Pre-Service and In-Service Science Teachers' Technological Acceptance of 3D, Haptic-Enabled Virtual Reality Instructional Technology

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ABSTRACT

Combined three-dimensional, haptic-enabled, virtual reality (3D HE VR) systems allow students to actively engage and explore various science concepts by leveraging user-friendly and immersive interfaces. Successful implementation of these learning tools in science classrooms hinges upon teachers' perceptions of the technology's potential as a viable pedagogical tool. Prior studies using the Technology Acceptance (TA) Model (TAM) suggest pre-service teachers have greater TA compared to in-service teachers. This study sought to explore how 3D HE VR designed to diminish Ease of Use (EOU) issues, influenced TA (through reported preferences) between pre-service and in-service science teachers. Five pre-service and five in-service teachers reported Perceived Utility (PU) and EOU upon using a 3D HE VR system (zSpace®) to learn science concepts. Quantitative data were collected from pre- and post-test content assessments. Qualitative data were collected and transcribed from field notes and interviews. Both teacher groups evidenced learning gains and reported EOU using zSpace®. However, preference for the technology compared to traditional methods varied between teacher groups. Sampled pre-service teachers held a significant preference for hands-on activities for instruction whereas in-service teachers reported greater TA, citing its potential to increase student interest in science and opportunity for personalized learning. This research suggests that when perceived EOU is mitigated, PU may more readily mediate TA among in-service teachers as they can envision the use of 3D HE VR technology use in teaching practices. Further exploration is needed to leverage in-service teachers' classroom experience to implement novel forms of technology into their science instruction.

Key Words: Haptics; In-service teachers; Instructional Technology; Pre-service teachers; Science Education; Technology Acceptance Model; Virtual Reality

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Introduction

Computer based technologies have become a staple of the K-12 educational landscape since the 1990s. As computer power has increased per Moore's Law, instructional technologies have become more robust in their capability for personalizing learning and providing high quality content to the user. The research literature on technology enhanced learning environments has documented the benefits of technological tools in the K-12 science classroom in scaffolding the inquiry process (Anastopoulou et al., 2012) as well as scientific modelling (Wu, 2010). With rapid advances in computer hardware, educational technologies can create unique and vivid learning experiences with three-dimensional (3D) images, haptic feedback, and real-time user interactions. Lederman (2000) has described the possible positive impact of technology for students when it is situated in developing specific scientific competencies and pedagogically appropriate; thus, making science more accessible and establishing a clearer relationship between science and technology itself. Therefore, the potential benefits of a user-friendly, multi-sensory instructional tool, using 3D, haptic-enabled (HE) and virtual reality (VR) technologies within a single platform, invites new questions for the science education community.

Teachers' impressions and assessments of novel instructional tools are fundamental for the use of instructional technology in the science classroom; specifically in their willingness and ability to adopt and integrate technology into their teaching practices. Previous research by Teo (2014) has affirmed a dominant narrative that pre-service teachers hold greater *Technological Acceptance* (TA) than their in-service counterparts. The *Technology Acceptance Model* (TAM) indicates that TA forms from the intersection of two constructs, the user's *Ease of Use* (EOU) and *Usefulness* (U). Historically, these technologies had required a steep learning curve, where EOU was hindered by those without computer knowledge or skills. However, emergent technologies like 3D, HE, and VR are each intentionally designed to be immersive and interactive, as well as intuitive to the user (Earnshaw, Gigante, & Jones, 1993). Prior research suggests that teachers' technology integration is based upon their concerns with EOU (Baek, Jung, & Kim, 2008; Mumtaz, 2000), even among younger and pre-service teachers who are part of the *digital generation* (Li, Worch, Zhou, & Aguiton, 2015). This begs the question of how teachers, when presented with instructional technologies that do not require training or computer skills, perceive the utility of these emergent technologies and their use in the science classroom.

With the advent of these easy-to-use devices, it is unknown how pre-service and in-service teachers perceive acceptance of these technologies when EOU is mitigated by natural usability. This paper employed TAM (Davis, Bagozzi, & Warshaw, 1989) and used by Teo (2014), to explore pre-service and in-service teachers' *Perceived Ease of Use* (PEOU) and *Perceived Usefulness* (PU), the two components of TAM, upon using 3D HE VR technology.

This single case consisted of five pre-service and five in-service teachers using 3D HE VR to virtually build series and parallel circuits and explore the anatomy and physiology of a virtual human heart. Through individuals reporting their preferences for both EOU (learning) and U (teaching) for using the technology for science instruction, groups' responses may be compared to explore differential TA behavior.

Affordances of Three-Dimensional, Haptic-Enabled, Virtual Reality for Science Instruction

Virtual reality is defined as using computer-based technologies to replicate the effects of the 3D world by using interactive objects to produce a strong sense of *virtual presence* (Bryson, 1996). Virtual presence (or more simply, *presence*) is the psychological perception of being in another environment although physically situated in reality (Slater, McCarthy, & Maringelli, 1998; Witmer & Singer, 1998). Presence comprises of involvement and immersion to have the user "perceive that they are interacting directly, not indirectly or remotely, with the environment" (Witmer & Singer, 1998, p. 227). Involvement is defined as the users' ability to control the virtual environment with minimal distraction from the outside environment. Whereas immersion describes the qualities of the virtual environment (sensory engagement and realistic features) as compared to the real world. Technologies that render 3D images with a perception of depth, create the illusion of 3D space for seemingly realistic user interactions (Eschenbrenner, Nah, & Fui-Hoon, 2008). Some emergent virtual reality technologies are *visuo-haptic*, coupling 3D visualization and haptic stimuli. Haptic or touch feedback allows for user interaction with tactile sensation (hardness, weight) through force feedback (Jones & Minogue, 2006) through a HE hardware device. Users able to manipulate *and feel* objects within the 3D space, as if they were manipulating them in reality (McLaughlin, Hespanha, & Sukhatme, 2002). Haptics may also be used to experience abstract scientific phenomena to help students conceptualize unseen forces, like van der Waals interactions between molecules (Lee & Lyons, 2004). Haptic feedback has been empirically shown to contribute to an immersive experience for the user (Jones & Minogue, 2006).

Since 3D HE VR systems are designed for user involvement and immersion, it is hypothesized that these tools have a great potential to induce presence for the user (Witmer & Singer, 1998). Inducement of presence is significant as learner-computer interactivity (involvement) and representational fidelity (immersion) have shown gains in users' spatial understanding, motivation, engagement and learning outcomes compared to 2-Dimensional (2D) interventions (Dalgarno & Lee, 2010). According to a study by Limniou, Roberts, and Papadopoulos (2008) chemistry students who participated in 3D learning sessions understood molecules' structure and chemical reactions better when compared to learning the same concepts using 2D computer-based animations. As an added benefit, the authors reported that "students were enthusiastic, as they had the feeling that they were inside the chemical reactions and they were facing the 3D molecules as if they were real objects front [sic] of them" (p. 584). Thus, 3D, HE and VR technologies have been researched in a variety of instructional contexts, demonstrating success in both teaching and learning for surgical training (Cannon et al., 2014; Fang, Wang, Liu, Su, & Yeh, 2014; Gomoll, O'Toole, Czarnecki, & Warner, 2007), studying dance (Eaves, Breslin, & Van Schaik, 2011), physical rehabilitation (Levin, Weiss, & Keshner, 2015; Shin, Ryu, & Jang, 2014), and therapy for engaging in social interactions (Smith et al., 2015).

Largely, 3D, HE, and VR technologies have been utilized separately for adult users or learners, with fewer studies exploring their affordances for younger learners (Hite, 2016). Three-dimensional VR technologies have shown there are learning gains for primary level students (Bouta & Retalis, 2013) as well as a greater efficiency for younger learners' understanding of science concepts through immersive engagement (Stull, Barrett, & Hegarty, 2013). Virtual presence and its relationship to student learning is a growing field of research (Hite, 2016) because users may become more engaged in learning activities due to the realistic contexts these systems provide to "design meaningful learning activities in immersive virtual learning environments" (Cho, Yim, & Paik, 2015, p. 70).

Pre-Service and In-Service Teachers Use of Technology in Classroom Instruction

Individuals' use of technology has been documented and measured and continues as advanced technology becomes prevalent in workplaces, homes, and schools. Early research of technology acceptance studied users' attitudes towards technology (Taylor & Todd, 1995) and users' acceptance of technology (Davis & Venkatesh, 1996). From this work, the PU and PEOU of computer-based technologies have been shown to mediate an individual's acceptance behavior; as such, these two constructs (attitude and acceptance) comprise TAM (Davis, 1989; Davis et al., 1989). An extension of TAM would be in exploration of teachers' perceptions of computer-based instructional technologies. Barriers to teachers using technology in instruction have been largely related to computer literacy and comfortability (Ertmer, 1999), historically prejudicing in-service teachers who had less access to and familiarity with computer technology. As computers have become ubiquitous, recent studies using TAM have not found any significant relationship between age and gender for attitudes towards computers (Teo, 2008). Although research continues to show differences in technology acceptance between teachers where those with a shorter length of service held higher levels of technology acceptance (Teo, 2014). According to Teo (2009), pre-service teachers indicated their willingness to utilize technology if they perceived incorporating the technology would be useful to their teaching practices. When teachers held this positive perception of technology, they were evaluated as more efficient and effective educators for their students. However, preservice teachers' self-efficacy in implementing technology into their teaching practices is dependent on their experiences with these technologies (Magliaro & Ezeife, 2007). A litmus test for users in PU (and less important to PEU), is learning (content) using the technology; research by Saadé and Bahli (2005) found improved learning outcomes for the individual played an important role in explaining future intention (acceptance) of using the technology for subsequent learning. Therefore, teachers, whose occupation is content understanding, may find their own learning an important point in their PU and ultimately technology acceptance and future intention for classroom use.

This invites the question of why in-service teachers are viewed as luddites in using instructional technology. The *Lazy User Model* (LUM) by Tétard and Collan (2009), described a user's unwillingness to adopt new technology due to exertion of new effort when traditional methods have sufficed in the past. Arguably, in-service teachers may view new technology as too complicated or simply inferior to their existing pedagogical practices. Research in *pedagogical discontentment* can further clarify this issue as it is defined as "the unease one experiences when the results of teaching actions [practices] fail to meet with teaching goals" (Southerland, Sowell, & Enderlie, 2011, p. 439). This is important as experienced in-service science teachers are more resistant to modifying their practice; yet when they experience this dissonance, they become receptive to new teaching strategies, influenced by both cognitive and affective factors (Southerland et al., 2012). Therefore, a study that would wish to evaluate TAM among teachers would need to measure not only content gains when using new technology, but also explore the affective perceptions of their PU and PEOU to ascertain future classroom use. Therefore, it is important to explore teachers' perceptions (in-service and pre-service) of the viability of technology as learning tools for their students. Based upon this dichotomy between pre-service and in-service teachers, Teo, Lee, and Chai (2008) recommended further studies comparing in-service and pre-service teachers' perceptions of technology acceptance with emergent instructional tools. Previous research has examined in-service teachers' preferences for pedagogical approaches in teaching science, and sampled teachers (and students) preferred using 3-D, HE, VR compared to most traditional (e.g. textbook, videos, simulations, etc.) means (Jones et al., 2016). Further research is needed to explore how teachers from various levels of experience rank their acceptance or preference for novel technologies against other instructional approaches.

Studies of teacher attitudes and acceptance have led to research investigating teachers' pedagogy while using technology. Research exploring teachers' knowledge of technology and how it functions within their pedagogical schema led to the development of the Technological Pedagogical Content Knowledge (TPACK) model (Koehler & Mishra, 2009). The TPACK framework seeks to explain the convergence of the following realms of teacher knowledge: pedagogical and content knowledge (PCK), technological and content knowledge (TCK), and technological and pedagogical knowledge (TPK). While TPACK offers a rich conceptual frame to understand the situated nature of teaching (Mishra & Koehler, 2006), it has limitations. Moreover, PCK can be difficult to measure provided teaching itself is a complex and ill-structured domain (Koehler & Mishra, 2009). With the addition of a technological component to the already complex and elusive measurement of PCK, this has made quantifying TPACK in research a difficult task. Most recently, influences from the learning sciences using the design experiment schema (Cobb, Confrey, Lehrer, & Schauble, 2003) have been employed to support new models of teacher relationships with technology such as the classroom orchestration framework (Dillenbourg & Jermann, 2010; Kollar & Fischer, 2013). This new model emerged as a means of understanding the role of the teacher throughout the planning, arranging, and conducting of a lesson within a technology enhanced learning environment.

To add to this body of research, this exploratory study explored pre-service and in-service science teachers' perceptions of a 3D HE VR instructional technology tool (zSpace®) and conceptualizations of its potential use in the classroom. This work is to further investigate findings by Teo (2014) that teachers with shorter lengths of teaching service, held greater technological acceptance than longer serving classroom teachers. The choice to sample and compare pre-service and in-service teachers using the TAM model (as a lens of analysis) was to understand when PEOU use diminishes (e.g. neither teacher group has had prior experiences with zSpace®, a technology intentionally designed to be intuitive and interactive), how does PU influence technology acceptance between teacher groups? As participants learn science content using the technology, could that augment the user's PU? This work builds on other studies that recommend research on teachers' perceptions of cutting-edge instructional technologies to explore how they would adopt them into their teaching practices (Teo et al., 2008). More important, this research may reconsider how to develop teachers' technology acceptance (both pre-service and in-service) to support student learning using emergent technologies.

Methodology

The following research questions were investigated in this study:

1) Is the use of 3D HE VR technology to teach series and parallel circuits and the anatomy and physiology of the human heart associated with learning gains for pre-service and in-service teachers?
2) What are pre-service and in-service science teachers' perceptions of the pedagogical utility of 3D HE VR technology and what are their respective preferences as compared to other instructional strategies (more interesting and increases their understanding)?
3) How are perceptions different between pre-service and in-service teachers on the pedagogical utility of 3D HE VR technology, as compared to other instructional strategies (more interesting and increases their understanding)?

Participants.

This study was conducted with five pre-service and five in-service teachers in an urban area of North Carolina using a 3D HE VR system (zSpace®). Purposive sampling (Hesse-Biber, 2016) was chosen of teachers by level of experience (no classroom experience with pre-service teacher candidates and some classroom experiences with in-service teachers) and among those who had no prior experiences in using zSpace® technology. This was to ensure participants had equivalent skills (i.e. none) with other 3D, HE, and VR technologies. This component of the sampling process is important as prior use (Prensky, 2001) may influence (or in this study, prejudice) technology acceptance (Teo, 2014). Therefore, pre-service teacher participants were recruited from a graduate (master's) program in science education. In this secondary science certification program, students were enrolled in a 1.5 years hybrid program, where students took both seated and online classes. Each participant within this group held a bachelor's degree in a science field and had completed most of their coursework (24 out of 33 total hours) at the time of the study. The selection criteria for pre-service teachers included those who had not completed a teaching with technology course, nor their student-teaching internship, to ensure they held no prior knowledge of technology-based pedagogies or classroom experiences in the teacher's role. The in-service (i.e. active full-time classroom teachers) participants were recruited from nearby schools who held current state certification in secondary math and/or sciences. All individuals with interest had their teacher experience quantified; their formal teaching experience ranged from 2 to 10 years ($M = 6.6$, $SD = 3.58$) for a combined 33 years of formal teaching experience. Although some of the in-service teachers could be ascribed as early career teachers, generally, in-service teachers of any experience level are remarkably different than their pre-service counterparts. Prior research suggests that any use of technology in instruction influences teachers' attitudes and use of computer technology (Yildirim, 2000). Also, longitudinal studies and meta-analyses indicate that teachers learn a great deal about their profession and develop self-efficacy when they enter the classroom, during student teaching (Hoy & Spero, 2005), and in their first few years of teaching (Marso & Pigge, 1989). Since the pre-service participants have received the vast majority of the training (courses), but not the experience (student teaching) of teaching, these may not be considered as similar groups and worthy of comparison in their learning with and pedagogical perceptions of zSpace®.

Equipment.

This study utilized the zSpace® system that combines 3D images with feedback within a VR desktop-based environment. The zSpace® VR hardware is desktop-based that uses stereoscopic images to produce 3D images. Although desktop VR hardware produces less user immersion than other hardware systems like head mounted or projection VR systems, (Hite, Childers, & Jones, 2019; Lee, Olwal, Ishii, & Boulanger, 2013), it can provide a robust interactive VR experience for the user (Hite, 2016; Jones et al., 2016). The systems consists of a central processing unit (CPU), a 24-inch-high definition liquid crystal (1080p, 120Hz) 3D stereoscopic display screen complete with built-in tracking sensors to track the viewing angle of the user, a 3-button stylus with integrated haptic technology and infrared LEDs for manipulating interactions within the virtual reality space, and a set of polarized eyeglasses with reflective sensors to track head and body movement in real-time (zSpace®, 2016). This hardware is complemented with 3D and VR software applications to create detailed 3D simulated images, which appear both within and outside of the screen, that can be manipulated (e.g. rotated, zoomed, dissected, etc.) by the user with an HE stylus. Figure 1 shows the components of the zSpace® system.

Figure 1. zSpace® 200 display (zSpace®, 2014).

Specific VR technologies leverage aspects of prior user experiences to reduce EOU issues. The user interface is designed to be intuitive and easy to use with head-tracking and an ergonomic stylus, requiring no prior experience and only a few minutes of use to fully utilize the device (zSpace®, 2015). The zSpace® technology uses hardware components of which any teacher would have prior knowledge, including a pencil (stylus), glasses (eyewear), and VR interface (computer screen). Whereas other VR technologies like Head Mounted Displays (HMDs) are comprised of hardware technologies that are confining, unfamiliar, and can be disorienting for users (Sharples, Cobb, Moody, & Wilson, 2008). In using HMDs in the classroom, teachers cannot view the user's (students') experiences in the VR environment. With desktop VR, teachers can monitor students, and aid them (by taking the stylus) in navigating their environment. With this modality of VR, there are means for teacher-student interaction in guiding the experience, scaffolding the content with real-time interaction.

Intervention.

Each participant had three hours of total time on the zSpace® system. The first hour was devoted to basic use of the system: wearing the eyeglasses, navigating using the stylus and manipulating objects in the virtual space. This self-directed time provided participants practice moving, rotating, scaling and dissembling objects using the HE stylus. Afterwards, participants were guided individually by a researcher through two separate curricular modules, one hour for each module, exploring the human heart and electrical circuits, respectively.

In the first module, participants explored the anatomy and physiology of the human heart, felt a simulated heart beat with the HE stylus, viewed vocabulary connected to heart anatomy (e.g. left atrium, right atrium, left ventricle, right ventricle, superior vena cava, inferior vena cava, pulmonary artery, pulmonary vein, aorta), and investigated the pumping action (structure and function) of the four cardiac valves. Figure 2 shows the zSpace® interface (not in 3D) for the human heart module.

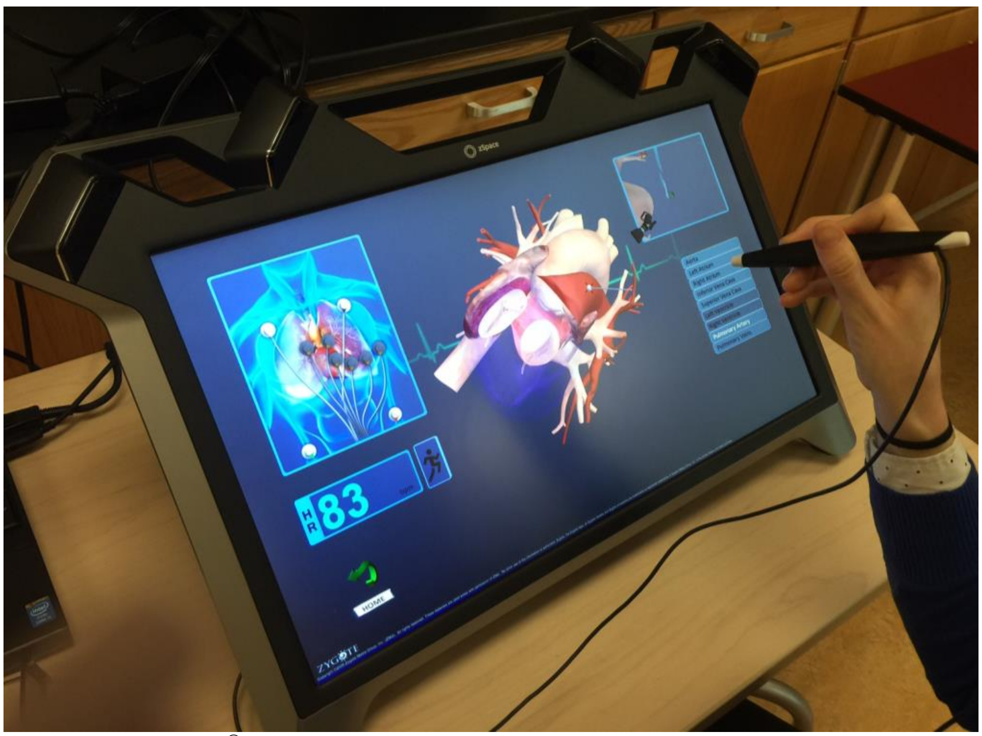

Figure 2. zSpace® 200 display (not in 3D) of Heart Module (Hite, 2014a).

In the second module, participants learned the parts of a circuit (e.g. wires, battery, switch, bulb), discerned the difference between series and parallel circuits, viewed current flow in a circuit through simulated electron movement, and troubleshot circuits by adding or subtracting components to build a functional closed circuit. Figure 3 shows an example of the zSpace® interface (not in 3D) for the circuit module.

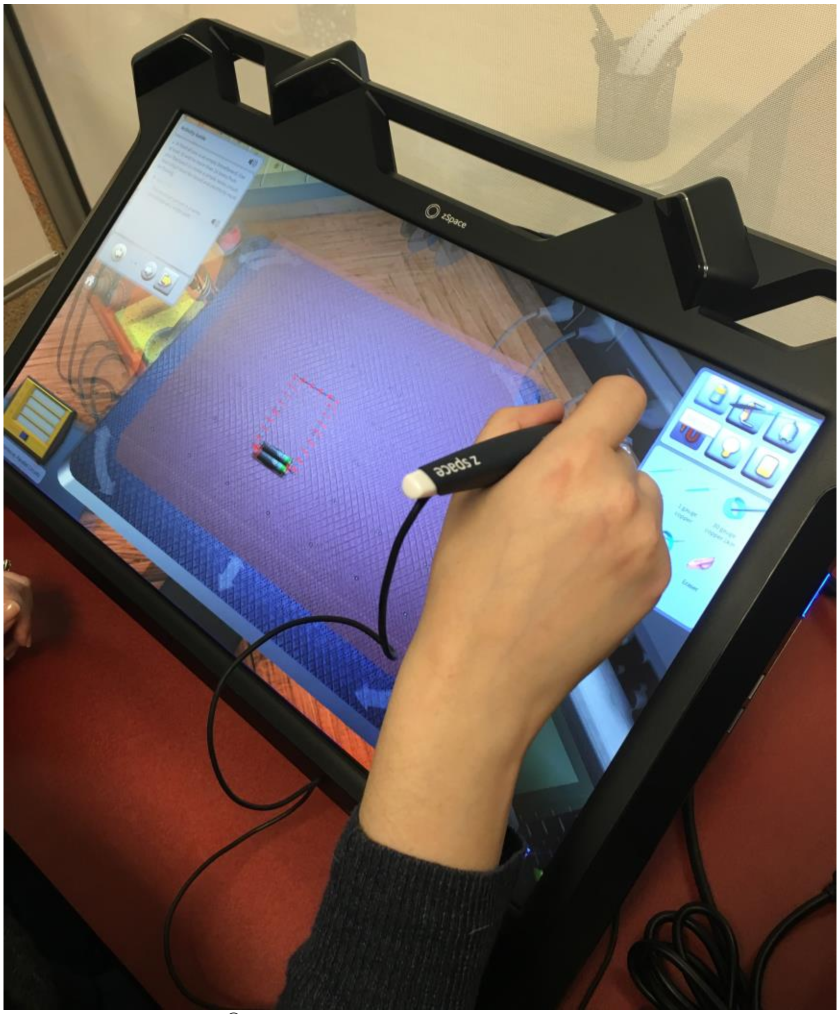

Figure 3. zSpace® 200 display (not in 3D) of Circuit Module (Hite, 2014b).

Data Collection.

Prior to engaging with content-based software, participants were given a pre-test on the human heart and circuits, lasting approximately thirty minutes. Upon completion of their 3D HE VR experience, they were given a post-test on the human heart and circuits, respectively, to evaluate their knowledge of (1) the anatomy and physiology of the human heart and (2) series and parallel circuits. Both assessments are found in Appendix A. These two content domains were chosen because they represent relevant science concepts taught in the middle grades. Content validity of each test was ensured by a panel review of four expert science teachers with 6-12 science certification. Reliability was completed using the Kuder-Richardson (KR) 20 formula as a check of the internal consistency of items. It is applicable for this analysis as both tests assessed a single homogenous domain of knowledge containing items of varying difficulty in a single, untimed test administration. The first assessment was aligned to the concepts of the structure (anatomy) and function (physiology) of the heart with 13 selected response items and a performance-based task on cardiac circulation. The KR-20 value was 0.664 which is within acceptable range for a classroom test (Reynolds, Livingston, & Willson, 2009). The second assessment was aligned to concepts of electron flow in series and parallel circuits with 13 selected response items and performance-based tasks of evaluating series and parallel circuits.

The KR-20 value was 0.205. Both content assessments were used in a prior research with teachers (*N*=10) and 6th grade students (*N*=22) using the same zSpace® hardware and software (Jones et al., 2016), with KR-20 reliability values of 0.750 and 0.745 respectively. The reliability values for teachers' scores (0.664, 0.205) should be interpreted with caution provided the small sample size and greater heterogeneity of domain knowledge for within the teacher group, leading to ceiling effects on post-assessments (Reynolds et al., 2009), especially in the circuit assessment.

Furthermore, participants were asked prior to instruction on the heart to use a white board and draw arrows to show cardiac blood flow into, within, and exiting the heart and label major blood vessels and chambers, indicating the location of the four heart valves. Prior to instruction on circuits, participants were asked to identify circuits in series and parallel, as well as interpret the functionality of circuits based on images of hypothetical circuits (see Appendix B for both assessments). Proficiency was scored with a rubric (see Appendix C) developed by the same four expert science educators. Inter-rater agreement was 95% and 94% respectively.

Additional qualitative data were collected through open-ended interviews lasting 45 minutes in length. The 13-question interview protocol was developed by 4 expert science educators to explore respondents' experiences learning science using a 3D HE VR system, how this technology may be used in the K-12 classroom, preferences for learning science, and types of instructional methods for teaching science. The interview protocol was informed by Davis' (1989) TAM to explore respondents' acceptance and use of new technology. The interview protocol included questions about ease of using a 3D HE VR system, positive and negative attributes of using the system, benefits and challenges of using the system in an instructional context, and personal preferences for teaching and learning with technology. The final question asked participants to compare their zSpace® experience with other forms of instructional methods or strategies to teach science (i.e. teacher instruction, hands-on activity with materials, models, simulations, textbook, videos and reading on the internet). Participants ranked their preferences by *most interesting* and which *best increased your understanding* on a scale of 1 to 8, (one indicating most preferred and eight as the least preferred). Each interview was audio recorded by the researcher for transcription, coding, analysis, and reporting. The interview protocol is available in Appendix D.

Analyses.

To determine if participants had learning gains from the use of this novel instructional technology, the data were analyzed with a paired, two-tailed t-test (alpha value of 0.05) to examine whether there were differences for pre-service and in-service teacher scores on each assessment. Non-parametric sign tests were used to evaluate gains on single individuals and items from pre- and post-assessment for both teacher groups. This type of analysis was done to reduce error by analyzing only the signs of the difference scores, due to the low number of test items and sample size. If there are more positive differences than negative, we can reject the null hypothesis (for a sample size of 10, it would be 8 positive values for a two-tailed alpha = 0.05). The interview data (see Appendix D, question 13) ranking zSpace® to other instructional methods (which was more interesting and increased their understanding) were analyzed between teacher groups by comparing means, calculating standard deviation, and deriving p-values from an unpaired t-test at 95% confidence.

To qualitatively triangulate teachers' pedagogical perceptions of this instructional tool, interview data were transcribed from audio recordings sourced from teacher utterances during all zSpace® sessions and final interviews. The data were pooled from both sources and quotes were coded *a priori* by researchers according to the TAM framework (by PU or PEOU constructs). To provide the reader context and add trustworthiness, an audit trail was conducted to source participant (i.e. pre-service teacher [1-5] or in-service teacher [6-10]) quotes.

Results

Tables 1 and 2 show the results of the pre-service and in-service teachers' cardiac assessments; the heart content assessment (Table 1) and the heart open-ended assessment (Table 2).

Table 1
Results of Content Assessment of the Heart, Pre-service and In-service Teachers

Teacher Participant	**Pre-service**					**In-service**			
	Score (Pre-test)	Score (Post-test)	Difference	Sign Test		Score (Pre-test)	Score (Post-test)	Difference	Sign Test
Teacher 1	3	11	8	+	Teacher 6	10	11	1	+
Teacher 2	6	10	4	+	Teacher 7	4	9	5	+
Teacher 3	5	12	7	+	Teacher 8	4	11	7	+
Teacher 4	10	10	0	None	Teacher 9	6	10	4	+
Teacher 5	6	13	7	+	Teacher 10	3	9	6	+

Note. Maximum Score was 13 points.
Sign Test, Alpha 2-tailed, $p < 0.05$

The sign test had 10 positive scores out of 10 teachers for a p-value < 0.0020, indicating there was significant improvement between the pre-assessment and post-assessment (Table 1), on the content assessment of the heart.

Table 2
Results of Document Analysis of the Open-Ended Assessment of the Heart, Pre-service and In-service Teachers

Teacher Participant	**Pre-service**					**In-service**				
	Mean Score (Pre-test)	Standard Deviation (Pre-test)	Mean Score (Post-test)	Standard Deviation (Post-test)	Sign Test	Mean Score (Pre-test)	Standard Deviation (Pre-test)	Mean Score (Post-test)	Standard Deviation (Post-test)	Sign Test
Orientation 1[a]	4	0.548	6	0.671	+	3	0.548	6.5	0.758	+
Orientation 2[b]	6	0.707	7	0.894	+	5	0.707	6	1.095	+
Labeling (Major Vessels)	2	0.000	8.5	0.447	+	0	0.000	7.5	0.866	+
Labeling (Atria and Ventricles)	5.5	0.612	10	0.000	+	5	0.612	10	0.000	+
Labeling (Heart Valves)	0	0.000	0	0.000	None	0	0.000	0	0.000	None

Circulation to the Heart	6	0.671	10	0.000	+	4	0.671	7.5	0.866	+
Cardio-pulmonary Circulation	3.5	0.274	7.5	0.500	+	1.5	0.274	5.5	0.418	+
Circulation from the Heart	4.5	0.447	7.5	0.000	+	3.5	0.447	5	0.707	+

Note. Although heart valves were visible from instruction and represented on the whiteboard, they were not labeled in the software program. Participants were not expected to have any different level of knowledge from pre to post on this topic, but item was represented to see if there was a change in their knowledge.
Maximum Score was 10 points per category.
Interrater agreement on document analysis was 95%.
Sign Test, Alpha 2-tailed, $p < 0.05$
[a]Question asked which direction blood flowed from top of heart (towards the head)
[b]Question asked which direction blood flowed from the side of the heart (towards the lungs)

In the pre-service teacher group, a comparison of the pre-assessment mean (6.00) to the post-assessment mean (11.20) of the open-ended assessment of the heart indicated a significant difference (two-tailed, alpha = 0.05, p < 0.024) displayed in Table 2. This includes the participants' individual scores when tracing cardiac circulation within a 2D cross-sectional representation of the heart. The sign test had 14 positive scores out of 14 items (excluding labeling of the heart valves) for a p-value < 0.0001, indicating there was a significant improvement (two-tailed, alpha = 0.05) in understanding heart orientation in relation to the body (head, lungs), cardiac anatomy (major vessels, atria, ventricles), and cardiac circulation (blood movement towards, within and out of the heart).

Tables 3 and 4 show the results of the circuit assessments of pre-service and in-service teachers, first on the circuit content assessment (Table 3) and second, the circuit open-ended assessment (Table 4). In Table 3, the sign test indicated 5 positive scores out of 10 (i.e. remaining five were null), indicating there was not enough evidence (p-value < 1.2461, two-tailed, alpha = 0.05) to indicate significant improvement between pre-assessment and post-assessment administrations.

Table 3
Results of Content Assessment of Circuits, Pre-service and In-service Teachers

Teacher Participant	**Pre-service**					**In-service**			
	Score (Pre-test)	Score (Post-test)	Δ	Sign Test		Score (Pre-test)	Score (Post-test)	Δ	Sign Test
Teacher 1	10	10	0	None[a]	Teacher 6	10	10	0	None[a]
Teacher 2	9	10	1	+	Teacher 7	10	10	0	None[a]
Teacher 3	8	10	2	+	Teacher 8	9	10	1	+
Teacher 4	8	10	2	+	Teacher 9	10	10	0	None[a]
Teacher 5	10	10	0	None[a]	Teacher 10	8	10	2	+

Note. Maximum Score was 10 points.
Sign Test, Alpha 2-tailed, $p < 0.05$
[a]Ceiling effects impacted pre-and post-score differences.

Participants' individual and items scores for identified series circuits, parallel circuits, electron flow, and predicted functionality of various circuits is shown on Table 4. The sign tests indicated 18 positive scores out of 22 scores for a p-value < 0.0043 (two-tailed, alpha = 0.05) indicating there was a significant improvement in the understanding of series circuits, parallel circuits, electron flow, and components of a functioning circuit.

Table 4
Results of Document Analysis of Open-Ended Assessment of Circuits, Pre-service and In-service Teachers

Teacher Participant	**Pre-service**					**In-service**				
	Mean Score (Pre-test)	Standard Deviation (Pre-test)	Mean Score (Post-test)	Standard Deviation (Post-test)	Sign Test	Mean Score (Pre-test)	Standard Deviation (Pre-test)	Mean Score (Post-test)	Standard Deviation (Post-test)	Sign Test
ID of a Series Circuit	9	1.115	9	0.664	None	9	1.443	10	0.964	+
ID of a Parallel Circuit	9	1.115	9	0.634	None	9	1.443	10	0.964	+
Direction of Electron Flow in Series Circuit	6	1.206	9	0.634	+	5	1.545	10	0.964	+
Direction of Electron Flow in Parallel Circuit	6	1.165	9	0.634	+	5	1.545	10	0.964	+
Removal of Bulb in Series Circuit	7.5	1.054	8	0.685	+	7.5	1.373	8	0.940	+
Removal of Bulb in Parallel Circuit	7.5	1.054	8	0.685	+	7.5	1.373	8	0.940	+
ID of a complete circuit	9	1.115	9	0.634	None	9	1.443	9	0.908	+
ID of an incomplete circuit	8	1.055	8.5	0.644	+	8	1.382	8	0.940	+
ID correct battery orientation	7.5	1.054	8.5	0.644	+	6.5	1.400	8.5	0.913	+
ID correct application of a switch	8.5	1.076	10	0.707	+	8	1.382	8	0.940	None
ID correct application of electron flow	7	1.073	10	0.707	+	7.5	1.373	8	0.940	+

Note. Ceiling effects were pronounced in this curriculum as participants had prior knowledge of simple series and parallel circuits.
Maximum Score was 10 points per category.
Interrater agreement on document analysis was 94%.
Sign Test, Alpha 2-tailed, $p < 0.05$

Summary statistics including means and standard deviation values for both the pre-service teacher group and in-service teacher group for each assessment given in the study (Tables 1, 2, 3, and 4) are shown in Table 5. There were a few significant relationships of note, first, both the preservice group (with a pre-assessment mean of 6.00 and a post-assessment mean of 11.20) and the in-service group (with a pre-assessment mean of 5.4 and a post assessment mean of 10.00) on the heart content assessment were both significant (with a two-tailed, alpha = 0.05, p < 0.024 and a two-tailed p-value < 0.011, respectively). Next, for correctly tracing blood flow to, within, and out of the heart (i.e. the open-ended heart assessment), both the pre-service group (3.94 for the pre-assessment and 7.06 for the post-assessment) and in-service group (2.75 for the pre-assessment mean and 6.00 for the post assessment mean) had significant gains (with a two-tailed p-value < 0.004 and a two-tailed p-value < 0.007, respectively). The open-ended assessment analysis for circuits revealed that the pre-service group (with a pre-assessment mean of 7.73 and a post assessment mean of 8.91) and the in-service group (with a pre-assessment mean of 7.45 and a post assessment mean of 8.86) were both significant (with a two-tailed p-value < 0.011 and a two-tailed p-value < 0.031). However, for the circuit content test there were no significant changes, from pre to post assessment, for neither teacher group.

Table 5
Dependent T-Tests of Pre-service and In-service Teachers' Scores for All Assessments

	Heart Content Test (Table 1)		**Circuit Content Test (Table 3)**		**Heart Open-Ended Assessment (Table 2)**		**Circuit Open-Ended Assessment (Table 4)**	
Teacher Group	Pre-service	In-service	Pre-service	In-service	Pre-service	In-service	Pre-service	In-service
Pre-assessment								
mean	6.0	5.4	9.0	9.4	3.9	2.8	7.7	7.5
SD	2.5	2.8	1.0	0.9	2.1	2.0	1.1	1.4
Post-assessment								
mean	11.2	10.0	10.0	10.0	7.1	6.0	8.9	8.9
SD	1.3	1.0	0	0	3.2	2.9	0.7	1.0
p-value	***0.002****	***0.011****	***0.090***	***0.208***	***0.004****	***0.007****	***0.011****	***0.031****

Paired t-test, Alpha 2-tailed. * $p < 0.05$

Table 6 displays the paired differences between pre-service teachers' and in-service teachers' responses based upon science instruction that was "more interesting." Participants were asked to rank zSpace® as compared to seven other types of instructional strategies used in the traditional science classroom: reading on the internet, watching videos, use of textbooks, simulations, models, hands-on activities with materials and teacher direct instruction.

Table 6
Teacher Perceptions of Instructional Options, Ranked by "More Interesting."

Teacher Group	**Pre-service (N=4)**		**In-service (N=5)**		
	Group Mean	Standard Deviation	Group Mean	Standard Deviation	***p-value***
zSpace®	2.25	0.500	1.40	0.548	***0.047****
Reading on the Internet	7.25	0.957	6.00	1.000	***0.099***
Videos	5.00	0.816	5.00	1.000	***1.000***
Textbook	7.50	0.577	7.80	0.447	***0.406***
Simulation	3.50	1.291	3.80	1.304	***0.741***
Model	4.50	1.291	4.40	1.673	***0.925***
Hands-on Activity with Materials	1.00	0.000	1.60	0.548	***0.068***
Teacher Instruction	5.00	1.826	6.00	1.581	***0.407***

Note: A score of 1 indicates the most agreement with the statement, 8 the least.
One pre-service teacher was not given this question during the interview.
Unpaired t-test, Alpha 2-tailed. * $p < 0.05$

Table 7 displays the paired differences between pre-service teachers' and in-service teachers' responses based upon science instruction that "increases my understanding" of a science topic. Participants were asked to rank zSpace® as compared to seven other types of instructional strategies used in the traditional science classroom: reading on the internet, watching videos, use of textbooks, simulations, models, hands-on activities with materials and teacher direct instruction.

Table 7
Teacher Perceptions of Instructional Options, Ranked by "Increases my Understanding."

Teacher Group	**Pre-service (N=4)**		**In-service (N=5)**		
	Group Mean	Standard Deviation	Group Mean	Standard Deviation	***p-value***
zSpace®	2.75	0.957	2.80	1.789	***0.962***
Reading on the Internet	8.00	0.000	5.20	2.775	***0.087***
Videos	6.75	0.500	5.80	1.304	***0.215***
Textbook	5.75	1.258	4.60	2.408	***0.419***
Simulation	3.75	1.258	4.80	1.643	***0.329***
Model	4.25	1.5	7.00	1.414	***0.026****
Hands on Activity with Materials	1.00	0.000	2.60	2.510	***0.249***
Teacher Instruction	3.75	1.500	3.20	1.483	***0.599***

Note: A score of 1 indicates the most agreement with the statement, 8 the least.
One pre-service teacher was not given this question during the interview.
Unpaired t-test, Alpha 2-tailed. * $p < 0.05$

Both pre-service and in-service teacher groups had significant learning gains on each of the four assessments in the two content domains. The lack of change from pre-to post-assessments on certain items indicated there were ceiling effects due to a range-of-instrument constraint on the circuit assessments as compared to the heart assessments. Because participants scored highly on both pre-test and post-test, there was a poor visualization of variance (Reynolds et al., 2009) in their content knowledge of circuits (Table 5). This may also indicate that participants had a better content knowledge of series and parallel circuits than heart anatomy and physiology. In-service teachers ranked the virtual reality (zSpace®) option of instruction much higher than pre-service teachers for a more interesting experience (Table 6) and approximately equal for increasing their understanding of the science topic (Table 7). In-service teachers ranked immersive and interactive experiences (using models, teacher instruction, textbooks and internet reading) as less interesting for science instruction, yet pre-teachers had similar results with a higher preference for hands-on activities with materials (Table 6). However, when asked what instructional modality increased their understanding, pre-service teachers more strongly preferred virtual options (zSpace®, simulations), and teacher instruction, over other types of instruction (Table 7). In both instances, pre-service teachers preferred hands-on activities with materials as their first option methods for being more interesting (Table 6) and increasing their understanding of science content (Table 7).

During interviews, teachers were asked if they would prefer to use the zSpace® system as compared to traditional methods of instruction. Participants were asked to reference their 3D HE VR experience exploring the interior and exterior of a human heart to a comparable hands-on dissection of an animal heart. A pre-service participant (Teacher 1) said:

> I think I like the traditional ways better, but it's like a good substitute. It's fun to do it every now and again, but I feel like if you did it all the time it would lose some of its spark and not be as interesting.

This indicated the pre-service teacher acceptance of technology laid only in PEOU, not acknowledging PU to students' conceptual understanding. When queried to an in-service teacher (Teacher 2), she replied:

> The 3D HE VR experience] questions was [sic] your understanding of the fact that science isn't a bunch of facts, it is an observation of nature and a bunch of things. It's not people telling you the heart is this or that or circuits do this or that.

The in-service teacher clearly recognized how the technology may be scaffolded to explore this essential concept acknowledging both PEOU and PU in the TAM framework.

This finding was replicated in a separate question when participants described how learning in a 3D HE VR environment was different from traditional practices of teaching science. One of the pre-service teachers (Teacher 3) said, "I think it kind of encourages the students in class more than in just using the textbooks. But sometimes, I think the real experiment would be better." This teacher acknowledged the utility of the instructional tool (EOU) yet held a decided preference for traditional methods. Conversely, an in-service teacher (Teacher 6) remarked:

> This gave the opportunity to be able to question things and discover depending on what the user needed. So, when I was having difficulty understanding the heart, I was able to stop, refocus the heart where I needed it to be, and start over…. so in a classroom, if a student doesn't understand it, you don't always have the tools or capability to show it another way, or a second way, or a third way. Where [sic] with this program it gave a lot of opportunities within the program itself to be able to look at the problem in a different way.

In this example, the in-service teacher referenced both PEOU and PU of TAM through a pedagogical lens. In her experience, she recognized that students struggle with lab-based activities that present information in only one format, whereas the 3D, virtual world afforded additional opportunities to explore scientific phenomena through differentiated instruction.

To understand participants' preferences in a real-world context, teachers were asked their preferences in using zSpace® as a dissection tool in the science classroom. A pre-service teacher

(Teacher 4) replied:

> [dissection], but that's just my personal [view], I like cutting things open and the feeling they are real, you know how the organs feel and the tactile aspect of it. But, I think that in terms of anatomy, all of the same goals [of instruction] as [the] zSpace® virtual frog you could [do] with the real frog.

In this case, the pre-service teacher accepted the usefulness of the technology as a pedagogical tool, yet her personal preference would prevent technological adoption in the classroom. An in-service teacher (Teacher 5) related that she:

> like[s] both…I think the kids like it [dissection] because there is that gross factor, but I don't know in terms of actually learning if it is more beneficial…You have to go step by step or they just rip the frog apart and don't try to find any structures.

In this instance, the in-service teacher's acceptance of the technology was not only rooted in TAM, but also included PK, where prior experiences in dissection have yielded mixed results for students. Another in-service teacher (Teacher 7) said:

> I would prefer doing it on the zSpace®, because I don't necessarily like the thought, I mean, I realize they raise the frogs for scientific purposes, but you are killing something that was alive so you can cut it open. So on zSpace®, you are not harming a living thing.

This teacher acknowledged ethical issues of dissection, likely sourced from their experiences in the classroom where students may hold religious or moral principles barring them from participation in authentic scientific activity.

Limitations

Due to resource restrictions (i.e. expense of equipment and access to participants), findings and the generalizability of this study are limited. Therefore, the degree to which this sample is representative of teachers' perceptions of 3D HE VR instructional technology is unknown. Because of ceiling effects seen with the circuit pre and post assessment, content area findings within the study are limited. Based upon the findings between these groups, sampling from a larger population of pre-service and in-service teachers would provide more information about teachers' preferences of instructional methods.

Discussion

This research study explored pre-service and in-service teachers' perceptions of technology acceptance using a 3D HE VR technology platform called zSpace®. In this case, neither group was likely to have technological fluency in this medium to privilege one side or the other as digital immigrants or digital natives (Prensky, 2001). This finding proposes that feelings of insecurity reported by teachers in accepting and adopting technology when teaching technologically savvy students (Teo, Lee, Chai, & Wong, 2009) may be moderated when using the zSpace® platform with sufficient training opportunities. This study suggests when pre-service and in-service teachers have similar technological backgrounds (e.g. the same level of knowledge and experience with a novel form of instructional technology that is designed for intuitive use) as a proxy for equivalent PEOU, teachers are now free(er) to access their pedagogical beliefs (prior experiences teaching without and with) technology (Ertmer, 2005) to increase their PU, consequently influencing their TA. This idea is supported by this study in that content learning mattered to sampled participants, yet varied among the teacher groups to how they perceived the technology as a viable learning tool. Pre-service teachers viewed their change in understanding using zSpace® as a novelty, whereas in-service teachers saw their own learning as a strong indicator of helping students learn complex abstract content (like circuits and the heart). TPACK suggests that the confluence of content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK) "produces the types of flexible knowledge needed to successfully integrate technology use into teaching" (Koehler & Mishra, 2009, p. 60). In this case, although there were equivalent perceptions of EOU (or TK) in both groups (as reported and shown by learning gains by both teacher groups in this study), in-service teachers had an advantage over their less experienced peers in TA by accessing their CK and PK capabilities for envisioning how it would be used in (their) science instruction.

Previous studies have demonstrated pre-service teachers held more progressive attitudes towards computer technology as compared to expert teachers. The results from this study found in-service teachers held more progressive attitudes towards 3D HE VR technology as compared to novice teachers. Both groups gained knowledge when using the zSpace® system; learning gains suggest that users perceived both EOU and U from the perspective of a teacher and a science learner. Controlling for PEOU using a novel technology type, PU was the large mediating factor for TA between the two teacher groups. This was exemplified when both groups described PEOU, however, only in-service teachers also described its PU in their science teaching practice. According to a study by Venkatesh (2000), factors of a user's self-efficacy, motivation and emotion played a considerable role in forming early perceptions about the ease of use of a new system. These variables may disproportionally affect novice teachers, hindering their progression in their technology acceptance processes. The interview data revealed that in-service teachers leveraged content and pedagogical knowledge sourced from their classroom experience to describe their preference for and acceptance of 3D HE VR technology. According to a study by Baylor and Richie (2002), successful technology integration was predicted by teacher openness to change and the percentage of technology use with others. Perhaps these experiences may facilitate a form of technological pedagogical discontentment (Southerland et al., 2012; Southerland et al., 2011) where direct experiences demonstrating the efficacy of the technology (e.g. personal exploration using the technology to personally assess ease of use and experience their own content learning), teachers may begin to self-examine their current teaching practices in lieu for technology-enhanced classroom activities to teach abstract science concepts (Hite, 2016). Therefore, further work regarding appropriate professional development (PD) for pre-service and in-service teachers with novel types of instructional technology is needed. Findings suggest in-service teachers use their technological, content and pedagogical knowledge to mediate their instructional practice when accepting novel technologies. Therefore, PD programs should consider leveraging this situated expertise encouraging in-service teachers as early adopters of emergent (high P/EOU) forms of instructional technology. Conversely, for pre-service teachers, findings suggest they have little to no context for integrating their knowledge for utilizing novel technologies in science teaching. Therefore, PD for pre-service teachers may entail viewing experienced teachers (observation, video) teaching using emergent technologies in the classroom. Pre-service teachers may be able to develop their technological, pedagogical and content knowledge and acceptance of technology situated in a genuine classroom context.

Ethical approval: "All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards."

Informed consent: "Informed consent was obtained from all individual participants included in the study."

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Appendix A
Selected Response Heart and Circuit Assessments

Human Heart Assessment

1. How many chambers are in the human heart?
   A) One
   B) Two
   C) Three
   D) Four

2. Where is blood pressure the highest in the heart?
   A) Aorta
   B) Atria
   C) Ventricles
   D) Pulmonary Vein

3. The heart-beat (sound) heard is made by which of the following?
   A) Contraction of the ventricles and atria
   B) Emptying of the veins
   C) Closing of the heart valves
   D) Draining of the arteries

4. Two large veins drain blood from the upper body and from lower body and empty it into the ________________ of the heart.
   A) Right Atrium
   B) Left Atrium
   C) Right Ventricle
   D) Left Ventricle

5. Which part of the heart pumps oxygen poor blood directly to the lungs?
   A) Right Atrium
   B) Left Atrium
   C) Right Ventricle
   D) Left Ventricle

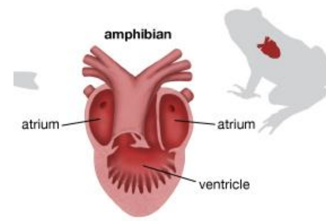
6. Which part of the heart has thicker heart muscle: The atria or ventricles?
   A) Atria
   B) Ventricles

7. What is the function of the left atrium in the human heart?
   A) To receive oxygen-rich blood from the left and right pulmonary veins.
   B) To receive oxygen-poor blood from the left and right pulmonary veins.
   C) To receive oxygen-rich blood from the superior vena cava, inferior vena cava and coronary sinus.
   D) To receive oxygen-poor blood from the superior vena cava, inferior vena cava and coronary sinus.

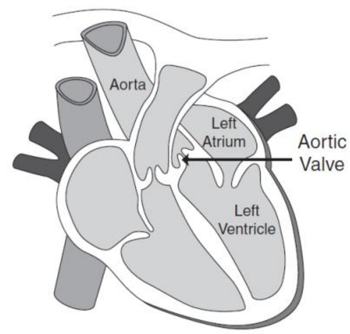
8. Complete the following:
   The _____ ventricle receives blood from the _____ atrium and pumps it to the aorta.
   A) Right, Right
   B) Left, Left
   C) Left, Right
   D) Right, Left

9. The aorta supplies oxygenated blood to the body. What category best describes the aorta?
    A) Artery
    B) Vein
    C) Capillary
    D) None of these

10. *The amphibian heart is a 3-chambered heart, shown here.* What is the consequence of having 1 fewer chamber as compared to the human heart?
    A) Oxygen rich and oxygen poor blood mix in the ventricle.
    B) The heart does not contract with as much force.
    C) The lungs are not as effective in oxygenating blood.
    D) The atria leak blood back into the ventricle.



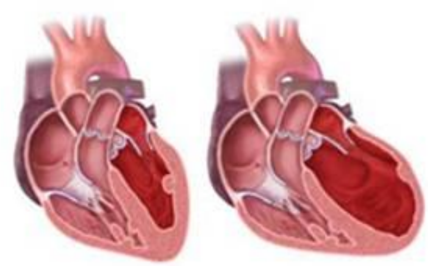
11. *Please look at the diagram of the heart to answer the following question.* When contracted, the left ventricle pumps oxygen-rich blood to the body. What is the purpose of the aortic valve (shown with an arrow) that separates the left ventricle from the aorta?
    A) To prevent blood from flowing back into the left ventricle.
    B) To prevent blood from flowing into the aorta.
    C) To push blood into the left ventricle.
    D) To push blood into the aorta.



12. Without the heart, what function would the body not be able to do?
    A) Move blood around the body and to the extremities.
    B) Exchange Oxygen and Carbon Dioxide in the blood.
    C) Separate oxygen-rich and oxygen-poor blood.
    D) Provide energy to the skeletal muscles.

13. Which correctly identifies this phase of the cardiac cycle: heart ventricles relax and the heart fills with blood?
    A) Systole
    B) Diastole

14. If the heart muscle were to enlarge and thicken (as seen in the picture), what would be the effect on heart function?
    A) The heart would pump more blood and faster.
    B) The heart would pump more blood, but more slowly.
    C) The heart would pump less blood, but faster.
    D) The heart would pump less blood and more slowly.

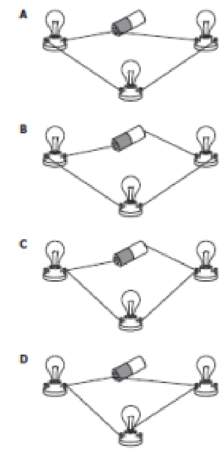


15. What correctly describes what occurs during a heart attack?
    A) The heart tissue starts to beat out of control
    B) The heart tissue begins to beat out of sync.
    C) The heart tissue dies from a blocked artery that feeds the heart muscle.
    D) The heart tissue dies from a blockage inside the atria or ventricles.

Circuits Assessment

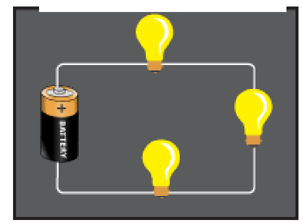
1. What is the best description of electrical energy?
   A) transmitted energy
   B) a special form of heat or thermal energy
   C) potential energy in a different form
   D) the energy of moving electrons

2. A student prepared four electric circuits using a battery, wires and three light bulbs. Which circuit can make the three light bulbs light?
   A) A
   B) B
   C) C
   D) D

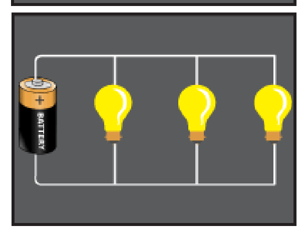


3. How many paths can the current flow in a series circuit?
   A) None
   B) One
   C) More than one

4. *Look at the image right of a series circuit.* What would happen if one of the light bulbs were to burn out?
   A) All the other bulbs would go out.
   B) Only one of the other bulbs would go out.
   C) The remaining bulbs would get dimmer.
   D) Nothing would happen to the other bulbs.



5. *Look at the image right of a parallel circuit.* What would happen if one of the light bulbs were to burn out?
   A) All the other bulbs would go out.
   B) Only one of the other bulbs would go out.
   C) The remaining bulbs would get dimmer.
   D) Nothing would happen to the other bulbs.



6. What is the **resistance** of a radio that uses a 9 Volt battery and carries a current of 3 amps?
   A) 3 volts
   B) 27 ohms
   C) 3 ohms
   D) 0.333 ohms

7. One light connected to a battery would be _______________ compared to two light bulbs connected in series to the same battery?
   A) Brighter
   B) Dimmer
   C) The same

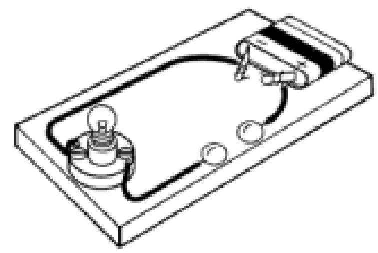
8. Charge flows from the __________ terminal of the battery to the _________ because of the force of _______________ between unlike charges.
   A) negative, positive, attraction
   B) positive, negative, attraction
   C) negative, positive, repulsion
   D) positive, negative, repulsion

9. Inserting a switch in a complete circuit allows which of the following to happen?
   A) The flow of current to be increased.

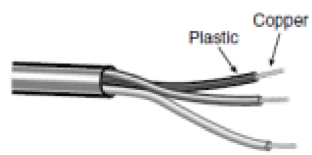
B) The flow of current to be constant.
C) The flow of current to be stopped and restarted.
D) None of these

10. Adding more batteries to a circuit will increase which of the following?
A) Resistance
B) Current
C) Voltage
D) None of these

11. *The instrument shown is used to see if materials conduct electricity.* Which of these groups contains items that could complete the circuit?
A) Rubber ball, plastic comb, nail
B) Paperclip, penny, screw
C) Cork, dollar bill, cotton ball
D) Pencil, eraser, plastic spoon



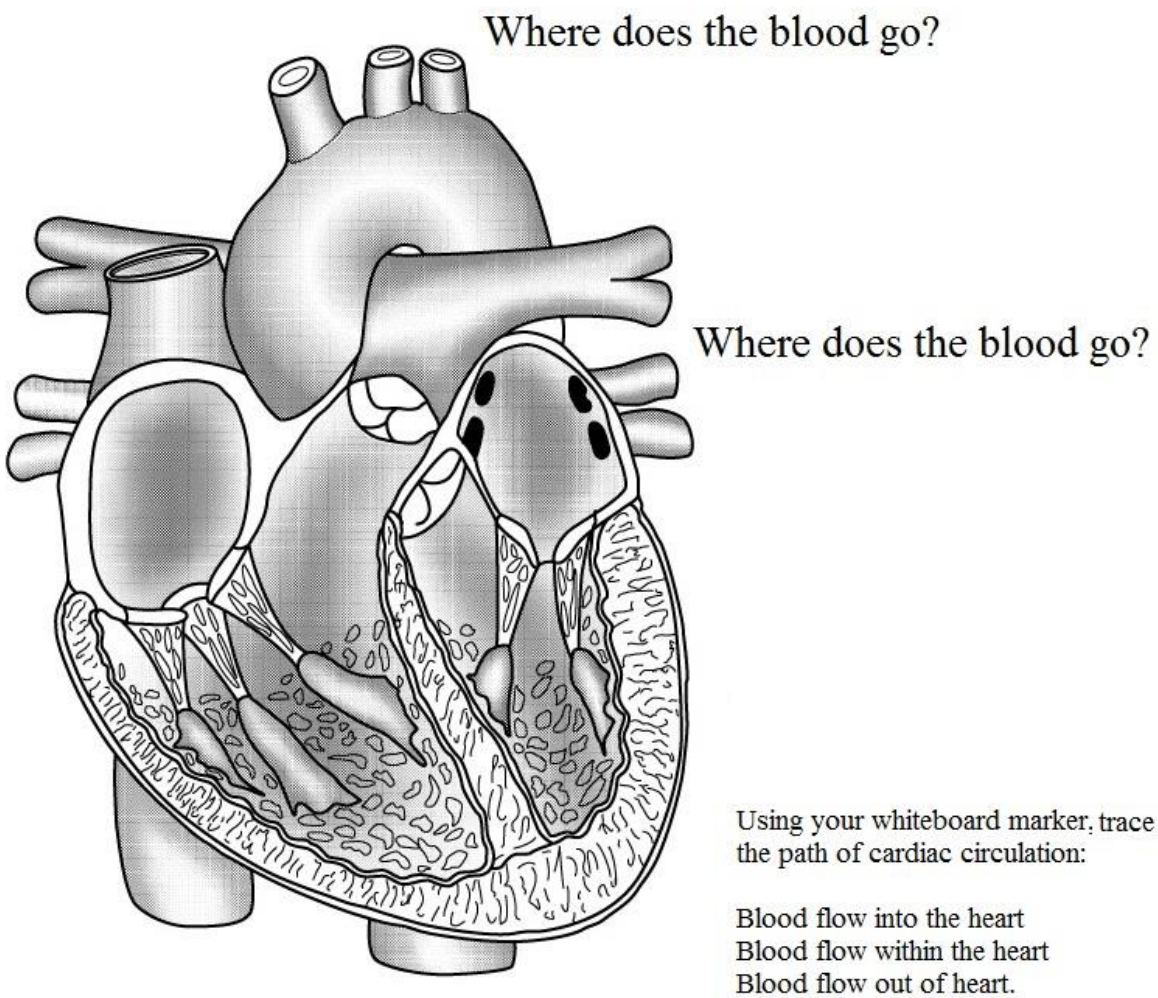
12. Electrical wires are wrapped in plastic because…
A) It helps to conduct the current in the circuit.
B) It helps to warm the current in the circuit.
C) It helps to insulate the current the circuit.
D) It helps to maintain the current in the circuit.



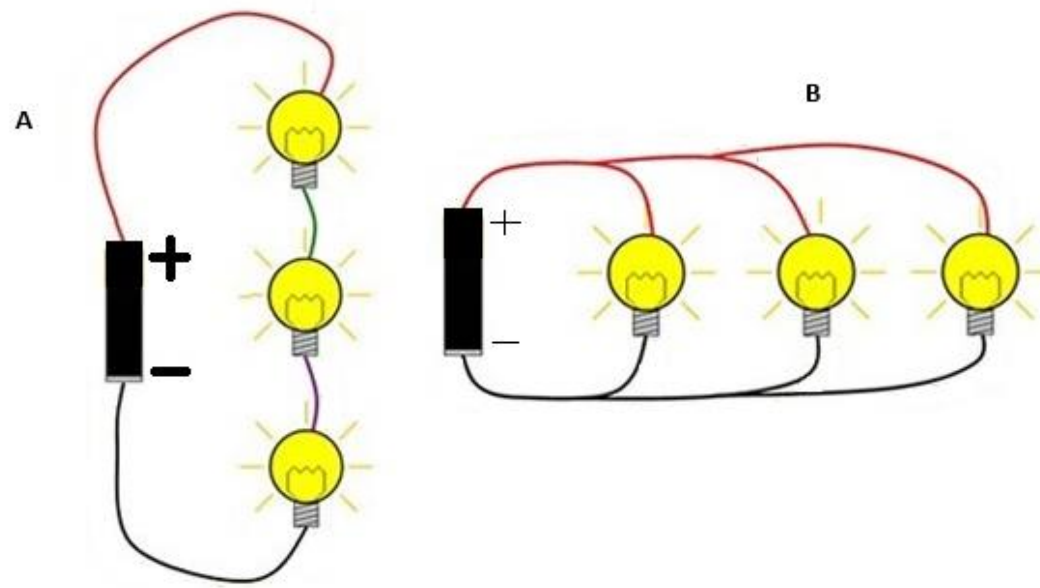
13. Which statement about the types of electrical current is *correct*?
A) Electrical current that flows first in one direction and then in the other is called high frequency current (HFC), which is obtained from batteries.
B) Electrical current that flows in one direction only is called direct current (DC), which is obtained from electrical outlets.
C) Electrical current that flows first in one direction and then in the other is called alternating current (AC), which is obtained from electrical outlets.
D) Electrical current that flows in one direction only is called low frequency current (LFC), which is obtained from batteries.

Appendix B

Open-Ended Heart and Circuits Assessments



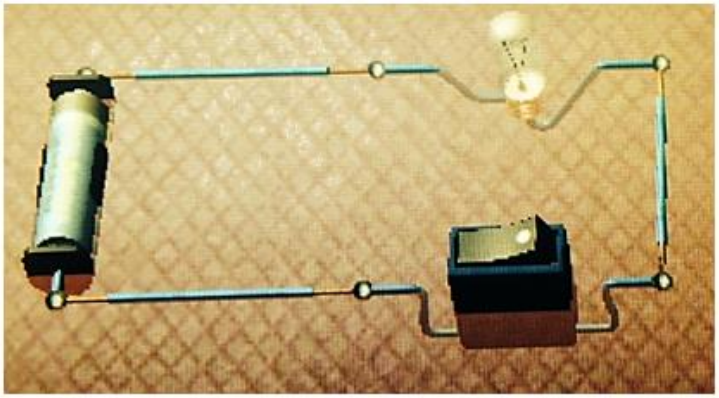
1. Which of these Circuits is series? __________________ (Write either A or B)
2. Which of these Circuits is parallel?__________________ (Write either A or B)



3. In the two circuits above, **draw arrows** to represent the flow of electrons.
4. What would happen if you removed one light bulb from circuit A and did not reconnect any wires?
5. What would happen if you removed one light bulb from circuit B and did not reconnect any wires?

Examine the following circuits. Put your answers in the boxes below the picture. Pre_______ Post _______

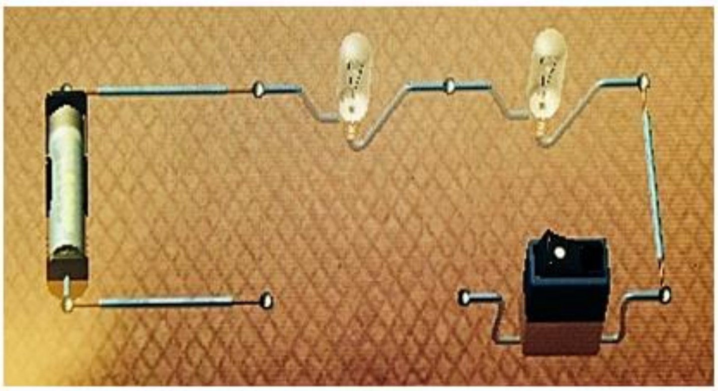
State yes or no if the circuit will work, meaning that the bulb(s) will light, when you flip the switch to the "on" position.



Will Circuit #1 work? Circle YES or NO

If Yes, Circle the bulb or bulbs you think will light up.

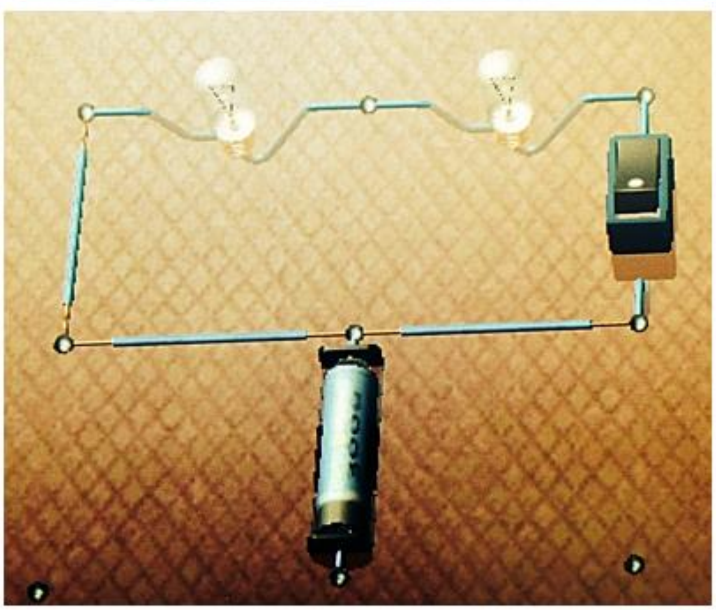
If No, describe why and indicate this on your diagram.



Will Circuit #2 work? Circle YES or NO

If Yes, Circle the bulb or bulbs you think will light up.

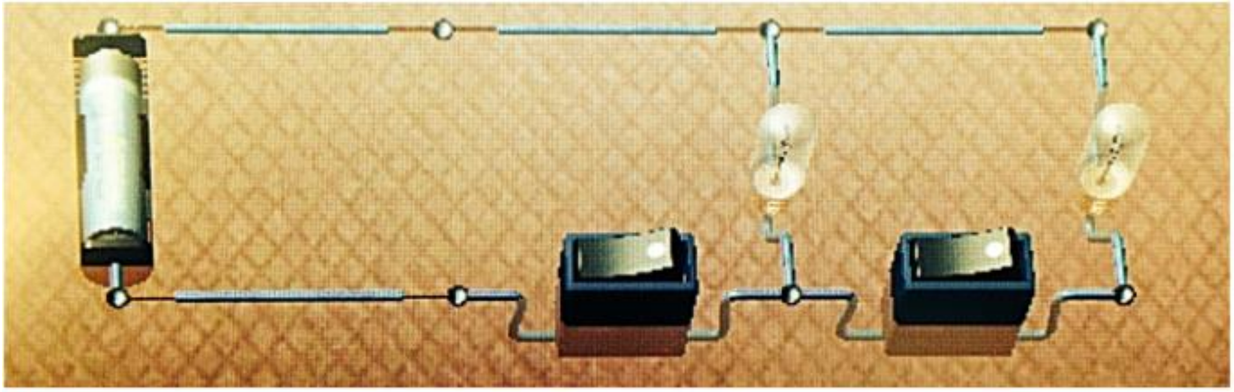
If No, describe why and indicate this on your diagram.



Will Circuit #3 work? Circle YES or NO

If Yes, Circle the bulb or bulbs you think will light up.

If No, describe why and indicate this on your diagram.



Will Circuit #4 work? Circle YES or NO

If Yes, Circle the bulb or bulbs you think will light up.

If No, describe why and indicate this on your diagram.

Will Circuit #5 work? Circle YES or NO

If Yes, Circle the bulb or bulbs you think will light up.

If No, describe why and indicate this on your diagram.

Appendix C

Open-Ended Heart and Circuits Assessment Rubrics

Response / Answer Scoring Heart Module	**0 points**	**0.5 points**	**1 point**	**1.5 points**	**2 points**
Where does the blood go? (Top)	No response	N/A	Incorrect (Lungs, etc.)	blood circulation to the top portion of the body (head, brain)	blood circulation to the top portion of the body (head, brain) and descending to lower extremities
Where does the blood go? (Side)	No response	N/A	Incorrect (Body, arms, etc.)	blood circulation to the lung	blood circulation to both sides of the lungs
LABELING: Major Blood Vessels	No response	Improperly labels Aorta and SVC/IVC	Labels as Artery or Vein (without proper name)	Labels as Artery or Vein (with one proper name)	Has proper labels for both Aorta and Superior Vena Cava and/or Inferior Vena Cava
LABELING & ORIENTATION: Right versus left - Atrium & Ventricle Labels	No response	Incorrect labels for atria and ventricles (aorta, etc.)	Atria and Ventricles are mislabeled entirely (up/down, left/right)	Atria and Ventricles are labeled with incorrect orientation of left and right	Atria and Ventricles are correctly labeled AND correctly labeled as left and right
LABELING: Heart Valve Labels	No response	N/A	Labeled	N/A	Connects Labels to heart part (Aortic or pulmonary valve)
CIRCULATION: Blood circulation TO the heart	no response	Begins in the wrong location, arrows going the wrong way, no clear movement	Correctly traces from LA to LV (wrong side of the heart)	Correctly traces from RA to RV (ignoring SVC/IVC)	Correctly traces through SVC/IVC to RA, RV
CIRCULATION: Cardiopulmonary	no response	Incorrect - no indication of movement to and from lungs	Indicates that blood leaves to the lungs through PV or PA (not labeled), return from lungs is unclear	Correctly traces out to Lungs with opposite return (not properly labeled) only one side	Correctly traces out to Lungs (PV) and opposite return (PA) (correctly labeled)
CIRCULATION: Blood circulation FROM the heart	no response	Begins in the wrong location, arrows going the wrong way, no clear movement	Correctly traces from RA to RV (wrong side of the heart)	Correctly traces from LA to LV (ignoring Aorta)	Correctly traces through LA to LV, out of Aorta

Response / Answer Scoring Circuit Module	**0 points**	**0.5 points**	**1 point**	**1.5 points**	**2 points**
Identification of a Series Circuit	no response	N/A	incorrect (B)	N/A	correct (A)
Identification of a Parallel Circuit	no response	N/A	incorrect (A)	N/A	correct (B)
Direction of Electron Flow in a Series Circuit	No arrows	No relationship to the battery	Clockwise arrows (positive to negative)	Arrows coming in both directions from the battery	Counterclockwise arrows (negative to positive)
Direction of Electron Flow in a Parallel Circuit	No arrows	No relationship to the battery	Completely backwards (positive to negative) with clockwise loops	Arrows coming in both directions from the battery	counterclockwise loops throughout the parallel circuit
Removal of Bulb from Series Circuit	no response	N/A	Circuit would continue to work	not work (maybe with some explanation)	The circuit would be open; the function that the missing bulb interrupts electron flow
Removal of Bulb from Parallel Circuit	no response	N/A	Circuit would NOT continue to work	work (maybe with some explanation)	The circuit would be still be closed as electrons have different paths interrupts electron flow
Circuit 1	no response	Circuit will not work	Circuit will work, no bulb circled	N/A	Circuit will work with bulb circled
Circuit 2	no response	Circuit will work	Circuit will not work, no explanation	Circuit will not work, with basic explanation (wire missing)	Circuit will not work, with logical explanation (wire missing; interrupts electron flow)
Circuit 3	no response	Circuit will work	Circuit will not work, no explanation	Circuit will not work, with basic explanation (battery is wrong)	Circuit will not work, with logical explanation (both ends of battery must be attached for electron flow)
Circuit 4	no response	Circuit will not work	Circuit will work, no bulbs circled	Circuit will work with one bulb circled	Circuit will work with both bulbs circled
Circuit 5	no response	Circuit will not work	Circuit will work, no bulbs circled	Circuit will work with one bulb circled	Circuit will work with both bulbs circled

Appendix D
Interview Protocol

1. Did you like using the zSpace® system, yes or no? Why or why not?
2. What was different about learning with this system compared to learning in your regular science classroom?
3. Do you think you learned things with this system that you could not have learned otherwise? (If yes, please explain).
4. Were you able to navigate easily using the system?
    a. The Eyewear?
    b. The Stylus?
    c. Moving around in the Z-environment?
5. Did you have any problems seeing the objects you were investigating?
6. Were there parts of the instruction that were confusing?
7. What did you like best and least about using the zSpace® system?
    a. Negative:
    b. Positive:
8. If you had a chance to use the system to learn science most of the time would you prefer to use the zSpace® system than the traditional ways you learn science?
9. If you had a chance to use zSpace® to learn science, for example, dissecting a shark, building a fire alarm with circuits, or exploring the inside of human body, what topic most interests you and why?
10. A typical lesson in science might involve a teacher reviewing the anatomy of a frog with the whole class. In small groups, students might dissect the frog to examine the structure and function of its organs. In zSpace® you could learn about frog anatomy by taking it apart. Which of these methods would you prefer and why? As a student, what do you see as the benefits and challenges of each of these?
    a. Benefits:
    b. Challenges:
11. Did you think the experience felt realistic?
12. When you reflect on your learning, what is helpful or not about learning with zSpace® to addresses your educational needs?
13. Complete this table. First, describe how zSpace® is different than the "other method" listed. Then rank order (1-8, where one is most preferred and 8 is least, one of which being zSpace®) your responses for the questions in the two remaining columns.

How is zSpace® Different?	**Other Instructional method**	**Which is more interesting?** (Ranking 1-8)	**Which increases your understanding?** (Ranking 1-8)
	Teacher instruction		
	Hands on activity with materials		

	Model/s		
	Simulation/s		
	Textbook		
	Video (example: YouTube)		
	Reading on the Internet (Blog, website)		
	zSpace®		