For example, by asking multiple questions with different consequential outcomes about blood typing, students may be guided to a better understanding of cross-type reactions. Additionally, with incorrect answers, students would be able to get immediate feedback on whether or not they understand the concepts and be given insight into the correct answers.

It would be interesting to see how many interrelated pieces of information novice learners are able to use in an introductory biology classroom. A better understanding would aid in the creation of lessons and inform faculty on how to better structure their lessons.

**Perceived Workload**

Initially, it was somewhat surprising that the control and experimental groups found the task equally mentally demanding. As studies have indicated, the use of heuristics increases the speed at which decisions can be made and decreases the cognitive load necessary to complete a task (Gigerenzer & Gaissmaier, 2011; Hutchinson & Gigerenzer, 2005; Todd & Gigerenzer, 2000). Therefore, it was expected that the experimental group would report a significantly lower mental demand on the task than the control group based on the access to visual heuristics.

However, two things become apparent when taking a closer look at the narrative and when the NASA TLX was administered. First, the NASA TLX was administered at the end of the narrative with three decision points between the last heuristic and the end of the narrative. Second, the task directly before the NASA TLX was administered was the overall explanation. The NASA TLX score may therefore reflect the difficulty in managing 5 points of information rather than show differences between the control and experimental groups on the heuristics questions. This placement may have diluted the sensitivity to differences between the control and experimental groups.

Since the narrative was online and there was no time limit, the finding that students did not feel rushed nor were they physically challenged was not surprising. Interestingly, both the control and experimental groups felt equally successful in completing the adaptive narrative, even though the experimental group had a greater number of correct answers in the body percent question, almost twice as many detailed responses than the control group, and a significantly fewer number of non-answers than the control group. One would have expected the experimental group to feel more successful in completing the adaptive narrative. Possible explanations are: the NASA TLX score reflects how successful they felt completing the overall explanation and is not reflective of their perceived performance on individual questions; since there were no negative consequences to choices both groups felt equally successful; and novice learners do not possess the metacognitive skills to be aware of their performance (Sarsfield, 2014).

Not surprisingly, the low NASA TLX scores indicated that the narrative did not cause emotional distress in the students. This finding is reflected in prior studies that showed that the use of storytelling led to greater engagement and enjoyment of the lessons (Sadik, 2008). While the adaptive narrative may have been challenging, it was not perceived negatively. This finding supports the use of stories in classes to improve perceptions about a topic, student engagement, and motivation (Hung et al., 2011; Mokhtar et al., 2011; Morais, 2015; Sadik, 2008). Stories may also help prevent learner fatigue. While the adaptive narrative did not ensure the correct use of information, examination of intra-individual responses in the adaptive narrative demonstrated consistency throughout the explanations. In other words, an individual giving a detailed description in the blood typing response was very likely to give a detailed response in the body percent response and a detailed overall explanation.

**Limitations**

As mentioned in earlier sections, providing students with various scaffolding techniques would likely have improved their ability to use the heuristics. However, the adaptive narrative was designed so that decisions, even incorrect ones, would not cause the narrative to end abruptly. This design decision was made to minimize potential back-tracking in the story. Nevertheless, it also meant that students did not receive immediate feedback on their decisions.

The introductory biology course that the participants were enrolled in had a reading prerequisite; however, there was no writing prerequisite. Therefore, it cannot be completely discounted that some of the poor explanations were more indicative of writing skills rather than information processing ability. It is possible that students have not had practice giving written explanations and were unfamiliar or unclear with what was considered a complete explanation at the college level. A corollary limitation was the focus of the study on introductory biology students at a single community college. An improvement to external validity would be the inclusion of other colleges and disciplines in future research.

The NASA TLX is a standardized survey used in numerous studies to examine the perceived workload of a treatment. To keep the flow of the narrative unbroken, the NASA TLX was administered at the end of the story. Unfortunately, this placement may have diluted the sensitivity to differences between the control and experimental groups in individual responses. Additionally, the NASA TLX is a self-report of perceived work load. As indicated by the scores on the rubrics and the evaluation of the responses, the perceived work load was much lower than actual performance.

## Future Research

**Interviews and think aloud protocols.** While the responses given in the adaptive narrative provided useful insights into the decision making of students, interviews with both students and faculty would help give even greater understanding. Interviews would allow specific follow-up questions to be asked concerning the difficulty of the questions, further elaboration of the responses, and a more in-depth assessment of the work load (Saldaña, 2016). Interviews with faculty would also be beneficial to gain their insights into the use of adaptive narratives. If they are assigned as an in-class project, faculty are direct observers of the students doing the assignment. They may be able to give valuable feedback on the speed, motivation, and utility of the assignment. After all, while the benefit is to students, the one implementing the adaptive narrative is the instructor and it must be accepted as a worthwhile classroom tool.

Similarly, think aloud protocols may be used to better understand the thought processes behind the decisions and help understand the difficulty students had incorporating all five data points in the summary response. Some studies have indicated a difference in the information given between self-reported answers and think aloud protocols (Bowen, 1994; Ericsson & Simon, 1980; Eveland & Dunwoody, 2000). Think aloud protocols allow the investigator to listen to the thought process as it is occurring rather than rely on written self-reports. This would also mitigate the possibility that the poor answers were due to writing skills rather than knowledge use.

**Linking courses.** Stories integrate multiple elements lessening the isolation in which subjects are taught which may also enhance the transfer of information. There is evidence that integrating multiple subjects when teaching a concept, results in the higher transfer of information (Plomer et al., 2010). For example, it may be that an English instructor is better at teaching students how to write explanations than a Biology instructor but requires domain specific scenario to write about. By linking courses or class assignments, students would be able to construct a narrative in the English class using the information taught in the Biology class. By not only having to memorize information but having to simultaneously use the information in a creative environment, the transfer of information may be expedited.

## Implications

**Motivation.** As mentioned in a number of studies, stories increase engagement in the classroom. This study also found evidence in the NASA TLX to indicate that students were motivated to complete the story and found it non-stressful. This may be of particular benefit when introducing difficult or boring topics.

**Assessment tool.** The adaptive narrative used in this study gave valuable insights into students' ability to use multiple points of information along with their ability to use heuristics. By using the adaptive narrative as an assessment tool, it was able to be determined that students struggle using heuristics without the proper scaffolding and schema development. Also, the difficulty in using multiple points of information became apparent. More traditional assessment tools (e.g. exams) would likely miss these interactions and would lead instructors to erroneously assign blame other factors (e.g. students' studying habits) for the incorrect answers.

**Storytelling and adaptive narratives.** The results of this study suggest that novice students do not possess the necessary schema to use complex, multiple units of information even when heuristics are presented. Therefore, it would be beneficial to focus classroom activities away from the simple transmission of information and toward the practice of developing the requisite skills needed to use the information. One technique that has shown promise in the development of these skills is scaffolding (Belland, 2014; Jonassen, 2011). In this, the utility of storytelling as a scaffold to develop necessary schema and improve heuristic use should be examined. While it may require an initial investment in time and energy on the part of the instructor, the following paragraphs outline the implications of using storytelling and adaptive narratives in instruction.

Through the creation of a narrative, students would have the opportunity to practice information in new ways. The creation of a story requires not only factual knowledge but also how individual pieces of information interact with one another and influence outcomes. This is also the basis of two common scaffolding techniques: analogical encoding and causal reasoning (Jonassen, 1997). By comparing and contrasting two pieces of information (analogues), the learner can determine similarities and patterns which may be used to advance the narrative. Causal reasoning requires the learner to understand the relationship between the factors involved in the scenario so that predictions may be made. This is particularly necessary in the creation of a narrative since predictions are required to write the next scene. Through feedback on their narrative, students would also receive additional scaffolding necessary to create the necessary schema.

Additionally, allowing students to explore the wrong answer can teach valuable lessons on the interaction of information, consequences of decisions, and may reinforce the correct concepts. A study examining learning from mistakes in medical trainees indicated that students felt that they had learned the most from serious mistakes causing harm (Fischer et al., 2006). Additionally, trainees indicated that they would have benefitted from structured mentoring concerning the mistakes that they had made (Fischer et al., 2006). Researchers have called upon exploring failure as an instructional design technique with different types and levels of failure incorporated into instruction (Tawfik, Rong, & Choi, 2015).

Adaptive narratives may be a way to introduce the opportunity to make mistakes within a structured setting while giving important feedback. Since of the hallmark components of stories is conflict, stories may be used to introduce scenarios that need to be rectified. Adaptive narratives can then be used to ask individuals questions and require decisions to be made, causing the story to advance down a number of different paths. The consequences of each decision point may be used to reinforce the information presented as well as give novice learners the experience of how the information may be correctly used.

Adaptive narratives may also decrease the frustration novice learners sometimes experience when confronted with failure since they allow them to experience autonomy while progressing through the storyline. Autonomy in the learning process is important for novice learners because it helps them develop intrinsic motivation (Niemiec & Ryan, 2009). Intrinsic motivation has many positive benefits among which is the persistence in the completion of a task despite experiencing failure along the way (Lei, 2010). There is evidence to suggest that the more invested a learner is the material, the more willing they may be to independently pursue supplemental information outside of the classroom (American Association for the Advancement of Science, 2011; Auchincloss et al., 2014; Ballen et al., 2017). The combination of giving autonomy to novice learners while scaffolding instruction makes further exploration of the utility of adaptive narratives compelling.

**Intersection of scaffolding and heuristic use.** While the intent of heuristics is to reduce cognitive load and aid in the decision-making process, this study indicates that their efficacy is dependent on the individual's familiarity with the subject matter. When two different heuristics were given, students in the introductory biology class were only able to use the heuristic that was based on information already familiar to them.

Therefore, the timing of the introduction of the heuristic for novice learners is important. Instructors should ensure that the development of the necessary schema is well underway before introducing a heuristic to the class. To aid in schema development it is recommended that instruction is paired with the appropriate scaffolding techniques. Over time, the scaffolds may be phased out and heuristics introduced. The heuristics may then activate the necessary schema to help make quick and error free decisions.

Based on the findings of this study and prior research, the following model is suggested for the use of narratives and heuristics in classroom instruction when targeting novice learners (see Figure 2). The story is represented by a battery symbolizing the storage of information and the potential that the information has. As mentioned, due to their nature, stories lend themselves to a number of different scaffolding techniques. These scaffolding techniques may be seen as the wires that connect to the battery and are used to transmit the information. The pattern of the scaffolding techniques creates the schema which, when solidified, represents the novice learner having achieved a foundation for the information. Only with a good battery (story) and good circuitry (scaffolding and schema) can heuristics be used.

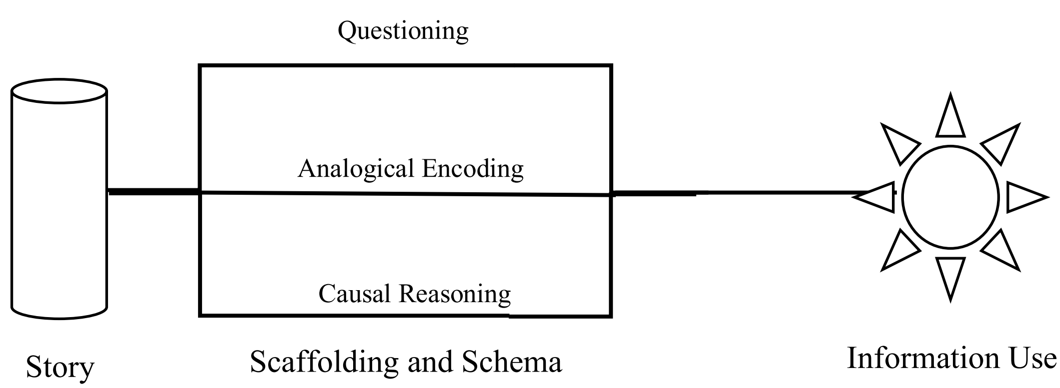


*Figure 2 – Model incorporating new scaffolding in instruction for novice learners. This model uses scaffolding to promote schema development to use information presented in a story.*

As this model suggests, heuristics cannot promote information use if the underlying schema are not complete or developed. This would be analogous to attempting to activate a circuit missing the necessary wires required to conduct the information (see Figure 3). This was shown in students not being able to use the heuristic given in the blood typing question. The story and the heuristic were present, but the wires (scaffolding and schema) necessary to complete the circuit were missing.

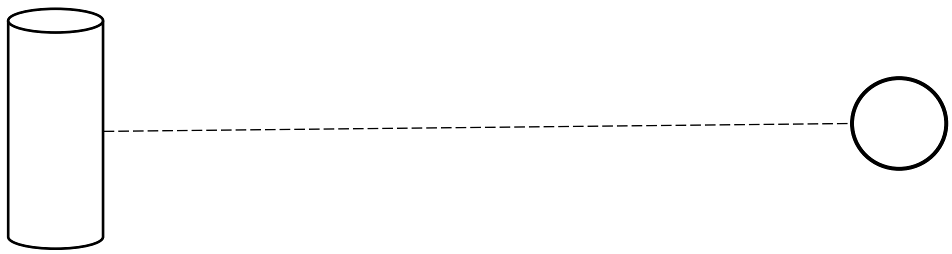

*Figure 3 – Model showing no scaffolding. Since no scaffolding is being used the necessary schema is not developed in novice learners. The dashed lines show an incomplete circuit where the information from the story cannot be used regardless of a heuristic because there are no circuits to activate.*

Nevertheless, learners often have prior exposure that allow them to be familiar with some of the underlying concepts being presented in instruction. In other words, the necessary schema has already been developed and may be activated by heuristics even if the information itself is new (see Figure 4). In the body percent question, students were already familiar with general proportions of the body and percentages, so they were able to successfully use the heuristic presented. The use of the heuristic is symbolized by the increased thickness of the wires, permitting a faster flow of information.

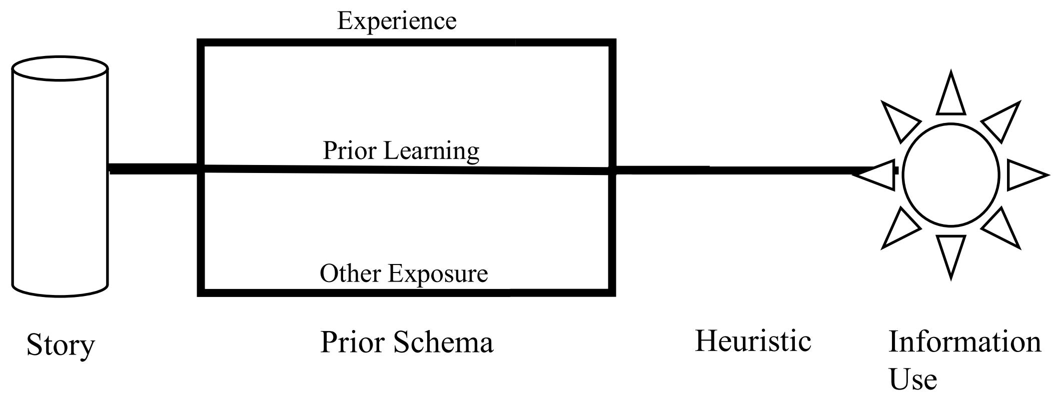


*Figure 4 – Model incorporating prior scaffolding in novice learners. Since prior exposure has acted as a scaffold, the schema necessary has already been developed and is ready to be activated by a heuristic (shown by the increased thickness of the wires) leading to the use of the information presented in a story.*

**Implications for teaching and instructional design.** Finally, although not depicted due to the complexity, the students' difficulty with using two different heuristics and five different points of information may be represented by a complex circuit with two switches, and multiple sets of complete and incomplete circuits. Since information could only travel down the complete circuits, it is not surprising that students only included two to three points of information in the overall response.

This study suggests that in order for all of the pathways to be activated and to have multiple points of information used simultaneously, careful scaffolding must be included in the instruction to connect all of the points (see Figure 5). Depending on the complexity of the interacting points of information, the scaffolding given should not neglect referring back to prior information presented in favor of connecting later points of information. The model presented in Figure 5 allows for the transfer of knowledge between points of information and the use of information even if a single scaffold is not effective. Furthermore, if a single point of information is not understood the connection between the two other points of information is not compromised.

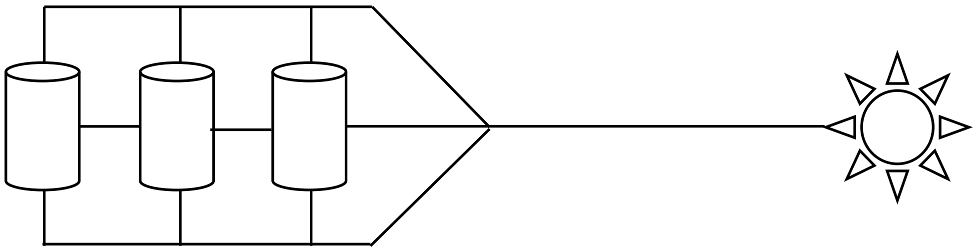

*Figure 5 – Model illustrating the use of scaffolding to connect multiple points of information together for novice learners. The batteries represent points of information, the lines the scaffolds used to develop the pattern (schema), while the sunburst represents information use.*

As literature suggest, heuristics simplify the number of points of information being used to make decisions and reduces cognitive load. In keeping with the electrical circuit analogy, this is symbolized by the heuristic reducing the number of wires and increasing their width (resulting in a reduction in resistance). The addition of a heuristic after the appropriate schema has been developed leads to a simplified pathway which should decrease cognitive load and increase the speed with which decisions are made (see Figure 6).

*Figure 6 – Model illustrating the effects of a heuristic on schema. The complexity of the interaction is reduced and the pathway of information flow is increased leading to a decrease in cognitive load and an increase in the speed of decision making.*

This model also has implications for instructional design. Intrinsic cognitive load has long been seen as an immutable part of instruction with instructional design only playing a role in affecting extrinsic cognitive load (Sweller, 1994). It has been noted that as the interaction between multiple points of information increases, intrinsic cognitive load likely also increase

(Sweller, 1994). However, as this model suggests, by giving well timed heuristics, the number of points of information needing to be taken into consideration to make a decision decreases. This reduction should result in a reduction in intrinsic cognitive load while increasing the speed with which problems may be solved. Therefore, instructional design may be able to influence the intrinsic cognitive load of a task.

## Conclusion

This study indicates that novice students are able to use a familiar heuristic in solving and explaining problems. However, the benefit of a heuristic was negated when it is based in abstract concepts. It is suggested that novice learners may benefit more from scaffolding techniques integrated into instruction when dealing with unfamiliar and intangible concepts. The study also showed that novice learners had difficulty incorporating more than three points of information into a summary explanation. Again, without the appropriate scaffolding, the amount of information used by novices is likely limited.

Regardless of performance, students viewed their performance on the adaptive narrative positively and were not distressed by the complexity of the narrative. This suggests that narratives may be used to not only transmit information but also act as scaffolds to build schema to aid in the synthesis of complex interactions. This may be especially beneficial in fields where a positive perspective, student engagement, and student persistence are traditionally low.

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# APPENDIX A: ADAPTIVE NARRATIVE

The following is the version of the adaptive narrative given to the experimental group. The version given to the control group is identical with the exception of the visual heuristic given in the blood typing and body percent questions.

## Down the Rabbit Hole: A Case of Mistaken Identity

You will be reading a story and at certain points in the narrative you will be asked to make choices.

Once you make a choice, you will be asked to explain your decision. Please give as detailed an explanation for your decision as possible. PLEASE DO NOT BACKTRACK DURING THE STORY.

When you are done, please make sure to take a screen shot of the submission screen and email it to your instructor.

### Introduction

You are Barbara Alicia Roberta Beatrix Johnson (or Barb as you call yourself), a new custodial worker on your way to beginning your first night shift at a police department in the middle of Boston, Massachusetts. You look down at your watch. It is peak rush hour time. Boston is a bustling major metropolitan area home to over 655,000 people and almost double the number of cars and almost as many ongoing road construction projects.  A skilled taxi driver will know how to avoid the traffic and get you to work quickly. The subway is slower but will be less expensive. What mode of transportation do you decide to take to get to your job on time: taxi or subway?

Taxi

Subway


**Taxi**

You manage to flag down one of the city's many taxis.

You are glad that you chose an experienced taxi driver who knows the city's traffic patterns from experience. He is able to avoid the massive traffic jam that already has the roads at a standstill.

In an odd series of unfortunate coincidences, several accidents involving semi-trucks, indecisive squirrels, and a confused chicken have resulted in the closure of all major highways and thruways in the city. Officials warn that people may be sitting in their cars late into the night until the situation is resolved.

You arrive at the police station with 5 minutes to spare. You thank your driver and decide to give him a tip. How much do you tip: 10% or 15%?

10%

15%

Taxi and Tip – Please give an explanation for your answer

**Police Station Lobby [After the Taxi or Subway]**

You make it to the lobby of the police station. You check your watch. The evening custodial supervisor is late showing up. You have no other option other than to wait patiently inside the station office area. You and the attendant officer engage in periodic, unspoken staring matches. Suddenly, a very assertive man bursts through the inner doors and with thick Bostonian accent asks the attendant officer if "Bahb" has shown up.

Mistaking his accent for “Barb” you quickly introduce yourself. He seems confused at first but quickly escorts you out of the office area and towards the morgue.  Once you are alone inside the morgue, he gives you $10,000 in cash in an envelope and tells you that you will have the rest of the payment after completing the autopsy.

He also makes an aside that you are not at all like what he was expecting for “a hire”. He warns that if you do not deliver a credible cause of death that you may be facing your own untimely demise.

In the meantime, the real Bob is stuck in the bad Bostonian traffic jam realizing an ever-increasing disdain for squirrels and chickens and roadways.

**Inside the Morgue [After Police Station Lobby]**

The man takes you over to a dead body on a gurney and gestures to the instruments and anatomy and medicine books on the nearby counter. He tells you that there are two blood samples that need to be typed and gestures over to one of the counters where there are vials and papers neatly arranged. The samples came from the victim's clothes and were prepared by the autopsy staff earlier in the day. He also mentions that the dead body's blood type is O-.

Realizing that you are in way over your head with little way out, you play along. You smile at the man and assure him that you have everything under control. Before leaving you, he tells you that he'll be back in a couple of hours to check in on you. Again, you lie and assure him that you have everything under control. With that, he leaves.

**Realization [After Inside the Morgue]**

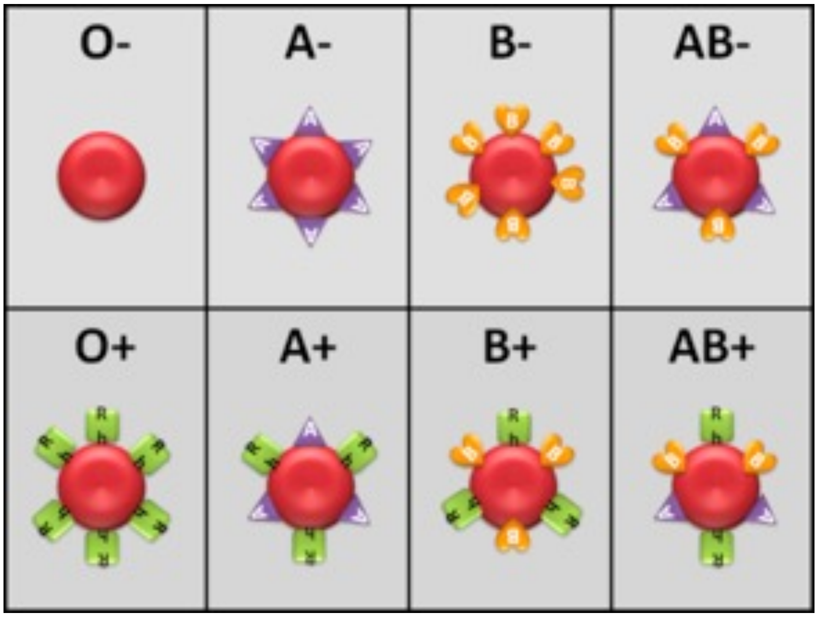
You run over to the door and as a precaution, lock it from the inside. You look around the room. It is fairly small compared to morgues that you've seen on t.v. shows. There is probably room for only two adult bodies to be out of the eight cadaver chambers that you see. There are some cabinets presumably filled with equipment and several trays on stands to hold instruments while an autopsy is being completed. The only way in or out of the room is the way you came in.

It dawns on you that the real "Bahb" is out there somewhere and you will be in even more trouble if he shows up while you are still there. You look at the money that you were given. Ten thousand dollars will pay for a very lovely extended stay south of the border while things cool down. If you can figure out a plausible cause of death, you may be set for some time. If your explanation is believable enough, you'll make it out of this alive and with more money to escape to a tropical paradise.

**Blood Typing Info [After Realization]**

Delaying contact with the dead body, you go over to the blood samples. You see two vials of blood, three vials of anti-serum, some eye droppers, and cards with three double circles in them. Scratching your head, you look around to see if there's anything that can help you figure out the blood types. There are several anatomy and physiology textbooks and a binder near the equipment helpfully labeled "blood typing protocols". You open the binder and begin reading.

When we talk about blood types we are talking about O -/+, A-/+, B-/+, and AB-/+. What gives the blood types their designation? The antigens located on the surface of the red blood cells. An antigen is a unique protein that acts as a cell marker. Take a look at this image. Hopefully you can see a clear pattern. O- type blood has absolutely no antigens on the surface of the red blood cell. O+ blood has the Rh antigen on the surface represented by the green box. A- type blood has an "A" antigen on the surface of the red blood cell only; whereas A+ blood type has both the A (triangle) and the Rh (green box). You will see that B- and B+ also follow these rules. It is "B" because of the "B" antigen found on the surface of the red blood cell. If it has the Rh antigen, it is then considered positive. If it doesn't, it is negative.

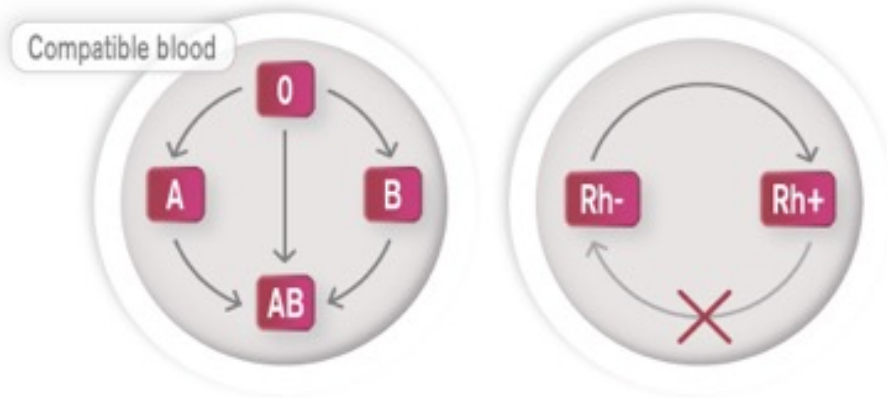



**Blood Typing Info continued**

Each blood type also has antibodies that are opposite to the antigens on their red blood cells. For example, Type A+ blood will have B antibodies. Type B+ will have A antibodies. Type AB+ will have no antibodies. O+ will have A and B antibodies. These antibodies will bind to foreign blood if a transfusion is improperly given. An improper transfusion can lead to life-threatening complications, including death, because the blood cells will be bound together.


**Blood Typing Info 2**

That is a lot of information about blood typing. You pinch the bridge of your nose and rub your eyes. Taking a deep breath, you turn the page. There on the next page is a very simple diagram showing blood interactions.




You follow the instructions and type both of the blood samples.

You see that the blood from both of the vials is type B+.

"Huh, same blood," you think to yourself. "Well, if the body is O-, then there must've been someone else involved. I wonder who that was?"

Could the mystery person have donated blood to the body (when alive) in real life?

Yes

No

Blood Typing – Please give an explanation for your answer

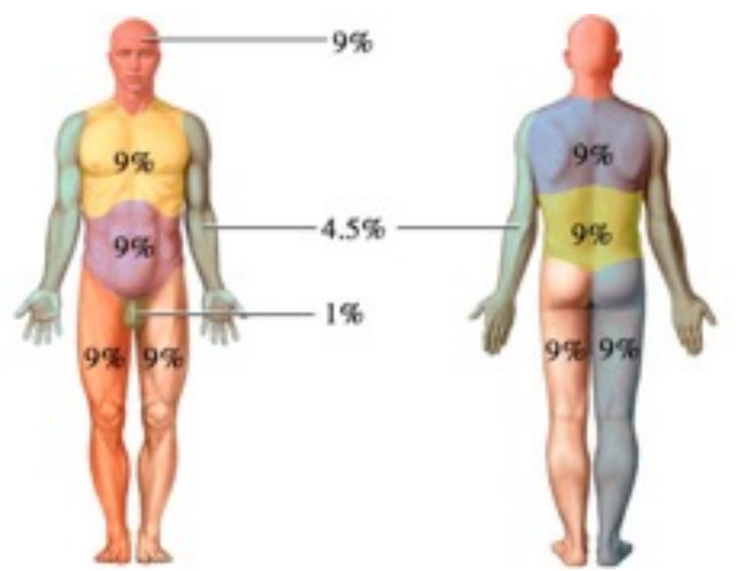
**Investigation Part 1 [After Blood Typing]**

You walk over to the body. Someone has already prepared the body for an autopsy meaning that the clothes have been removed. You can't avoid looking at the face any longer. As you look, you realize that you recognize the individual. It is the son of a very prominent local politician with alleged ties to an equally prominent organized crime syndicate. Suddenly, the private autopsy, the money, and the lack of usual morgue staff makes more sense. They don't want this information getting out. Well, you certainly aren't going to shout it from the rooftops.

You look around once again. A pen and paper would be helpful to keep notes. You see some by the biology textbooks that you noticed earlier. Those will come in handy too as you try to make yourself sound believable. You glance back at the body. You notice that there are large areas of bruising on the body.

**Investigation Part 1 continued**

Bruising - "Wow, that seems like an awful lot of bruising," you mumble to yourself. "It looks like almost the entire upper and lower back is bruised." You flip through one of the biology textbooks and come across a passage describing the "rule of 9s". It's a rule-of-thumb used to evaluate the percent area burned in burn victims. You figure, you can use it to estimate the area of bruising. You see the following picture.




What would you estimate the percent of the body that is bruised?

21%

18%

Bruising – Please give an explanation for your answer.

**Subway [Although out of physical order, if subway was chosen the individual would be directed here. They would then loop back to the Police Station Lobby after choosing coffee or tea and giving an explanation.]**

As you walk to the subway you are ever happier about your decision. On your way, you hear a breaking news story about the city's roads coming to a complete standstill. In an odd series of unfortunate coincidences, several accidents involving semi-trucks, indecisive squirrels, and a confused chicken have resulted in the closure of all major highways and thruways in the city.

Officials warn that people may be sitting in their cars late into the night until the situation is resolved.  The trains are running on time and you realize that even with the walk from the subway station, you will arrive at the police station with 5 minutes to spare.

As you walk, you pass by a corner bodega. You realize that it is going to be a long night and a little bit of caffeine might be a good idea.  It is a standard little city corner deli with limited options.


Do you decide to order a coffee or a tea?

Coffee

Tea

Coffee or Tea – Please give an explanation for your answer

**Part Two – Further Investigation [After Body Percent]**

Feeling a little more comfortable with the dead body, you look a little more closely and notice that there are other areas have a bluish tint to them.

Which do you focus on: bluish tint or bruising?

Bluish tint

Bruising

**Part Two – Further Investigation Bluish Tint**

You decide to focus in on the blue tint and go back to the medical textbooks to find out more information. You look back at the section of the skin where they mention the different reasons for the many variations in skin color. There is a reference there to blue skin directing the reader to the respiratory system. You read:

Cyanosis or the bluish discoloration of skin is caused by the collection of deoxygenated blood in areas of the body. When blood oxygen saturation levels drop below approximately 80%, cyanosis becomes observable. Cyanosis may be characterized as either central or peripheral.

Central cyanosis is bluish discoloration around the core of the body, lips and tongue; whereas, peripheral cyanosis is bluish discoloration around extremities, fingers, and toes.

Central and peripheral cyanosis are usually caused by a decrease in circulation or ventilation. Things that may cause central and peripheral cyanosis are strokes, drug overdose, asphyxiation, seizures, chronic obstructive pulmonary disease, heart failure, heart attack, and hypothermia.

**Part Two – Further Investigation Bluish Tint**

You take another look at the body. The individual looks like a relatively young (mid to late 20s) male. It's unlikely that he suffered from a stroke or had chronic conditions like a cardiovascular disease. With the weather being unusually warm in Boston, he wouldn't have suffered from hypothermia either.

Based on what you have read you conclude that the bluish tint was most likely either due to drug overdose or asphyxiation. Which do you focus on: drug overdose or asphyxiation?

Drug overdose

Asphyxiation

**Bluish Tint – Drug Overdose**

You realize that you will need to give a more specific cause of death other than simply drug overdose. You look through the other textbooks searching for more information. You come across a section that describes the results of drug overdoses. You read:

Often drug overdoses cause a reduction in respiration rate to the point of causing cyanosis (blue tint of the skin) resulting in death. Many of these drugs are used to treat seizures or anxiety disorders. Unfortunately, this also causes them to be abused.


For example, barbiturates are typically prescribed for seizures and cluster headaches mostly because overdose is much rarer unless they use is combined with alcohol or other drugs (e.g. benzodiazepines) which greatly magnify their effect. Barbiturates reportedly produce a sense of euphoria and have been the drug cause of death for a number of famous people including Judy Garland, Marilyn Monroe and Jimmy Hendrix.

An increasingly common drug in overdose cases are opioids. Opioid addiction usually begins with the drugs being prescribed for pain relief. Due to the mechanisms by which the drug binds to receptors on nerves, after prolonged use, the body becomes addicted to the opioid and craves more. Additionally, opioids are often used recreationally by people who they were not prescribed to because of their ability to cause a euphoric feeling.

**Bluish Tint – Drug Overdose**

You look back at the body for other clues. You know that barbiturates have killed a number of famous people but opioid addiction and deaths are also on the rise. Lacking more evidence (and autopsy skills) you realize that you are going to have to guess that the cause of death and bluish color was either barbiturates or opioid overdose.

Barbiturates

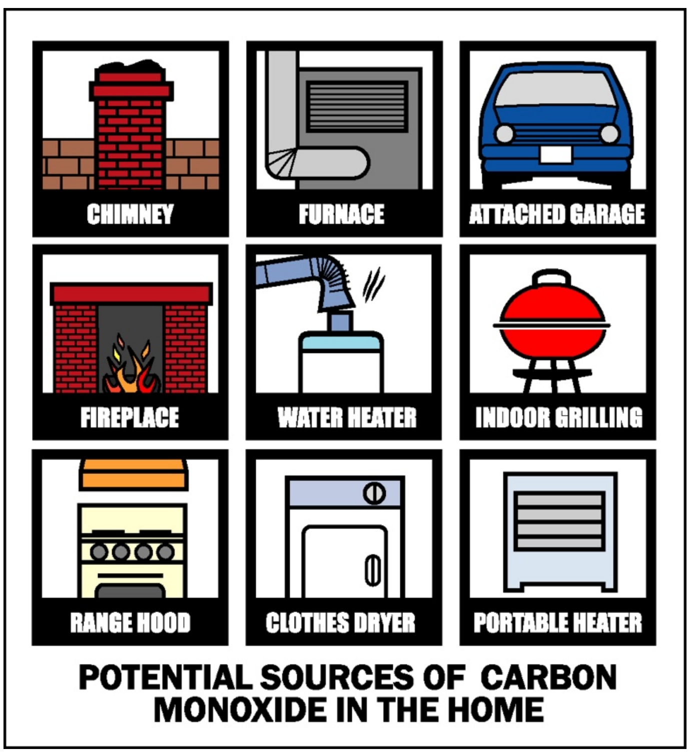
Opiods

**Bluish Tint – Asphyxiation**

You realize that you will need to give a more specific cause of death other than simply asphyxiation. You look through the other textbooks searching for more information. You come across a section that describes the results of carbon monoxide and strangulation due to smothering. You read the following:

Carbon monoxide is a colorless and odorless gas found in the exhaust of most motorized vehicles. Often inhalation is not noticed until the individual loses consciousness. The way that carbon monoxide affects the body is by competing for the binding site usually occupied by oxygen on red blood cells.

When carbon monoxide is present, it binds with 210 times the affinity to red blood cells! This means that oxygen cannot be carried by the blood, resulting in asphyxiation and the blue coloration of the skin particularly around the face.




There are other more obvious causes of asphyxiation. More commonly, asphyxiation is a result of the blockage of the air passageway. Causes may be obvious with signs of strangulation or less obvious such as the use of a pillow or preventing the chest cavity from expanding.

**Bluish Tint – Asphyxiation**

You look back at the body for other clues. You think that if you squint hard enough you might be able to see a mark around the neck...but it might also be your imagination and frazzled nerves. Taking a deep breath, you touch the spot on the neck and realize that it's just a crease in the skin.

Lacking more evidence (and autopsy skills) you realize that you are going to have to guess that the cause of death and bluish color was either due to carbon monoxide exposure or strangulation due to smothering.

Which do you choose: carbon monoxide exposure or strangulation due to smothering?

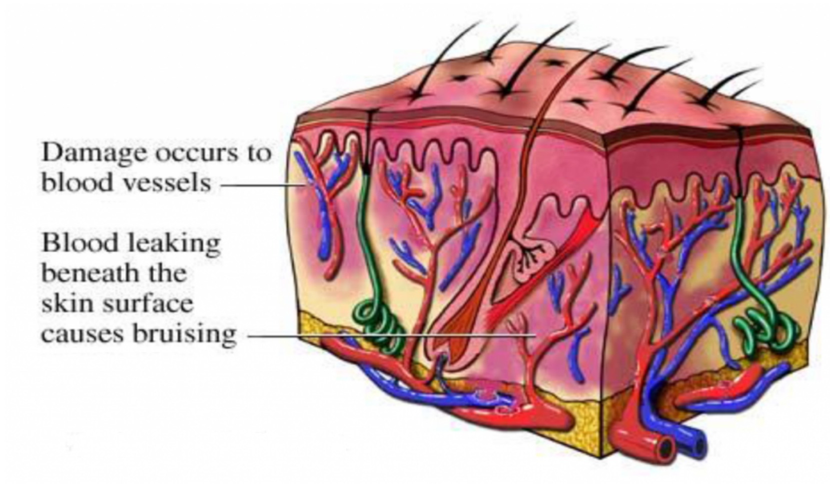
Carbon monoxide exposure

Strangulation

**Part Two: Further Investigation - Bruising**

You decide to focus in on the bruising and go back to the medical textbooks to find out more information. You look back at the section on blood vessels where they mention the causes and results of bruising. You read the following:

Bruising is caused by a rupture of blood vessels resulting in the pooling of blood in the interstitial space (i.e. space between the cells). Sometimes the rupture of blood vessels may be very deep to the surface of the skin and bruising does not become noticeable until some time after the injury. The size and intensity of the bruising is proportional to the injury that caused it. In other words, the larger the impact, the more blood vessels that are damaged, the more blood that leaks into the interstitial space, and the larger the bruise. One notable exception to this is the case of livor mortis.




Livor mortis is the appearance of bruising due to the pooling of blood after death. Upon death, the capillaries already permeable become even more so. As a result, blood is released into the interstitial space. This blood then flows through the interstitial space due to gravity where it pools and congeals.

The discoloration is not seen in the areas of the body that are in direct contact with a surface because the capillaries in those areas are compressed.

Often forensic scientists will use this discoloration and obvious pooling pattern to determine the position that the body was left in upon death and whether or not it had been moved after death.

**Part Two: Further Investigation – Bruising**

You go back to the body. You notice discoloration that could be bruising on the torso as well as some on the back. Based on what you have read you conclude that the bruising could either result from being attacked or due to livor mortis.

Which do you focus on: results of an attack or livor mortis?

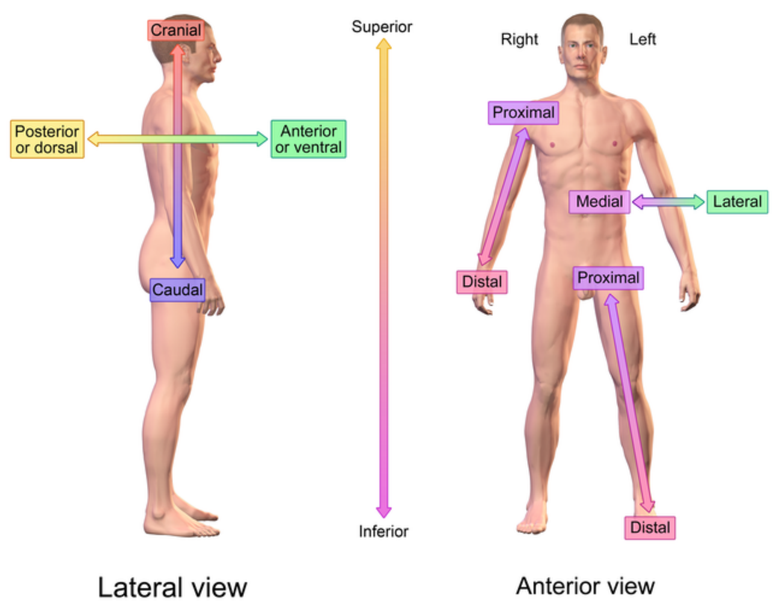
Attack

Livor mortis

**Bruising – Attack**

Thinking about it further, you realize that you should probably use medical terminology when giving the explanation so you look through the introduction chapters of the medical textbooks searching for anatomical terminology. The introduction clearly describes the use terms used for identifying marks on bodies. You read the following:

In describing location, the first step is to use what is known as “proper anatomical position”. Proper anatomical position orients the person standing upright, feet flat on the ground, legs shoulder-width apart, arms at the sides with palms facing forward, and the head level. Therefore, the individual’s left is always the left, even though it is on the viewer’s right-hand side.




**Directional References**

The following terms are used to describe locations on an individual’s torso and head: superior, inferior, medial, lateral, anterior, posterior, supine, and prone.

Superior means above while inferior means below. For example, your nose is superior to your mouth (above your mouth) but is located inferior to your eyes (below your eyes). Please note, that superior and inferior simply mean above and below. The object that you are trying to describe does not have to be directly above or below the reference point.

Medial refers to the midline of your body and lateral refers to the sides of your body.

Anterior refers to the front of your body (location of your face, chest, belly-button, etc.) and posterior refers to the back of your body (location of your back, buttocks, etc.). These terms can also be used for arms and legs. For example, your knee is on the anterior portion of your leg whereas your calves are on the posterior portion of your leg.

Two more very important anatomical terms are reserved for the arms and legs only. The term proximal or close to the site of attachment (i.e. shoulder for the arms, hips for the legs) and distal or far from the site of attachment (i.e. toward tips of fingers and toes) are used. This way, no matter what position your arms and legs are in, you can accurately describe the location of the object or injury.

Prone and supine are also used to describe the general orientation of the body. For example, when you are laying on your back, you are in the supine position. Similarly, when your palms are facing anteriorly (forward) they are considered in the supine or supinated position. When you are lying face down, you are in the prone position. Similarly, when your palms are facing posteriorly (backward) they are considered in the prone or pronated position.

**Bruising – Attack**

You go back to the body. You have a rough understanding of the general location of vital organs. You notice that there are a large number of bruises on the chest area (although you do think that you see some discoloration around the back of the body). Based on your limited forensics knowledge, you conclude that the cause of death and bruising was due to blows to chest area.

How will you describe the location of the bruising?

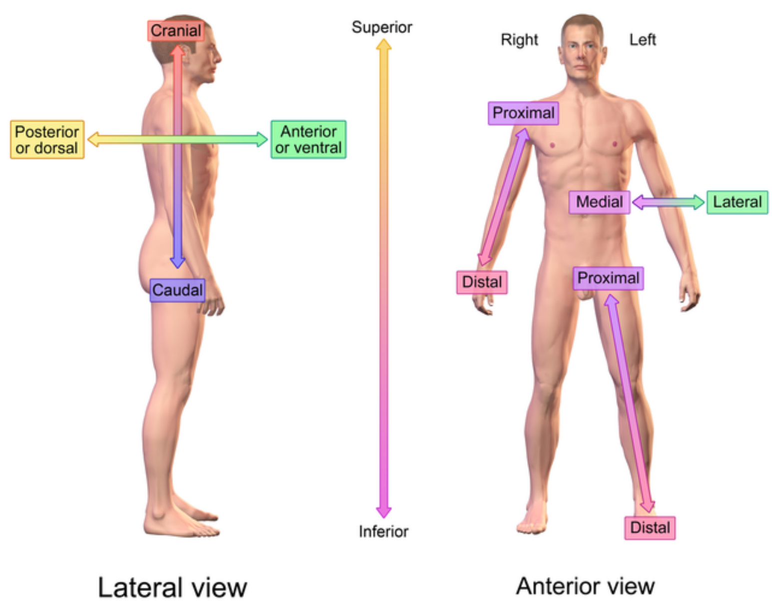
Superior portion of torso

Inferior portion of torso

**Bruising – Livor Mortis**

Thinking about it further, you realize that you should probably use medical terminology when giving the explanation so you look through the introduction chapters of the medical textbooks searching for anatomical terminology. The introduction clearly describes the use terms used for identifying marks on bodies. You read the following:

In describing location, the first step is to use what is known as "proper anatomical position". Proper anatomical position orients the person standing upright, feet flat on the ground, legs shoulder-width apart, arms at the sides with palms facing forward, and the head level. Therefore, the individual's left is always the left, even though it is on the viewer's right-hand side.




**Directional References**

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**Bruising – Livor Mortis**

You think about what you read about livor mortis and you notice that there is pooling of blood along the back of the body.

Which do you choose: the body was found prone or the body was found supine?

Prone

Supine

**Conclusion**

No sooner do you make your decision than you hear a jiggling of the door. The guy is back for your conclusion as to the cause of death.

You walk to the door as confidently as possible and unlock it. He pushes the door open and walks past you clearly agitated. A little flustered, you tell him that you locked the door to ensure privacy. Obviously, you didn't want the wrong person like the new evening custodian accidentally walking in there at the wrong time.

He accepts your answer and visibly relaxes a little. He looks at you waiting for your explanation. He reminds you to be as detailed as possible.

Based on your decisions, what is the explanation that you give him? Please be as detailed as possible.

**End**

He smirks and shakes his head in a mixture of sadness and disappointment. He reaches into his pocket and hands you a thick envelope. Not wanting to press your luck, you thank him for the work and walk out of the morgue. You leave the police station as quickly as possible trying your hardest to act naturally.

As you walk out the door, you pass a man walking in who looks suspiciously like he would make a living performing autopsies. You quickly turn left and disappear into the Boston evening with hopes of a tropical adventure in your future.

**Consent Form**

Please read the consent form on the next screen and check to agree to have your answers used in a research study. You will be helping a graduate student with her PhD dissertation. If the entire class participates in the study, the entire class will receive a pizza party. Please know that no identifying information will be collected.

**Consent Form**

INFORMED CONSENT DOCUMENT

Heuristic Use in Decision Making by College Biology Students

OLD DOMINION UNIVERSITY

PROJECT TITLE: Decision Making in the Sciences: Understanding Heuristic Use by Students in Problem Solving

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

The purpose of this study is to explore whether the use of storytelling can serve as a viable instructional strategy to increase learning and comprehension of biology information taught at one of the Maricopa Community Colleges in Arizona. The feedback provided will be used to further enhance and improve teaching practices. You are being asked to participate in this study because you are participating in an introductory biology course.

RESEARCHERS

Responsible Principal Investigator: Jill Stefaniak, PhD, Assistant Professor, College of Education, STEM Education & Professional Studies

Investigators: Elizabeth Csikar, MS, Graduate Student in Instructional Design and Technology, Old Dominion University

DESCRIPTION OF RESEARCH STUDY

One of the goals of biology education is to promote problem solving skills in students. Undergraduate students enrolled in a major's biology class or one that serves as a prerequisite for a science based profession, will be required to solve problems using information that they have learned in novel settings. This is an important goal since common tasks in biology careers involve the diagnoses of problems, the construction of solutions, and the making of decisions made based on the two.

Problem solving relies on the ability to use prior knowledge in novel settings. Although scientific information often has a high intrinsic cognitive load, one method used to reduce cognitive load in scientific problem solving is heuristics. Heuristics, in this case, is defined as easily remembered domain specific strategies used to solve task specific problems.

To create biology instruction that promotes problem solving skills, it is first important to determine what heuristics students are using when confronted with an ill-structured problem. Therefore, the goal of this study is to gain further understanding of the use of heuristics in the problem-solving process on ill-structured problems by undergraduate biology students.

EXCLUSIONARY CRITERIA

There are no exclusionary criteria. Any student enrolled in an introductory biology course at one of the Maricopa Community College schools will be eligible to participate.

RISKS AND BENEFITS

RISKS: The risks to you will be minimal. There is a risk of the release of confidential information. Any documented information will be secured and confidential. The information will be destroyed once the data has been aggregated and the study is complete.

BENEFITS: Your participation may help improve teaching practices provided to introductory biology students at a later date.

COSTS AND PAYMENTS

There will be no costs to you for participation in this research study. The researchers are unable to give you any payment for participating in this study.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

All information obtained about you in this study is strictly confidential unless disclosure is required by law. Your name or any other personal identifiers will not be collected during this study. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study at any time. Your decision will not affect your relationship with Mesa Community College, or otherwise cause a loss of benefits to which you might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of papercuts arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Dr. Jill Stefaniak the principle investigator at 757-683-6696, Dr. Tancy Vandecar-Burdin the current IRB chair at 757-683 3802 at Old Dominion University, or the Old Dominion University Office of Research at 757-683-3460 who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Elizabeth Csikar Dr. Jill Stefaniak

480-654-7503 757-683-6696

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. Tancy Vandecar-Burdin the current IRB chair at 757-683 3802 at Old Dominion University, or the Old Dominion University Office of Research at 757-683-3460 who will be glad to review the matter with you.

Who is your lecture instructor? (for purposes of pizza party)

Professor Arta Damnjanovic

Professor Lewis Obermiller

Professor Andrew Holycross

Professor Denise Clark

Do you consent to have your answers used in the above described research study?

Yes

No

**NASA Task Load Index**

These questions will ask you about the difficulty of completing this exercise.

How mentally demanding was the task? *

Very Low 1 2 3 4 5 6 7 8 9 10 Very High

How physically demanding was the task? *

Very Low 1 2 3 4 5 6 7 8 9 10 Very High

How hurried or rushed was the pace of the task? *

Very Low 1 2 3 4 5 6 7 8 9 10 Very High

How successful were you in accomplishing what you were asked to do? *

Very Low 1 2 3 4 5 6 7 8 9 10 Very High

How hard did you have to work to accomplish your level of performance? *

Very Low 1 2 3 4 5 6 7 8 9 10 Very High

How insecure, discouraged, irritated, stressed, and annoyed were you? *

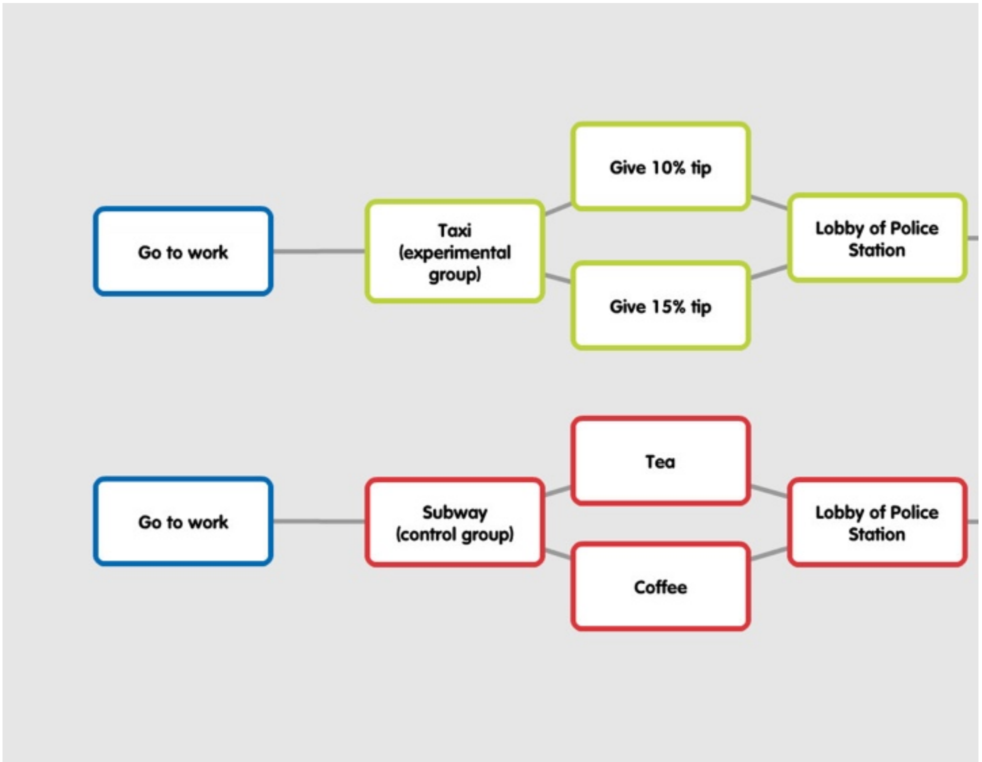
Very Low 1 2 3 4 5 6 7 8 9 10 Very High

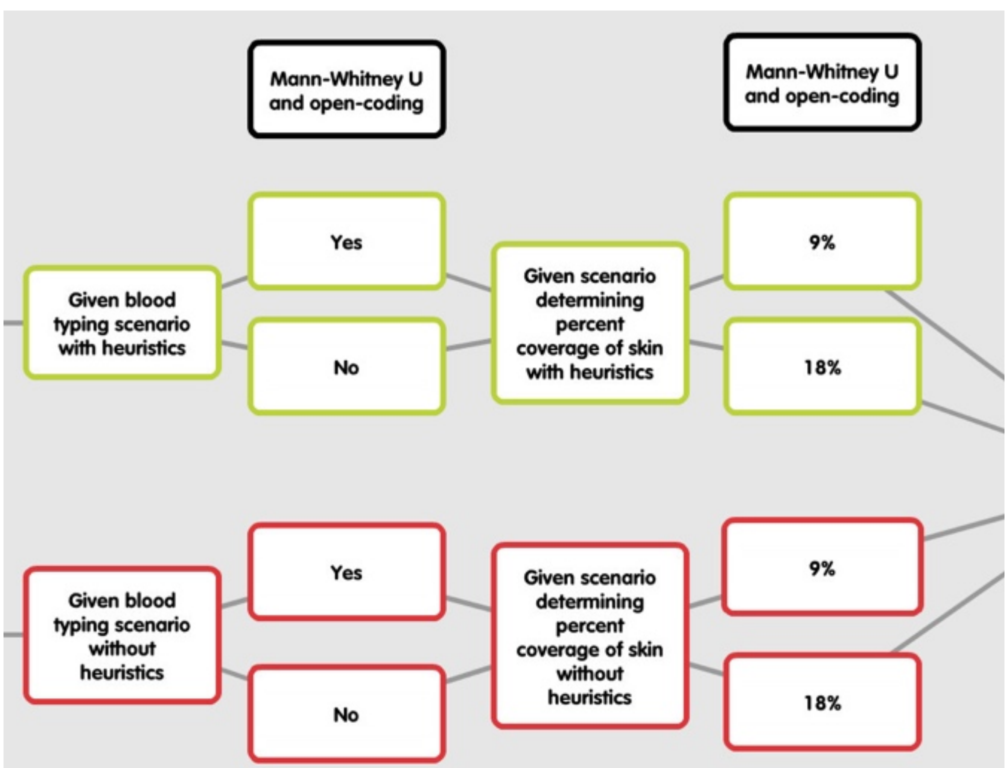
**Thank you**

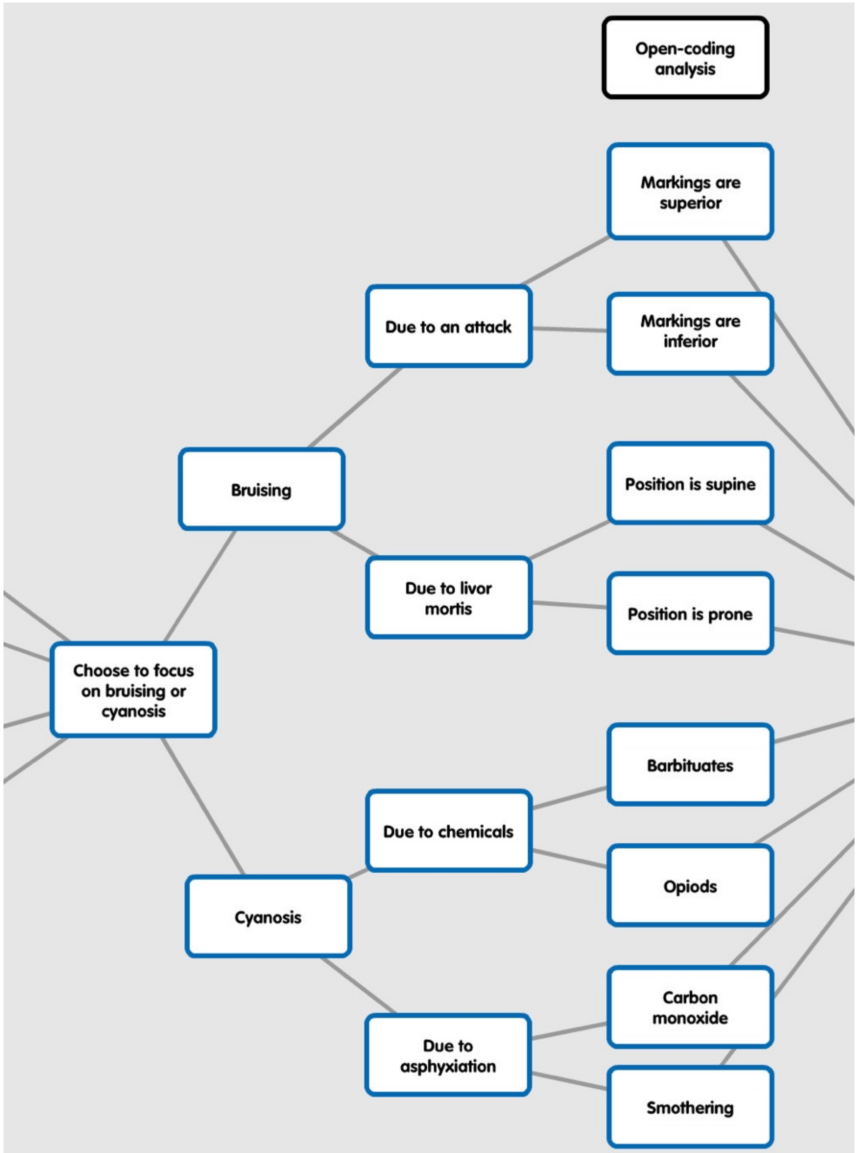

Thank you for participating this research project! Hopefully, you enjoyed the story and learned something about anatomy and physiology!

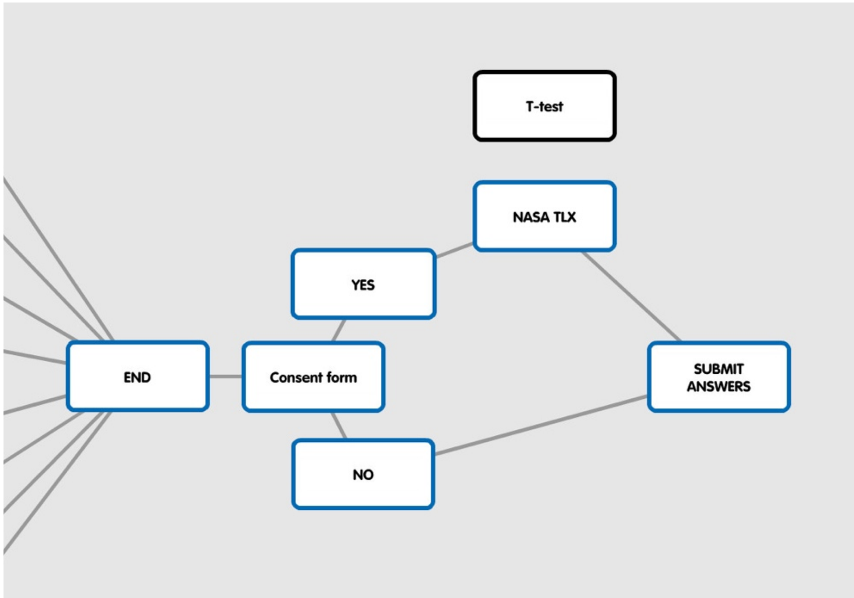
PLEASE MAKE SURE TO HIT SUBMIT and send a screenshot of the submission page to your instructor!

# APPENDIX B: ENLARGED MIND MAP




Open-coding analysis
Markings are superior
Due to an attack
Markings are inferior
Bruising
Position is supine
Due to livor mortis
Position is prone
Choose to focus on bruising or cyanosis
Barbituates
Due to chemicals
Opiods
Cyanosis
Carbon monoxide
Due to asphyxiation
Smothering


T-test
NASA TLX
YES
END
Consent form
SUBMIT
ANSWERS
NO

# VITA

**Liz Csikar**

STEM Education and Professional Studies Department

Darden College of Education

Old Dominion University

## PROFESSIONAL EXPERIENCE

- Residential Faculty and Assistant Chair of Life Sciences at Mesa Community College
- Teaching assistant for Anatomy and Physiology II, Ornithology and Vertebrate Zoology at Arizona State University
- Research experience in: immunohistochemistry; in situ hybridization; animal husbandry including pregnant and nursing kangaroo rats and field mice; field techniques including the trapping and handling of mammals, vegetative cover measurements as well as mammal and bird identification; cadaver prosections and animal dissections

## EDUCATION

- B.A. Literature and Rhetoric; Binghamton University, Binghamton, NY May 1998
- B.S. Biology Summa Cum Laude; State University of New York at Cortland, Cortland, NY May 2003
- M.S. Biology, Arizona State University, Tempe, AZ May 2011
- Ph.D. Candidate, Instructional Design and Technology; Old Dominion University, Norfolk, VA (Dissertation defense November 2018)