# *Investigating Potential Relationships Between Adolescents' Cognitive Development and Perceptions of Presence in 3-D, Haptic-Enabled, Virtual Reality Science Instruction*

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# Investigating Potential Relationships Between Adolescents' Cognitive Development and Perceptions of Presence in 3-D, Haptic-Enabled, Virtual Reality Science Instruction

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**Abstract**

Virtual presence describes a users' perception of a virtual reality (VR) environment (VRE), specifically, of their *involvement* (sense of control within a virtual environment with minimal distractions) and *immersion* (multi-input sensory engagement providing apparent realism of objects and interactions). In education, virtual presence is a significant construct as highly immersive VREs have been linked to users reporting memorable and exciting teaching experiences. Prior research has described that adults and children report different levels of presence when subjected to identical VREs, suggesting cognition may play some role in users' perceptions of presence. According to Piaget, concrete operational development is a watershed moment when adolescents develop the ability to understand abstract concepts and make assessments what is and is not reality. This period in cognitive development may influence children's and adolescents' perceptions of presence. This is an exploratory study of seventy-five 6th-grade and seventy-six 9th-grade students who participated in an instructional module about cardiac anatomy and physiology using a 3-D, haptic-enabled, VR technology. When surveyed on their perceptions of virtual presence, there were no reported differences between grade levels. When assessed using a Piagetian inventory of cognitive development, the analyses indicated that the sixth-grade students' understanding of spatial rotation and angular geometry was positively correlated with the reported perceived control and negatively correlated with distraction. This study suggests that the spatial acuity of younger learners plays an important role when using VR technologies for science learning. This research raises questions about the relevance of users' cognitive development when using emergent VR technologies in the K–12 science classroom.

**Keywords** Cognitive development · Instructional technology · Science education · Virtual presence · Virtual reality

## Introduction

Three-dimensional (3-D) tools, haptic-enabled (HE) devices, and virtual reality (VR) platforms have revolutionized new forms of demonstrations, labs, and simulations in science education (Bowman and McMahan 2007; Connolly et al. 2012). These emergent technologies engage learners in hyper-realistic spatial interfaces that are both immersive and interactive (LaViola 2008). According to research by Witmer et al. (2005), immersion describes a user's level of sensory engagement with minimal distractions whereas interaction describes their level of control and apparent realism within the virtual environment (VE). Educational research has shown that this technology can influence science learning with use of high-quality graphic images, simulated movements, and sensory stimuli, enabling students to visualize abstract science concepts, like particle relationships (Uchiyama and Funahashi 2013), construct large-scale complex models (Sampaio et al. 2010), and feel adaptive objects in real-time, such as the beating of a human heart (Hite 2016b).

The utility of 3-D, HE, VR technology as a pedagogical agent for student learning in science lies in their ability to provide immersive and interactive experiences (Zeltzer 1992), which, coupled together, contribute to the

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psychological state of virtual presence (Witmer and Singer 1998). Researchers have focused on measuring perceptions of presence as a way to examine how realistic and engaging these technologies are for studies in military simulations (Mantovani 2001), medical training (HsiuMei and ShuSheng 2011; Thacker 2003), and undergraduate science courses (Eriksson et al. 2014). Yet, little research focuses on the unique needs of younger (K–12) learners related to their level of cognitive development (Jones et al. 2016). This paper examines how younger learners, at their present level of cognitive development, experience presence while learning science in a 3-D, HE, VR environment. This study is part of a larger series of studies of learning science with VR, where relationships between VR and learning science were examined, as significant learning had occurred (Hite, 2016a). However, the purpose of this line of research was to explore why this relationship occurred. To better understand the factors that contributed to these learning gains, we examined participants' perceptions of presence and their cognitive development to assess any potential relationships between them. How students interact with and perceive the authenticity of VEs, produced by these devices as instructional guides, is paramount as they are incorporated into science instruction (Hite, 2016a; Zudilova-Seinstra et al. 2009). Science educators need to know more about the effectiveness of VR instruction for teaching science and the interaction and learning of students with different cognitive attributes with this technology.

## Defining Virtual Presence

Virtual presence occurs when a person is unable to differentiate the sensory information from a hardware-mediated environment from that of reality, interpreting the virtual input as though it were from the real world (Chertoff et al. 2008). As new types of VR in science are emerging, it is important to understand how learners perceive the virtual environment and the degree to which this environment appears real. Early research in presence suggested that theoretical factors contribute to the perception of presence, including body movements (Slater et al. 1998), sensory stimulation (Held and Durlach 1992), and feedback (Sheridan 1992). Witmer and Singer (1994) identified the aspects of presence using questionnaire results from participants engaged in virtual environments. Witmer and Singer (1998) described virtual presence as including the following four factors: control, sensory, distraction, and realism. Control factors included aspects of the virtual environment the learner may directly manipulate through the hardware interface to move through or control the virtual environment. Sensory factors provide either hardware-based sensorial feedback (e.g., haptics) or software-based perceptions of movement (e.g., movement up and down when walking).

Unlike the other aspects, distraction decreased the user's perception of presence, created by disturbances from the real world or through the interface (hardware or software) encumbrance. Realism included both appearance and behavior of objects, mimicking their real-world counterparts such to belie the user to their virtual nature. As Slater (2009) has noted, VR can produce vivid immersion experiences with few restrictions on user's control and the learner may feel a genuine sense of being there (place illusion) because what is occurring in the virtual environment is actually happening (plausibility illusion). Table 1 provides further information on the attributes and aspects by factor contributing to the presence questionnaire originally designed by Witmer and Singer (1998). Witmer and Singer (1998) suggested that the presence factors may interrelate and control may influence immersion more than involvement, whereas realism may affect involvement but not immersion. However, they conjectured that both sensory and distraction factors affect immersion and involvement. Given the complexity of the typical K–12 science classroom, understanding distraction factors, perceptions of place, and plausibility is important to designing effective VR-based science instruction.

## Inducing Presence Using 3-D, Haptic-Enabled, Virtual Reality Technology

A VRE that conveys a rich and robust science experience that is both compelling (Wouters et al. 2013) and engaging (Graesser et al. 2014) may cultivate within the user a psychological phenomenon described as a diminished sense of one's immediate surroundings coupled with a sensation of physical transportation to a simulated realm (Bulu 2012). This type of VR experience is becoming increasingly common where

**Table 1** Factors hypothesized to contribute to a sense of virtual presence

| Control factors | Sensory factors | Distraction factors | Realism factors |
|---|---|---|---|
| Degree of control | Sensory modality | Isolation | Scene realism |
| Immediacy of control | Environmental richness | Selective attention | Information consistent with the objective world |
| Mode of control | Active search | Interface awareness | Meaningfulness of experience |
| Anticipation of events | Multimodal presentation | | Separation anxiety/disorientation |
| Physical environment modifiability | Consistency of multimodal information | | |
| | Degree of movement perception | | |

By Witmer and Singer (1998, p. 299)

learners can (virtually) travel to the solar system (Mintz et al. 2001), feel a beating heart, or conduct realistic experiments visualizing current with circuits and motors (Jones et al. 2016). When students report that the virtual experience of performing a task or function feels as authentic as the real experience (McCreery et al. 2013), they have perceived virtual presence (Fowler 2015). Instructional technologies induce presence leverage control, sensory, distraction, and realism factors for user immersion and interaction (Witmer and Singer 1998). Since 3-D, HE, VR systems are crafted for user involvement immersed in a simulated world, then, these systems have a great potential to produce presence in science contexts.

First, 3-D, VEs create a visual illusion of objects having depth and realistic qualities (Dalgarno and Lee 2010; Wann and Mon-Williams 1996). This apparent realism refers to not only the visual quality of the display but also the consistency of an object's behavior through user communication and actions (Fowler 2015). This requires the VE to have consistency in object behavior and realistic actions, whose qualities (both behavioral and visual) reflect authentic interactions the user would have with the objects in the real world. According to Dalgarno and Lee's (2010) model of learning in 3-D VEs, the quality and authenticity of the display (representational fidelity) coupled with precise user actions (learner interaction) are paramount features of emergent *technologies*, including 3-D and VR. Both high fidelity and interaction hold the learner's perception of presence (Zeltzer 1992), minimizing their ability to be distracted from outside of the VE.

These technologies may also incorporate unique sensory modalities that provide force feedback to the users' actions, called haptics. Such HE learning technologies provide touch-based sensory feedback to the user through a hardware interface (e.g., grip, stylus, or hologram) which provides various tactile sensations (e.g., force or vibrations) to simulate texture, pressure, resistance, weight, or speed (Jones and Minogue 2006). This technology has been studied in K–12 classrooms to explore students' learning gains studying abstract scientific phenomena, such as temperature and pressure (Jones et al. 2014), eukaryotic cell structure (Jones et al. 2004), and lever systems (Wiebe et al. 2009). As presence is a psychological product of multiple sensory inputs (Witmer and Singer 1994), touch technology may play an important and promising role in inducing or sustaining presence in science virtual environments. Witmer and Singer (1998) contended that among the senses, visual information may most strongly influence presence; yet, other research has found that body interactions (Slater and Steed 2000) yielded increased perceptions of presence for the users. Coupled together as *visuohaptic* presentations (i.e., merged visual and tactile sensory information), they can produce a robust sense of presence for learning science. A study by Reiner and Hecht (2009) described that an object-presence illusion of a razor blade caused participants to move their hands more slowly and apply less force as compared to an identical task without the razor representation. Weir et al. (2013) found that when participants placed their hands in a virtual fire (BurnAR), they reported an involuntary warming sensation and smelled smoke.

## Variance in Users' Perceptions of Presence

Research has suggested that perceptions of presence vary among individuals in similar or identical virtual environments (Ling et al. 2013; Wallach, Safir, and Samana 2010). This research sought to add to this work by examining youths' perceptions of virtual presence for learning science. Research has determined that age has only a moderate effect on the perception of presence in young adults as compared to older adults (Siriarava and Ang 2012), and the authors of the study found that the variance was due to prior experiences using virtual environments. However, comparing adults to children, a study by Baumgartner et al. (2008) has demonstrated that the activation of a highly specific neural network mediates the experience of presence in adults in virtual environments. This suggests the absence of activity due to underdeveloped prefrontal regions that may contribute to an increased experience of presence among children in identical VEs. Overall, perceptions of presence are dependent on the immersive characteristics of the VR system and may be influenced by the user's unique contextual and psychological factors (Mestre 2015).

The field of VR research has rapidly expanded with reports of varying degrees of immersion (e.g., actional, psychological, sensory, symbolic/narrative) by varying types of VREs (e.g., collaborative, multi-user, immersive), that can provide learners with the perceptual experience of an authentic concrete learning environment (Bailenson et al. 2005; Slater 2009). Most research in this area has explored how the design or usability of virtual environments plays a role in inducing presence and learning (Fowler 2015; Papachristos et al. 2014; Seo and Kim 2002; Tanaka 2004; Tromp et al. 2003; Whitelock et al. 2000). Bailey and Bailenson (2018) composed a meta-analysis of studies on children's presence experiences with VR. Sharar et al. (2007) suggest that children were more likely to report greater presence and realness compared to adults because their experiences in VR may be related to cognition and brain development. They highlight the dearth of VR research studies employing children (p. 192) and the need for further research exploring how VR relates to child development (p. 194). Research by Shin (2018) has indicated that cognitive processes mediated users' perceptions of presence; yet, this work included adults only. Given the lack of studies employing children's presence experiences in VR, this research seeks not only to contribute more information on the attributes of younger users experiencing presence in VR but also to explore cognitive development and perceptions of presence in a science learning context.

### Users' Perceptions of Presence and Cognitive Development

There is evidence that presence is a psychological state (Lombard and Ditton 1997) and exploring cognitive attributes (abilities) of the learner may provide insight to the process of inducing and maintaining students' perceptions of presence. Piaget (1971) postulated that there are four major phases of sequential intellectual development, each highlighted by newly developed cognitive abilities, maturing throughout the lifespan along a progressive continuum of neural development from childhood, through adolescence, and into adulthood. During each stage of cognitive development, children actively construct knowledge via development of schemas (mental representations), where information is either assimilated to fit with existing schemas or the schema is modified (accommodated) to fit with new information (Southwell 1998; Wadsworth 1996). This progression commences with sensorimotor or cognitive experimentation, followed by preoperational cognitive development where imagination, memory, and symbolism develop during mid-childhood. This progression culminates into the concrete operational stage, where individuals cultivate logical reasoning and a growing discernment of fantasy from reality. Piaget (1962) posited that from late adolescence and into adulthood is when this final stage of cognitive development (formal operational processing) occurs. This stage is when abstraction of intangible concepts is achieved and experience over instinct mediates how one views the world beyond themselves. It is this stage that is of particular interest in research, as it may provide insight to the ability of adolescents to mentally differentiate the virtual world from reality, influencing their perceptions of presence.

Assessments of Piagetian development typically include measures of classification, images, conservation, relations, and laws (Patterson and Milakofsky 1980). Learning concepts in science have been shown to be related to students' abilities to perform Piagetian tasks (Southwell 1998). Piagetian inventories have been validated empirically in content areas as well as various age and ability groups, including elementary-level students (Bakken et al. 2001), students with disabilities (Riley 1989), and in science courses (Bender and Milakofsky 1982; Coleman and Gotch 1998). Modern studies have too used Piaget to understand spatial reasoning among students in science courses (Cole et al. 2018), perhaps due to recent thoughts in using Piagetian theory as a domain-specific approach to study cognitive development (Siegler 2016). Hence, Piagetian assessments have the potential to document developmental differences among science learners of various ages.

Although science education researchers have questioned strict interpretations of Piaget's theories (Lourenço and Machado 1996), other researchers in psychology (Montealegre 2016) and neuroscience firmly support Piaget's conception of progressive staging related to advancing cognitive development (Arsalidou and Pascual-Leone 2016; Johnson and de Haan 2015). Baumgartner et al. (2008) demonstrated that activation of a highly specific neural network, in the prefrontal area of the brain, mediated the experience of presence in adults in identical VREs. The prefrontal cortex, the region of the brain most closely associated with planning and judgment (Fuster 2008) and discerning reality from imagination (Simons et al. 2008) is functional at 4 years of age; however, it organizes into its full potential only through later development (Satoshi 2008). This is interesting as it closely mirrors Piaget's findings of intellectual development, where researchers have suggested that changes in the prefrontal cortex through time lead to more robust understanding of abstract concepts and perceptions of reality (Casey et al. 2000, 2005). This brings into question Baumgartner et al.'s (2008) findings of variance in reporting presence among *children* in identical VREs. Given that presence relies on the "user's ability to perceive virtual information within these remote settings directly as an extension of their own experiences and senses" (McCreery et al. 2013, p. 1635), the literature suggests that cognitive ability may play a role in a user's perceptions of presence, especially in children and adolescents. Yet, most of the existing studies on perceptions of presence examined adults in non-educational environments. Therefore, exploring how adolescent learners' cognitive development may influence their perceptions of presence (control, sensory engagement, distraction, and realism; e.g., the four constructs of presence) may shed insight into the design and developmental appropriateness of science instruction with VR technologies.

## Methodology

### Research Questions

This study explored students' perceptions of presence after using a 3-D, HE, VR system (zSpace®) to explore various science concepts (e.g., human heart, robotics, and dissection). The aim of this research study was to explore any potential relationships between students' perceptions of presence in VR-based science instruction and their measured level of cognitive development. The researchers predicted that users' reported presence (i.e., perceptions of control, distraction, distraction, and realism) may vary by level of users' cognitive development (by 6th grade and 9th grade) and by measures of Piagetian cognitive development (i.e., classification, images, conservation, relations, and laws). The research questions addressed are as follows:

1) Are there differences in 6th- and 9th-grade science students' perceptions of presence when engaged in 3-D, haptic-enabled, virtual reality science instruction?

2) Is there a relationship between 6th and 9th grade students' cognitive dimensions and perceptions of presence?

a) What are the relationships between students' scores on the Inventory of Piaget's Developmental Tasks (IPDT) constructs and subtests and perceptions of presence?
b) What are the relationships between students' scores on the Inventory of Piaget's Developmental Tasks (IPDT) cognitive classifications and perceptions of presence?

## Participants

Two grade levels were selected based upon Piaget's levels of cognitive development (Piaget 1962) to sample students in two distinct phases of Piagetian development, children likely in the concrete operational stage (6th grade) and adolescents likely in the formal operational stage (9th grade). This selection for 6th and 9th grades was non-specific to age, rather providing the researcher a range of cognitive ability within and between grade levels (Mueller and Ten Eycke 2015). Also, the intervention (heart anatomy and physiology) aligned to the content of 6th and 9th grades' health and science when students encounter more complex and abstract concepts that are suited to VR learning. Participants were volunteers in 6th and 9th grades' health, life science, and biology classes in urban and rural counties in the Southeastern United States. Students were recruited for this study through science and health classes via personal visits to their respective schools; any student who provided written assent and parental consent participated in the research study. Seventy-five 6th-grade students participated from a public middle school in an urban setting. Seventy-six 9th-grade students participated from an urban ($N = 50$) and a rural ($N = 26$) public high school. Schools were matched by socioeconomic status (SES), race, ethnicity, and gender. The pool of the 6th-grade participants included 29 males and 46 females, who identified as White ($N = 42$), African American ($N = 24$), Asian ($N = 8$), Native American or American Indian ($N = 8$), Hispanic, ($N = 16$), non-Hispanic ($N = 59$), and Native Hawaiian or other Pacific Islander ($N = 3$) with a mean age of 11.22 years (median = 11, mode = 11). The pool of the 9th-grade participants included 32 males and 44 females who identified as White ($N = 50$), African American ($N = 19$), Asian ($N = 7$), Hispanic, ($N = 22$), non-Hispanic ($N = 54$), and Native American or American Indian ($N = 5$), with a mean age of 14.26 years (median = 14, mode = 14). Students had the opportunity to select more than one racial affiliation, which was accounted for in total numbers. Students with consent who completed the treatment (120 min on the zSpace® system described in the subsequent sections) and both assessments in their entirety (an inventory of Piaget's developmental tasks and a presence survey) were included in the study.

## Equipment

This study utilized a hardware that produced 3-D imagery, with HE feedback, within a VRE. The zSpace® platform consists of a central processing unit (CPU), a 23.6-in., 1080-p high-definition liquid crystal 3-D stereoscopic display screen, a 3-button stylus with integrated haptic technology, and a set of polarized eye-glasses with reflective sensors for tracking cameras (zSpace® 2016a, b). Figure 1 shows the components of the zSpace® system, including the 3-D eyewear (clip on for users with corrective lenses), the 3-button HE stylus, head-tracking cameras, and 3-D enabled display. This tool is able to create fully rendered 3-D images that appear within a VRE but also project out of the screen for full user interaction. Users are able to zoom, rotate, and manipulate objects using the HE stylus as well as view features of the VRE through nuanced head movements (to and fro) to examine these 3-D projected images. Researchers wore non-tracked eyewear (which only renders the user to view objects in 2-dimensions) to monitor student activity while using the system.

## Treatment

The participants completed the Inventory of Piaget's Developmental Tasks (IPDT) prior to instruction with the technology. Each participant was given four 30-min sessions to use the zSpace® system. During each session, the students were able to hear sounds of the VRE, view fully rendered 3-D objects, and control the VRE by moving their heads to manipulate perspective as well as drag, zoom, and rotate 3-D objects using their HE stylus in real-time. In the first session (30 min), the students explored various scientific phenomena, including a self-directed biological dissection of plants and animals as well as a butterfly observation in a simulated forest environment. The remaining time (90 min) was for specific science instruction, in which students externally and internally examined a haptic (beating) human heart. The human heart was the

**Fig. 1** The zSpace® system components (Hite, 2016b)

science content selected as it aligned with science and health curricula in the 6th and 9th grades and presented an interactive (3-D) and immersive (sensory) experience for the student user. The instruction included the following: interactive vocabulary that provided students scaffolded information as they chose different views of an external heart (cardiac anatomy); 3-D images with 360° views of active heart function (physiology); and haptic feedback of heart rate (relaxation and contraction of the cardiac cycle) while at rest and under duress (exercise). See Fig. 2 for how the user views the heart while engaged in the VRE. After completing their final 30-min session on the zSpace® system, the participants answered the presence survey (see the "Assessments and Analyses" section). The 6th-grade students received the treatment in a separate (research classroom) setting, whereas the 9th-grade treatment occurred at their school (cafeteria) location.

## Assessments and Analyses

**Presence Survey** The presence survey contained sixty-two 6-point Likert scale items designed to assess the 6th- and 9th-grade students' perceived presence during the science-based investigations with zSpace® by recording students' perceptions of control, sensory, distraction, and realism (see Appendix A). The survey was adapted from the presence framework and validated stem questions of Witmer's and Singer's (1998, p. 232) presence questionnaire that established (validated) the four constructs of presence into their survey instrument. Notably, this instrument been used in current research on students' perceptions of presence (Childers and Jones 2015; Jones et al. 2016; Childers et al 2018). Items from that survey were adapted to reflect the 3-D and HE capabilities of the zSpace® system. Last, a panel of science educators, middle-school students, zSpace® educators, and computer programmers with specialized knowledge this technology reviewed and refined each item for content validity. After treatment on zSpace® to learn about the heart, the study participants were asked to indicate their level of agreement for 61 items related to the following four presence factors: control ("I felt that I was in control of the zSpace® 3-D environment during the session"); sensory engagement ("My sense of touch was highly engaged during the session"); distraction ("The stylus was distracting"); and realism ("I lost track of time during the zSpace® session"). The survey is a Likert scale format from 1 to 6 (i.e., strongly disagree to strongly agree). The presence survey was taken online or on paper and aggregated using Qualtrics software. This instrument is part of other studies exploring virtual presence when students are engaged in 3-D, HE, VR science instruction. Presence statements were analyzed by item response (1–6) and by construct using the Mann–Whitney's $U$ test (2-tailed, $\alpha = 0.005$) to ascertain significance between age groups within each construct of control, sensory, distraction, and realism. This test was selected due to the ordinal nature of the data (Likert) and to not assume data would be normally distributed (non-parametric). In this test, mean ranks provide aggregates of Likert scores (1 to 6), per item, to compare the 6th- and 9th-grade groups (where the null hypothesis is that the distribution of both groups is identical). Regardless if all (6th and 9th grades) or the grouped (6th- versus 9th-grade) students answered at the extremes (1 and 6), this variance is accounted for in this conservative test. Cronbach's alpha calculated for both groups was 0.944 ($N = 151$, for 86 total items). Table 2 shows the reliability values for the 6th- and 9th-grade student scores on the presence survey. Correlations using the Spearman's rank correlation (rho) coefficients were made to determine relationships between presence scores and IPDT tasks.

**Inventory of Piaget's Developmental Tasks** This validated assessment consists of 72 selected response (4 possible answer choices) items, segregated into 5 constructs and 18 subtests of Piagetian developmental tasks (Furth 1970); 14 items on conservation (quality, weight, volume, distance), 14 items on

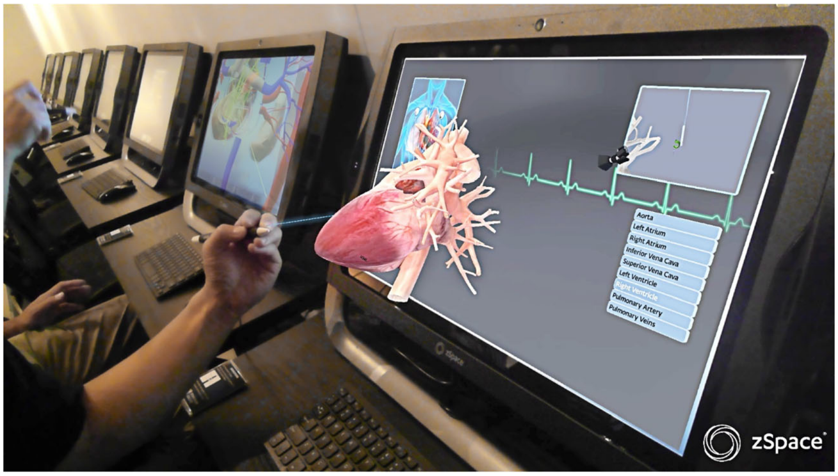

**Fig. 2** VRE representation of the human heart on zSpace® (zSpace® 2016a,b)

**Table 2** Reliability measures (Cronbach's alpha) for control, sensory, distraction, and realism items on presence survey

| Presence category | 6th grade ($N = 75$) | 9th grade ($N = 76$) | 6th and 9th grades ($N = 151$) |
|---|---|---|---|
| Control items ($N = 21$) | 0.933 | 0.927 | 0.930 |
| Sensory items ($N = 8$) | 0.762 | 0.776 | 0.768 |
| Distraction items ($N = 17$) | 0.769 | 0.797 | 0.781 |
| Realism items ($N = 15$) | 0.705 | 0.677 | 0.691 |
| Whole test ($N = 82$)[a] | 0.934 | 0.953 | 0.944 |

$\alpha \geq 0.9$, excellent; $0.7 \leq \alpha < 0.9$, good; $0.6 \leq \alpha < 0.7$, acceptable; $0.5 \leq \alpha < 0.6$, poor; $\alpha < 0.5$, unacceptable

[a] Contains items not reported here

images (levels, perspective, movement, shadows), 12 items on relations (sequence, seriation, inference), and 14 items on classification (matrix, symbols, classes, inclusion). The students took this inventory individually and given as much time as they needed to complete (untimed). Each item was scored as correct or incorrect; the students demonstrated proficiency in the 18 subtests with a minimum of 75% (three out of four) questions correctly answered (Patterson and Milakofsky 1980). Cronbach's alpha was calculated with a reliability value of 0.791 ($N = 18$) for the 6th- and 9th-grade student responses. Table 3 shows the relationships between construct areas, subtests, and item difficulty on the Inventory of Piaget's Developmental Tasks (IPDT). Again, correlations using Spearman's rank correlation (rho) coefficients were made to determine relationships between IPDT constructs, subtests, and cognitive classifications to presence scores.

## Results

Tables 4, 5, 6, and 7 show the comparisons for perceptions of presence between the 6th- and 9th-grade science students when engaged in 3-D, HE, VR instruction. Mean ranks provide information on the means for each item by group, to assess the assumption of equality (null-hypothesis) between the 6th- and 9th-grade groups. A Bonferroni's correction was completed within each presence construct due to the likelihood of making a type I error from multiple comparisons Armstrong (2014).

There were no significant differences in the presence scores between the 6th- and 9th-grade students for the *control* constructs (Table 4). Students in both grade levels reported similar perceptions of control for the zSpace® learning environment.

There were no significant differences in the presence scores between the 6th-grade and 9th-grade students for the sensory constructs (Table 5).

There were no significant differences in the presence scores between the 6th-grade and 9th-grade students for the distraction constructs (Table 6).

The analyses showed that there were no significant differences in the presence scores between the 6th-grade and 9th-grade students for the realism constructs (Table 7).

To explore relationships between students' cognitive dimensions in Piagetian development and perceptions of presence, a Spearman's correlation was performed with a $p$ value of 0.05 between the IPDT constructs, laws (Table 8), relations (Table 9), conservation (Table 10), images (Table 11), and classification (Table 12), with perceptions of presence constructs (control, sensory, distraction, and realism).

Table 8 shows the correlations between the students' performance on the IPDT inventory for laws (which includes questions on rotation, angles, and probability) and presence. The laws and control variables for the 6th grade were significantly correlated ($r = 0.260$, $p < 0.05$), as well as the subtests of rotation with control ($r = 0.293$, $p < 0.01$) and angles ($r = 0.229$, $p < 0.05$). There is also a significant negative correlation between the laws variable and distraction for the 6th grade ($r = -0.249$, $p < 0.05$). The constructs of sensory and realism

**Table 3** Inventory of Piaget's Developmental Tasks (IPDT) cognitive classifications (by age) and test, subtest constructs

| | Classification ($N = 16$) | Images ($N = 16$) | Conservation ($N = 16$) | Relations ($N = 12$) | Laws ($N = 12$) |
|---|---|---|---|---|---|
| Low range (7–8) ($N = 24$) | Matrix<br>Symbols | Movement | Quantity | Sequence<br>Seriation | – |
| Midrange (9–10) ($N = 24$) | – | Levels<br>Perspective<br>Shadows | Weight<br>Distance | – | Rotation |
| High range (11–13) ($N = 24$) | Classes<br>Inclusion | – | Volume | Inference | Angles<br>Probability |

Each of the 18 subtests contained 4 questions each

Inventory total, $N = 72$

**Table 4** 6th- and 9th-grade students' perceived perceptions of control from presence survey using Mann–Whitney's *U*

| Presence item | 6th grade mean rank | 9th grade mean rank | Mann–Whitney's *U* | *p* value |
|---|---|---|---|---|
| All control questions by factor (questions 1 through 21) | 73.54 | 81.46 | 2659.50 | 0.270 |
| 1. I felt that I was in control of zSpace® 3-D environment during the session. | 70.88 | 84.12 | 2454.50 | 0.041 |
| 2. zSpace® 3-D environment would respond to my actions. | 69.78 | 85.22 | 2370.00 | 0.021 |
| 3. zSpace® 3-D environment did what I wanted it to do. | 78.64 | 76.36 | 2876.50 | 0.730 |
| 4. The interactions I had with the zSpace® 3-D environment were natural. | 75.54 | 79.46 | 2813.50 | 0.559 |
| 5. I felt that the stylus allowed me to control what was occurring in the 3-D environment. | 72.88 | 82.12 | 2609.00 | 0.162 |
| 6. The stylus would do what I wanted it to do in the 3-D environment. | 71.52 | 83.48 | 2504.00 | 0.079 |
| 7. The interactions I had with the stylus to interact with the 3-D environment were natural. | 74.27 | 80.73 | 2715.50 | 0.325 |
| 8. The stylus would respond to my actions when I interacted with the 3-D environment. | 70.78 | 84.22 | 2447.00 | 0.040 |
| 9. The stylus allowed me to control the movement of objects in the environment. | 72.96 | 82.04 | 2615.00 | 0.162 |
| 10. I was able to predict what would happen if I moved an object in the 3-D environment. | 75.16 | 78.86 | 2784.50 | 0.581 |
| 11. I could move objects easily in the 3-D environment. | 77.63 | 77.37 | 2954.50 | 0.969 |
| 12. I could manipulate objects easily in the 3-D environment. | 78.48 | 76.52 | 2889.00 | 0.766 |
| 13. There was a delay between what I wanted to do and what happened on the screen. | 70.77 | 84.23 | 2446.50 | 0.056 |
| 14. I adjusted quickly to the screen during the zSpace® session. | 78.69 | 76.31 | 2872.50 | 0.725 |
| 15. I could easily move objects in the 3-D environment. | 72.24 | 82.76 | 2559.50 | 0.110 |
| 16. I could easily interact with different objects in the 3-D environment. | 74.40 | 80.60 | 2726.00 | 0.332 |
| 17. I could manipulate objects with a stylus in ways that I could not in the real world. | 80.69 | 74.31 | 2718.50 | 0.336 |
| 18. I could easily zoom in on objects. | 78.01 | 76.99 | 2925.00 | 0.881 |
| 19. I could easily zoom out from an object. | 76.38 | 78.62 | 2878.00 | 0.744 |
| 20. I could navigate inside of objects using the stylus. | 79.84 | 75.16 | 2784.00 | 0.487 |
| 21. I was able to navigate behind objects that I could not do normally in a 2-D simulation. | 75.87 | 79.13 | 2839.00 | 0.614 |

Mann–Whitney's *U*: differences in two independent groups, alpha 2-tailed

for the 6th grade were not significantly correlated with laws, and laws were not significantly correlated with the presence constructs for the 9th-grade participants.

Correlations between the students' performance on the IPDT inventory for relations (which includes questions on sequence, seriation, and inference) and presence are shown in Table 9. The relations and sensory variables for the 9th grade were significantly correlated ($r = -0.276$, $p < 0.01$). The other constructs within the relations were not significantly correlated with the presence for the 6th- or 9th-grade students.

Correlations between the students' performance on the IPDT inventory for conservation (which includes questions on quantity, weight, volume, and distance) and the presence are shown in Table 10. Weight and sensory variables were significantly correlated ($r = -0.244$, $p < 0.05$) for the 6th grade.

Table 11 shows the correlations between the students' performance on the IPDT inventory for images (which includes questions on levels, perspective, movement, and shadows). There were no significant correlations between images and presence for the 6th- and 9th-grade participants.

Correlations between the students' performance on the IPDT inventory for classification (e.g., matrix, symbols, classes, and inclusion) and the presence are shown in Table 12. The matrix and control variables for the 6th grade were significantly correlated ($r = -0.244$, $p < 0.05$). For the 9th grade, the inclusion and sensory variables were negatively correlated ($r = -0.237$, $p < 0.05$). There were non-significant correlations for the remaining constructs within the classification for the 6th and 9th grades.

The IPDT constructs were organized according to cognitive difficulty and related age ranges as validated by Patterson and Milakofsky (1980). Low-range questions, of which 7- to 8-year-old children typically score correctly, contain questions of matrix, symbols, movement, quantity, sequence, and serration. Mid-range questions, of which 9- to 10-year-old children typically score correctly, contain questions of levels, perspective, shadows, weight, distance, and rotation. Eleven- to thirteen-year-old children typically answer questions of classes, inclusion, volume, inference, angles, and probability correctly (see Table 3 for IPDT subtests by difficulty and construct).

The correlations between the students' performance on the IPDT inventory for cognitive classification (which includes questions on the low range, midrange, and high range) and the presence constructs are shown in Table 13. For the 6th-

**Table 5** 6th- and 9th-grade students' perceived perceptions of sensory factors from presence survey using Mann–Whitney's *U*

| Presence item | 6th grade mean rank | 9th grade mean rank | Mann–Whitney's *U* | *p* value |
|---|---|---|---|---|
| All sensory questions by factor (questions 1 through 8) | 79.29 | 75.71 | 2826.50 | 0.617 |
| 1. My sense of sight was highly engaged during the session. | 79.16 | 75.84 | 2837.00 | 0.614 |
| 2. My sense of hearing was highly engaged during the session. | 80.11 | 74.89 | 2763.50 | 0.443 |
| 3. My sense of touch was highly engaged during the session. | 82.36 | 72.64 | 2590.00 | 0.159 |
| 4. I was convinced that the objects I viewed with zSpace® were moving through space. | 75.62 | 79.38 | 2820.00 | 0.589 |
| 5. I was able to explore all of the 3-D environment with my sight. | 77.27 | 77.73 | 2947.00 | 0.945 |
| 6. I was able to explore all of the 3-D environment with my sense of touch. | 78.97 | 76.03 | 2851.00 | 0.675 |
| 7. I was able to closely examine objects during the zSpace® session. | 76.58 | 78.42 | 2893.50 | 0.777 |
| 8. I was able to closely examine objects from multiple viewpoints during the zSpace® session. | 76.20 | 78.80 | 2864.50 | 0.687 |

Mann–Whitney's *U*: differences in two independent groups, alpha 2-tailed

grade students, the high-range questions and perceived control were significantly correlated ($r = 0.255$, $p < 0.02$) as well as the mid-range questions to perceived distraction ($r = 0.281$, $p < 0.02$). There were no significant correlations for the constructs of cognitive classification and the presence for the 9th-grade students.

## Limitations

Results of this study are limited to the responses of the participants in the zSpace® sessions and their retrospective reports about using the technology. This was mitigated by surveying the participants immediately after use of the VRE. The degree to which this sample is representative of other students' perceptions of presence in 3-D HE VR is unknown. A limitation cited within existing presence research is the sole reliance on self-report (questionnaire)-based measures to describe or generalize virtual presence (Azevedo 2015; Slater 1999, 2004; Slater and Garau 2007). Self-report measures, like the presence survey, have been shown to be effective in measuring user perceptions of presence (Wallace et al. 2017), but not user responses to the virtual environment (Bailenson et al. 2005, p. 390). In the analysis, there is a possibility that significance found between variables was due to chance, although each correlation was completely separate.

## Discussion

The results showed that there were no significant differences in the 6th- and 9th-grade students' perceptions of presence while learning science with virtual reality, suggesting they experienced similar levels of presence in the 3-D, HE, VR environment. In addition, this research explored any relationships between students' cognitive abilities and perceptions of presence. Of the 208 correlations completed for cognitive ability and perception of presence, nine were found to be statistically significant, indicating a potential relationship between development and presence. The nine correlations that were significant indicated that spatial rotation and angular geometry were positively correlated with reported perceived control and negatively correlated with distraction, for the 6th graders, suggesting the importance of spatial acuity when using VR technologies for learning science.

Overall, students who scored higher on the Piagetian inventory reported greater presence (Table 13). Students' scores in specific areas of the IPDT involving spatial and mental rotation were positively correlated to increased perceptions of presence (Tables 8 and 12). In particular, significant positive correlations were found for the 6th-grade scores in the construct of laws (Table 8) and the two subsets of rotation and angles. Another positive correlation to the control presence score was found in the subset of matrices (Table 12). This relationship suggests that students who were better able to interpret concepts like spatial rotation and angular geometry (as evidenced by their proficiency scores on the IPDT) reported more control of the 3-D, VR environment in the zSpace® sessions. One theory to describe how the human brain processes 3-D imagery is visuospatial constructive cognition, defined as one's ability to view the component parts of an object and construct a replica from those parts (Mervis et al. 1999). Mervis et al. (1999) have argued that this ability may play a role in students' perceptions of presence as individual differences in visuospatial constructive ability and pattern construction improved with age from children to adults. This too may explain the lack of a relationship between laws and presence scores among the 9th-grade students and the strong positive correlation between the 6th-grade students who scored highly in the highest range (ages 11–13) of the IPDT and presence control scores (Table 13). Yet, sequential thinking and

**Table 6** 6th- and 9th-grade students' perceived perceptions of distraction from presence survey using Mann–Whitney's *U*

| Presence item | 6th grade mean rank | 9th grade mean rank | Mann–Whitney's *U* | *p* value |
|---|---|---|---|---|
| All distraction questions by factor (questions 1 through 17) | 79.35 | 75.65 | 2822.00 | 0.606 |
| 1. I was aware of other events in the classroom during the zSpace® session. | 75.82 | 79.18 | 2835.50 | 0.631 |
| 2. I was aware of sounds outside of the zSpace® session. | 71.88 | 83.12 | 2532.00 | 0.108 |
| 3. I was aware of the stylus I used to control objects in zSpace®. | 77.14 | 77.86 | 2937.00 | 0.914 |
| 4. I was aware of the 3-D glasses I used to view objects in zSpace®. | 78.92 | 76.08 | 2855.00 | 0.679 |
| 5. I was aware of the zSpace® monitor I used to view objects in zSpace®. | 78.21 | 76.79 | 2909.50 | 0.834 |
| 6. I was aware of the zSpace® camera during the session. | 81.75 | 73.25 | 2637.00 | 0.220 |
| 7. I was very involved during the zSpace® session. | 81.48 | 73.52 | 2658.00 | 0.217 |
| 8. The 3-D glasses were distracting. | 81.73 | 73.27 | 2638.50 | 0.222 |
| 9. The stylus was distracting. | 81.34 | 73.66 | 2668.50 | 0.262 |
| 10. The 3-D objects in the environment were distracting. | 77.89 | 77.11 | 2934.50 | 0.909 |
| 11. Other students were distracting me during the zSpace® session. | 84.04 | 70.96 | 2461.00 | 0.047 |
| 12. The stylus interfered when I moved objects in the 3-D environment. | 73.72 | 81.28 | 2673.50 | 0.284 |
| 13. The glasses interfered when I moved objects in the 3-D environment. | 73.94 | 81.06 | 2690.00 | 0.304 |
| 14. I was able to concentrate easily during the zSpace® session. | 83.66 | 71.34 | 2490.50 | 0.066 |
| 15. I was comfortable using the stylus during the zSpace® session. | 82.18 | 72.82 | 2604.00 | 0.164 |
| 16. I was comfortable using the 3-D glasses during the zSpace® session. | 81.52 | 73.48 | 2655.00 | 0.229 |
| 17. I felt comfortable viewing the objects in the 3-D environment. | 80.27 | 74.73 | 2751.00 | 0.407 |

Mann–Whitney's *U*: differences in two independent groups, alpha 2-tailed

probability (a subset of laws) held no significance, suggesting the VE did not privilege logical thinking, as compared to spatial acuity. Furthermore, there was a significant negative correlation between laws and distraction presence scores (Table 8), as younger (6th grade) students who scored higher in the IPDT category of laws reported to be less distracted by

**Table 7** 6th- and 9th-grade students' perceived perceptions of realism from presence survey using Mann–Whitney's *U*

| Presence item | 6th grade mean rank | 9th grade mean rank | Mann–Whitney's *U* | *p* value |
|---|---|---|---|---|
| All realism questions by factor (questions 1 through 15) | 78.39 | 76.61 | 2896.00 | 0.804 |
| 1. The zSpace® 3-D objects were not realistic. | 78.43 | 76.57 | 2893.00 | 0.787 |
| 2. I felt disconnected during the zSpace® session. | 78.78 | 76.22 | 2866.00 | 0.706 |
| 3. My experiences during the zSpace® session were similar to real laboratory experiences. | 78.98 | 76.02 | 2850.50 | 0.674 |
| 4. The 3-D environment was realistic. | 81.57 | 73.43 | 2651.00 | 0.239 |
| 5. I felt disoriented when I put the stylus down. | 75.37 | 79.63 | 2800.50 | 0.544 |
| 6. I felt confused when I put the stylus down. | 78.73 | 76.27 | 2870.00 | 0.722 |
| 7. I felt disoriented when I removed the 3-D glasses. | 77.68 | 77.32 | 2951.00 | 0.960 |
| 8. I felt confused when I removed the 3-D glasses. | 78.96 | 76.04 | 2852.00 | 0.674 |
| 9. I lost track of time during the zSpace® session. | 79.90 | 75.10 | 2780.00 | 0.496 |
| 10. I could transition from the real world to using zSpace® easily. | 78.47 | 76.53 | 2890.00 | 0.778 |
| 11. The illusion of the 3-D environment was very real to me. | 77.91 | 77.09 | 2933.00 | 0.904 |
| 12. The object appeared to jump out of the screen. | 74.72 | 80.28 | 2750.50 | 0.411 |
| 13. Using zSpace® to view objects is more realistic than using a simulation on a computer. | 72.32 | 82.68 | 2565.50 | 0.112 |
| 14. Using zSpace® to view objects is more realistic than watching a video. | 74.56 | 80.44 | 2738.00 | 0.375 |
| 15. Using zSpace® to view objects is more realistic/that participating in lab at school. | 80.64 | 74.36 | 2722.50 | 0.368 |

Mann–Whitney's *U*: differences in two independent groups, alpha 2-tailed

**Table 8** Correlations between students' proficiency scores on the inventory of Piaget's developmental tasks (IPDT) laws test items (including subtests) and presence scores

| | 1 (control) | 2 (sensory) | 3 (distraction) | 4 (realism) |
|---|---|---|---|---|
| 6th grade (*N* = 75) | | | | |
| Laws (*N* = 12) | 0.260* | 0.095 | −0.249* | 0.073 |
| Rotation (*N* = 4) | 0.293** | 0.217 | −0.144 | 0.073 |
| Angles (*N* = 4) | 0.229* | 0.042 | −0.208 | −0.065 |
| Probability (*N* = 4) | 0.147 | 0.037 | −0.176 | 0.131 |
| 9th grade (*N* = 76) | | | | |
| Laws (*N* = 12) | −0.110 | −0.132 | 0.048 | −0.072 |
| Rotation (*N* = 4) | −0.055 | −0.076 | −0.016 | −0.120 |
| Angles (*N* = 4) | −0.073 | −0.033 | 0.020 | −0.001 |
| Probability (*N* = 4) | −0.061 | −0.158 | −0.007 | −0.022 |

Correlations with these variables are Spearman's rank correlation (rho) coefficients

Values range from 0 to 1

* $p < 0.05$ (Bonferroni's correction)

** $p < 0.01$ (Bonferroni's correction)

the external environment. This finding may relate to previous research suggesting individuals who are more cognitively equipped to comprehend and navigate VREs, experience greater immersion, and are less prone to visual or auditory distractions (Nordahl and Korsgaard 2010). This research may also provide insight to the (significant) negative relationship found between the 6th-grade students' proficiency scores in IPDT mid-range (ages 9–10) questions (i.e., subtests of levels, weight, perspective, rotation, shadows, and distance) and distraction scores (Table 13). The lack of significance among students in the lower range of IDPT and distraction may be related to students not understanding the question or a lack of metacognitive skills to assess the degree to which they were distracted in the VRE. Interestingly, there was no such significant relationship with the 9th-grade students, which could be related to the open environment of the school setting where the research occurred (school cafeteria) compared to the setting of the 6th-grade students (who were tested in a closed research laboratory). For the 9th-grade participants, significant negative correlations were found between understanding relations (e.g., objects in series) and inclusion (e.g., nesting sets within sets) and sensory presence scores (Tables 9 and 12). This is similar (but not due) to cognitive chaining, where basic mathematical operations (e.g., understanding a series) are cognitively executed partially in parallel, allowing for higher mental tasks. This places nonconscious strain on the brain, diverting cognitive resources away from other mental structures (Sackur and Dehaene 2009). Moreover, significant negative correlations for 6th-grade students were found for weight and sensory presence responses (Table 10). Piaget (1962) described the understanding of weight, like seriation, as a watershed moment in the transition from concrete operational development to formal operational thinking. This suggests that if some students have

**Table 9** Correlations between students' proficiency scores on the inventory of Piaget's developmental tasks (IPDT) relations test items (including subtests) and presence scores

| | 1 (control) | 2 (sensory) | 3 (distraction) | 4 (realism) |
|---|---|---|---|---|
| 6th grade (*N* = 75) | | | | |
| Relations (*N* = 12) | 0.087 | 0.058 | −0.072 | 0.067 |
| Sequence (*N* = 4) | 0.020 | −0.002 | −0.084 | 0.035 |
| Seriation (*N* = 4) | 0.058 | 0.029 | −0.223 | −0.045 |
| Inference (*N* = 4) | 0.191 | 0.134* | 0.063 | 0.148 |
| 9th grade (*N* = 76) | | | | |
| Relations (*N* = 12) | −0.049 | −0.276** | −0.128 | 0.017 |
| Sequence (*N* = 4) | −0.013 | −0.063 | −0.116 | −0.005 |
| Seriation (*N* = 4) | −0.051 | −0.220 | −0.027 | −0.084 |
| Inference (*N* = 4) | −0.052 | −0.128 | −0.046 | 0.133 |

Correlations with these variables are Spearman's rank correlation (rho) coefficients

Values range from 0 to 1

**Table 10** Correlations between students' proficiency scores on the inventory of Piaget's developmental tasks (IPDT) conservation test items (including subtests) and presence scores

| | 1 (control) | 2 (sensory) | 3 distraction) | 4 (realism) |
|---|---|---|---|---|
| 6th grade ($N=75$) | | | | |
| Conservation ($N=16$) | 0.184 | −0.116 | −0.034 | −0.008 |
| Quantity ($N=4$) | 0.140 | 0.016 | 0.106 | 0.039 |
| Weight ($N=4$) | 0.039 | −0.244* | −0.160 | −0.037 |
| Volume ($N=4$) | 0.171 | 0.075 | 0.016 | 0.050 |
| Distance ($N=4$) | 0.042 | −0.056 | −0.022 | −0.066 |
| 9th grade ($N=76$) | | | | |
| Conservation ($N=16$) | −0.126 | −0.154 | 0.111 | 0.016 |
| Quantity ($N=4$) | −0.129 | −0.132 | 0.154 | 0.020 |
| Weight ($N=4$) | 0.051 | 0.106 | 0.069 | 0.133 |
| Volume ($N=4$) | −0.163 | −0.131 | 0.002 | −0.037 |
| Distance ($N=4$) | −0.002 | −0.098 | 0.129 | −0.062 |

Correlations with these variables are Spearman's rank correlation (rho) coefficients

Values range from 0 to 1

*$p < 0.05$

yet to develop the cognitive architecture for abstraction (Satoshi 2008), their sense of immersion suffers as greater mental effort is being spent, and, as a consequence, they perceive less sensory involvement. Witmer and Singer (1998) hypothesized that sensory and distraction factors would affect both immersion and involvement in presence; therefore, negative correlations in sensory and distraction (immersion) factors and positive correlations with control (involvement) found in this study support their conjecture.

Although not significant, the 6th-grade participants (Table 4) reported less control over the zSpace® environment (control question 1, $p = 0.041$), more difficulty with the 3-D environment responding to their actions (control question 2, $p = 0.021$), and less stylus responsivity (control question 8, $p = 0.040$). In addition, they reported being more distracted by other students (distraction question 11, $p = 0.047$). User issues within the VRE responding to their actions or feeling like they had less control over the environment may contribute to distraction; Spronk and Jonkman (2012) found in their research that younger learners have more difficulty suppressing distractions than adults, providing fewer resources for self-control. They indicate that this reduction in attention is due to high cognitive load demands (e.g., multi-input sensory information) on the prefrontal cortex. Cognitive load and prefrontal cortex demand are of interest to this research as the latter cognitive structure was previously discussed as the origin of users' perceptions of presence (Miller and Cohen 2001; Satoshi 2008) and found to be underdeveloped in children (Baumgartner et al. 2008). This relationship is further complicated by cognitive load research and its relationship to perceived control available to the learner (Swaak and de Jong 2001). Other studies have also corroborated the cognitive

**Table 11** Correlations between students' proficiency scores on the inventory of Piaget's developmental tasks (IPDT) images test items (including subtests) and presence scores

| | 1 (control) | 2 (sensory) | 3 (distraction) | 4 (realism) |
|---|---|---|---|---|
| 6th grade ($N=75$) | | | | |
| Images ($N=16$) | 0.140* | −0.035 | −0.153 | −0.046 |
| Levels ($N=4$) | 0.151 | 0.042 | −0.179 | −0.051 |
| Perspective ($N=4$) | 0.149 | 0.076 | −0.033 | 0.060 |
| Movement ($N=4$) | −0.027 | −0.094 | 0.024 | 0.069 |
| Shadows ($N=4$) | 0.085 | −0.121 | −0.198 | −0.083 |
| 9th grade ($N=76$) | | | | |
| Images ($N=16$) | −0.105 | −0.092 | 0.022 | −0.035 |
| Levels ($N=4$) | −0.070 | 0.121 | 0.079 | −0.045 |
| Perspective ($N=4$) | −0.005 | −0.035 | 0.013 | −0.077 |
| Movement ($N=4$) | −0.159 | −0.177 | −0.002 | 0.048 |
| Shadows ($N=4$) | −0.029 | −0.087 | 0.098 | −0.097 |

Correlations with these variables are Spearman's rank correlation (rho) coefficients

Values range from 0 to 1

**Table 12** Correlations between students' proficiency scores on the inventory of Piaget's developmental tasks (IPDT) classification test items (including subtests) and presence scores

| | 1 (control) | 2 (sensory) | 3 (distraction) | 4 (realism) |
|---|---|---|---|---|
| 6th grade (*N* = 75) | | | | |
| Classification (*N* = 16) | 0.212 | 0.032 | − 0.016 | − 0.007 |
| Matrix (*N* = 4) | 0.244* | 0.081 | − 0.082 | − 0.189 |
| Symbols (*N* = 4) | 0.091 | − 0.065 | 0.028 | 0.115 |
| Classes (*N* = 4) | − 0.046 | − 0.048 | − 0.147 | 0.046 |
| Inclusion (*N* = 4) | 0.227 | 0.046 | 0.091 | 0.021 |
| 9th grade (*N* = 76) | | | | |
| Classification (*N* = 16) | 0.008 | − 0.016 | 0.068 | 0.018 |
| Matrix (*N* = 4) | 0.043 | 0.104 | − 0.164 | 0.051 |
| Symbols (*N* = 4) | − 0.036 | 0.111 | 0.053 | − 0.101 |
| Classes (*N* = 4) | 0.008 | − 0.014 | 0.134 | 0.066 |
| Inclusion (*N* = 4) | − 0.051 | − 0.237* | − 0.042 | 0.051 |

Correlations with these variables are Spearman's rank correlation (rho) coefficients

Values range from 0 to 1

*$p < 0.05$

effects, such as "distraction, fatigue, and cognitive overhead in mastering the interface influence the outcome," with perceptions of presence (Roussos et al. 1999, p. 258).

This study suggests that in 3-D, HE, VR science-based activities, 6th-grade students may experience less control over in VEs and greater distraction from outside sources. Both control and distraction influence an individual's perception of presence (Witmer and Singer 1998). Further, immersion tends to be greater in individuals who quickly adapt to and are able to concentrate within the virtual environment (Witmer et al. 2005). Prior studies have indicated that discrepancies between visual and haptic cues can hinder user interaction with virtual objects (Arsenault and Ware 2004; Ware and Rose 1999). This study found initial evidence that an individual's level of cognitive development may affect students' perceptions of presence, in particular their ability to concentrate (undistracted) in, process sensory information within, and exert control over the 3-D, HE, VR environment. However, the 6th-grade students with a strong spatial acuity (e.g., volume and angles as evidenced by the IDPT) that contributes to virtual environments (Bowman and McMahan 2007) reported more control of the 3-D, HE, VR environment in their presence survey. Thus, their greater level of control while minimizing distractions within the virtual environment may have facilitated perceptions of presence for these younger (6th grade) students. Students who had scored lower on aspects (e.g., distance, perspective, rotation) that contribute to virtual environments, however, reported *more* distraction within the 3-D, HE, VR space. One interpretation of this relationship is that students who are not yet concrete operational thinkers are not as able to spatially conceptualize and interact with the virtual environment. Thus, some more abstract science concepts may be difficult for younger students, even when they can explore them fully in virtual environments (Bronack et al. 2008).

Although this study did not examine how the variables that correlated with presence (spatial rotation and angular geometry) contributed to learning science concepts, suggesting

**Table 13** Correlations between students' proficiency scores on the inventory of Piaget's developmental tasks (IPDT) by cognitive classifications (proficiency by age) and presence scores

| Measure | 1 (control) | 2 (sensory) | 3 (distraction) | 4 (realism) |
|---|---|---|---|---|
| 6th grade (*N* = 75) | | | | |
| Low range (7–8) | 0.106 | − 0.029 | − 0.057 | − 0.027 |
| Midrange (9–10) | 0.192* | − 0.071 | − 0.281** | − 0.062 |
| High range (11–13) | 0.255** | 0.070 | − 0.106 | 0.094 |
| 9th grade (*N* = 76) | | | | |
| Low range (7–8) | − 0.137 | − 0.155 | − 0.037 | − 0.062 |
| Midrange (9–10) | − 0.057 | − 0.066 | 0.085 | − 0.083 |
| High range (11–13) | − 0.123 | − 0.191 | 0.066 | 0.014 |

Correlations with these variables are Spearman's rank correlation (rho) coefficients

Values range from 0 to 1

*$p < 0.05$ (Bonferroni's correction)

**$p < 0.02$ (Bonferroni's correction)

implications for teaching and learning science content with VR, science educators need to know how students perceive these VR experiences, what they learn from them, and how experiences vary among student populations. In teaching, VR allows science educators to design new learning experiences to engage students in science in new ways by exploring our natural world at the extremes (cosmic to nanoscale) (Jones et al. 2014). In learning, VR is effective in teaching abstract topics related to abstract and spatial understanding, like gravity, magnetism, and planetary motion (Merchant et al. 2014). The latter is particularly salient for students with cognitive disabilities and their use of VR for learning (Childers et al. 2016; Freina and Ott 2015; Vasquez et al. 2015), in and among the various VRE hardware (e.g., desktop, head-mounted displays, and projection) systems available (Hite et al. 2019). Further research is warranted to examine the intersectionality of users' cognitive development, perceptions of presence in VREs, and conceptual science learning.

## Conclusion

The goal of this research was to examine how cognitive development influences learners' perceptions of presence for experiences in 3-D, HE, VR technology for science. This work suggests that children may experience differential virtual presence due to cognitive inabilities to self-evaluate the stimulated environment vis-à-vis physical reality (Jones et al. 2016; Hite 2016a; Hite 2016b; Baumgartner et al. 2008; Spronk and Jonkman 2012). First, the present study corroborates this previous research, indicating that children may experience presence differently than adults and their adolescent counterparts. Second, this study also found that participants' levels of cognitive development, in particular within the domains of spatial thinking, reasoning, and understanding, are associated with reduced perceptions of virtual presence. This suggests that more work should be done comparing spatial skills to perceptions of presence among a variety of ages and demographic groups. This is of particular interest as gender differences in spatial skills (Devon et al. 1998) are an ongoing debate in research on women's STEM achievement (Linn and Petersen 1986) and underrepresentation in STEM fields (Sorby 2009). Previous research has demonstrated that as an individual spends more time in virtual environments (VEs), their spatial acuity grows (Dünser, Steinbügl et al. 2006; Osberg 1997; Rizzo et al. 1998), as well as their ability to self-evaluate presence (Freeman et al. 1999). Longitudinal studies are warranted to explore how students' spatial skills and self-awareness of presence from extended experiences in VEs develop.

Third, if students are cognitively unable to make assessments of reality (e.g., concrete operational thinking), they may experience a profound sense of immersive presence. Exploring the relationship between development and perceptions of presence with younger students (elementary) is an area of needed research as these technologies expand into classrooms, gaming, and the entertainment marketplace. For children, even the illusion of control and realism may create powerful effects on motivation and learning. Another avenue of research is to explore how immersion occurs in educational contexts, paying specific attention to the human-centered attributes of the VR than the hardware technologies (Stone 2009). If students struggle with a complex immersive environment, software developers should consider taking a less is more approach to immersion, in order to avoid overwhelming younger users (Bowman and McMahan 2007). Virvou and Katsionis (2008) found that adolescent and younger learners greatly rely on the VE to provide scaffolding and support as a strategy to minimize frustration and distraction. Research by Park et al. (2011) reported that content which was non-redundant and interesting, even in a low-load (narrative-based) format, resulted in the most effective learning outcomes for sampled students in the VE. Hence, developmentally appropriate use of 3-D, HE, VR technology is important, and an area needing further research.

Prior issues with usability, likability (Virvou and Katsionis 2008), software limitations (Jayaram et al. 2001), and the high costs of the required hardware (Dalgarno and Lee 2010) that had previously made this equipment cost-prohibitive to mainstream educational agencies continue to diminish. As the marketplace for 3-D, HE, and VR devices expands, so does their ability to permeate different levels and domains of science instruction. Since a key component of learning in VREs is invoking and maintaining the user's perception of presence (Schrader and Bastiaens 2012; Zeltzer 1992), the efficacy of these devices as science instructional tools hinges on their ability to induce perceptions of presence for science learners of all ages, backgrounds, and contexts.

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## Compliance with Ethical Standards

**Conflict of Interest** Authors Hite and Jones have received prior travel support (less than $1000 per year) and consulted (less than $2000 total) for the zSpace company.

**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.

## Appendix

### Presence Survey

**Directions**: Please darken the bubble that best addresses the subject of the question.

1. What is your age? ○ 11 ○ 12 ○ 13 ○ 14 ○ 15 ○ 16 ○ 17 ○ 18

2. I identify myself as a? ○ Female ○ Male

3. What best describes your ethnicity? ○ Hispanic or Latino or Chicano
○ Not Hispanic or Latino or Chicano

4. What best describes your race? *You may bubble more than one.*
○ American Indian or Alaska Native
○ Asian
○ Black or African American
○ Native Hawaiian or Other Pacific Islander
○ White

### Technology Use Inventory

**Directions**: Read each statement carefully. Circle the correct response for each statement.

| | | |
|---|---|---|
| 1. I use a computer at least once a week. | YES | NO |
| 2. I use an iPad/Tablet at least once a week. | YES | NO |
| 3. I use the Internet at least once a week. | YES | NO |
| 4. I play video games and/or computer games at least once a week. | YES | NO |

### Presence Survey

Directions: Read each statement carefully. Please write the number on the line provided next to the question that best represents how you feel when using zSpace®.

| Strongly Disagree | Disagree | Slightly Disagree | Slightly Agree | Agree | Strongly Agree |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |

CONTROL FACTORS

____1. I felt that I was in control of zSpace® 3-D environment during the session.

____2. zSpace® 3-D environment would respond to my actions.

____3. zSpace® 3-D environment did what I wanted it to do.

____4. The interactions I had with the zSpace® 3-D environment were natural.

____5. I felt that the stylus allowed me to control what was occurring in the 3-D environment.

____6. The stylus would do what I wanted it to do in the 3-D environment.

____7. The interactions I had with the stylus to interact with the 3-D environment were natural.

____8. The stylus would respond to my actions when I interacted with the 3-D environment.

____9. The stylus allowed me to control the movement of objects in the zSpace® environment.

____10. I was able to predict what would happen if I moved an object in the 3-D zSpace® environment.

____11. I could move objects easily in the 3-D zSpace® environment.

____12. I could manipulate (handle) objects easily in the 3-D zSpace® environment

____13. There was a delay between what I wanted to do and what happened on the screen.

____14. I adjusted quickly to the screen during the zSpace® session.

____15. I could easily move objects in the 3-D environment.

____16. I could easily interact with different objects in the 3-D environment.

____17. I could manipulate objects with a stylus in ways that I could not in the real world.

____18. I could easily zoom in on objects.

____19. I could easily zoom out from an object.

____20. I could navigate inside of objects using the stylus.

____21. I was able to navigate behind objects that I could not do normally in a 2D (like a flat screen) simulation.

## SENSORY FACTORS

____1. My sense of sight was highly engaged during the session.

____2. My sense of hearing was highly engaged during the session.

____3. My sense of touch was highly engaged during the session.

____4. I was convinced that the objects I viewed with zSpace® were moving through space.

____5. I was able to explore all of the 3-D environment with my sight.

____6. I was able to explore all of the 3-D environment with my sense of touch.

____7. I was able to closely examine objects during the zSpace® session.

____8. I was able to closely examine objects from multiple viewpoints during the zSpace® session.

## DISTRACTION FACTORS

____1. I was aware of other events in the classroom during the zSpace® session.

____2. I was aware of sounds outside of the zSpace® session.

____3. I was aware of the stylus I used to control objects in zSpace®.

____4. I was aware of the 3-D glasses I used to view objects in zSpace®.

____5. I was aware of the zSpace® computer screen I used to view objects in zSpace®.

____6. I was aware of the zSpace® camera during the session.

____7. I was very involved during the zSpace® session.

____8. The 3-D glasses were distracting.

____9. The stylus was distracting.

____10. The 3-D objects in the zSpace® environment were distracting.

____11. Other students were distracting me during the zSpace® session.

____12. The stylus interfered when I moved objects in the 3-D zSpace® environment.

____13. The glasses interfered when I moved objects in the 3-D zSpace® environment.

____14. I was able to concentrate easily during the zSpace® session.

____15. I was comfortable using the stylus during the zSpace® session.

____16. I was comfortable using the 3-D glasses during the zSpace® session.

____17. I felt comfortable viewing the objects in the 3-D zSpace® environment.

## REALISM FACTORS

____1. The zSpace® 3-D objects were not realistic.

____2. I felt disconnected during the zSpace® session.

____3. My experiences during the zSpace® session were similar to real laboratory experiences.

____4. The 3-D zSpace® environment was realistic.

____5. I felt disoriented when I put the stylus down.

____6. I felt confused when I put the stylus down.

____7. I felt disoriented when I removed the 3-D glasses.

____8. I felt confused when I removed the 3-D glasses.

____9. I lost track of time during the zSpace® session.

____10. I could transition from the real world to using zSpace® easily.

____11. The illusion of the 3-D zSpace® environment was very real to me.

____12. The object appeared to jump out of the zSpace® screen.

____13. Using zSpace® to view objects is more realistic than using a simulation on a computer.

____14. Using zSpace® to view objects is more realistic than watching a video.

____15. Using zSpace® to view objects is more realistic that participating in lab at school.

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