Mission HydroSci: A Next Generation Science Standards aligned virtual environment

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Abstract
This study explores middle school student learning of *Next Generation Science Standards* aligned content and practices associated with use of an innovative virtual learning environment. The learning environment, a computer-based game called *Mission HydroSci* (MHS), was developed with the aim of supporting student learning of water systems science along with the practice of scientific argumentation. Teachers implemented MHS within their science classrooms as a replacement unit for water science over a period of two weeks. Pre- and post-test data were collected from 633 students across ten schools. Data included an assessment of water systems content and a test of argumentation competencies. Students demonstrated positive and statistically significant changes in water systems understandings and argumentation; however, the effect sizes were modest. These results have informed several revisions to the MHS learning environment including modifications to the argumentation platform within the game and additional attention to key water systems concepts.

Introduction
When technology is paired with education, it has the potential to revolutionize how learning looks in the classroom. In this study, we study middle school students' learning of NGSS-aligned content and practices through the innovative use of technology via 3-D virtual learning environments (VLE). Specifically, we will discuss how our team addressed a current problem in science education: What does a multi-dimensional, Next Generation Science Standards (NGSS) aligned, technology-based classroom look like?

Virtual Learning Environments (VLE) is a common term that is used to describe educational software. A VLE is a web-based communications platform, that allows students, without limitation of time and place, to access different learning tools, such as program information, course content, teacher assistance, discussion boards, document sharing systems, and learning resources (Martins and Kellermanns, 2004). However, not all scholars agree on the specific elements that constitute VLE. Dillenbourg, Schnieder & Synteta (2002) have reviewed numerous VLEs, and argue that there are seven features of VLEs, including the ability to enrich physical classroom activities, the integration of technologies and multiple pedagogical approaches, immersion in a 3D world, and ability to co-construct the environment. Other researchers have specifically delineated a 3D-VLE from other VLEs, defined as an environment that leverages aspects of human perception by extending visual information into three spatial dimensions (Dalgarno & Lee, 2010). Researchers have noted (i.e. Dalgorni & Lee, 2010; Jacobson, Kim, Lee, Lim, & Low, 2008) that there are several studies from the mid 1990s to late 2000s suggesting that immersive 3D-VLEs, when designed and used appropriately, provide a higher level of learning and engagement when compared to more traditional 2-D learning techniques used to deliver equivalent educational content. While there are certainly costs associated with the development and implementation of 3D-VLEs, the research suggests that these can offer an increased level of student engagement and achievement.

Given their potential to engage learners in an educational concept while also effectively at promoting learning, VLEs have been used in a wide range of educational contexts. Within science education, VLEs have been previously used in a diverse range of science topics. Additionally within the science education literature, VLEs have been used to see promote learning of both science content knowledge as well as scientific argumentation.

Virtual learning environment (VLE) based interventions pertaining to science have been also shown to produce increases in student's content knowledge in a a wide range of sciences, from physics to earth sciences. Within physics, gains were seen in seventh grader,s knowledge of forces after interacting with the VLE, Carrot Land. Within Carrot Land students play as a rabbit whose goal is to collect as many carrots as possible using the least amount of energy. The VLE makes the content of frictional forces accessible by limiting the variables students have to interact with (i.e. amount of force used and direction of force vectors). By focusing on these variables students are able to see how they interact without the noise of other real world interactions, something only possible within a VLE. As such, Carrot Land was shown to produce greater gains in student knowledge of frictional forces as well as forces needed to overcome friction (Chen, 2015) when comparing control classrooms versus classrooms who did not have the Carrot land intervention.

The VLE named Selene: A Lunar Construction GaME allowed players to create and modify aspects of celestial bodies that were designed to have specific properties. These properties include water state, atmosphere composition, mass, etc. The game pushed players to use their content knowledge to progress through the various levels, by forcing them to apply knowledge of the various properties of celestial objects. As such, Selene was able to significantly increase student knowledge about various properties of celestial at a consistent rate among most users (Reese, Tabachnick, & Kosko 2015).

VLEs have also been utilized to increase student knowledge of water systems. Tiaga Park, a VLE, has students involved in a mystery pertaining to sick animals in a zoo. This immersive simulation was shown to increase students knowledge around water systems as their ability to understand complex systems with multiple input and output variables. (Barab, Zuiker, Warren, Hickey, Ingram-Goble, Kwon, & Herring, 2007).

Argumentation Gains through VLEs

VLE based argumentation interventions can successfully increase student argumentation skills. There are many subsets of argumentation including dialogic argumentation, generation of arguments, evaluative knowledge and argument quality assessment. VLEs have been shown to increase all of these. Iordanou (2015) and Kuhn (2016) used VLE interventions to increase the dialogic (debate) argumentation skills of students; the VLEs explicitly informed students into what makes a good dialogic argument and students' overall skills improved versus control groups that did not participate in the VLE.

Hafter (2014) was able to significantly affect student's evaluative knowledge and generative argumentation subsets, versus a control group, using a VLE as a simple training environment centered around argument structure and basing arguments off of legitimate information.

Lastly, Squire and Jan (2007) were able to produce gains in argumentation generation with students using the VLE, Mad City Mystery. Within Mad City Mystery, students generated hypotheses using science content to explain the cause of death of an in-game character. The researchers also found that participants' grade levels affected gains in different aspects of argumentation. The middle school students improved their ability to generate hypotheses, while high school students showed the greatest gains in ability to evaluate the quality of arguments more critical of the hypothesis of their teammates. Overall VLEs have been shown to elicit gains in player's dialogic argumentation, generation of arguments, evaluative knowledge and argument quality assessment skill sets. Based on these studies showing student gains in both content knowledge and argumentation competency, we have developed Mission HydroSci (MHS), an argumentation-based VLE focused on understanding water systems, which leverages the affordances of a VLE while simultaneously staying consistent with the vision of science and learning described within the NGSS.

Developing a Next Generation Science Standards aligned VLE

The Next Generation Science Standards: For States, By States (NGSS) (NRC, 2014) were developed to better integrate science content and scientific practices within the classroom. The NGSS provided a shift in focus toward essential skills to the practice of science as opposed to a the singular focus on content knowledge characterizing previous learning standards . To reach this goal, the NGSS takes the stance that scientific practices, including argumentation, and science content are inexorably connected, and should be reflected that way within the classroom. As such the NGSS describes many scientific practices but leverages the ideas from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012, p.45), when describing argumentation as a central classroom practice. Ultimately, if we expect to truly reflect science within the classroom, consistent with the vision of the NGSS, argumentation must become a central focus. However this will require novel approaches to curriculum and instruction.

In order to support the type of learning consistent with the vision of the NGSS, students need rich learning environments with a focus on science practices. VLEs can be leveraged to create these rich contexts, whereas predominant approaches used in K-12 science courses often fail to provide the kinds of rich contexts necessary to meet the demands of the NGSS (Barko & Sadler, 2013). While there have been several 3D-VLEs designed and implemented within science education, all of these focus on a singular dimension of science learning: either content or practice. As a results, the VLEs are not able to provide students' with an experience that allows for development of both science content knowledge and ability to engage in science practice in accordance with the NGSS.

To this end, we describe the development of a 3D-VLE called Mission HydroSci (MHS). This VLE helped students build more sophisticated understands of water systems while engaging students in the practice of argumentation. We chose to focus on argumentation due to its importance on the process of science (Duschl & Osbourne, 2002). At its core, science is a practice of discourse and argumentation about methods, goals, and explanations of natural phenomena imbedded in matters of history, philosophy and sociology (Duschl, 2007). As such, the ability to generate an explanation of a natural phenomenon that is convincing while simultaneously coordinating evidence and theory is vital to any scientific process (Sampson &

Clark, 2008). To truly engage students in the process of science, argumentation must be foregrounded within the classroom. “Argumentation and critique are at the very center of science… helping to connect the ‘hands-on’ work of scientific inquiry with the ‘minds-on’ work of developing scientific ideas and theories” (Osborne, Henderson, MacPherson, et al., 2016, p. 822). Due to practice of argumentation having such a central role in science, curriculum must reflect this practice (Duschl, Shweingruber, & Shouse, 2007).

Overview of MHS

This is a study of the intervention MHS, which is a VLE that is currently in development with the focus of providing a context for middle school students to learn water systems content, while also engaging in scientific argumentation. MHS is an innovative learning technology based curriculum which has the potential to engage students in scientific argumentation, scaffold their learning to argue scientifically and integrate the practices of argumentation with disciplinary core ideas related to water systems. MHS will be a replacement unit for water systems curriculum in middle school classrooms, with the full MHS unit spanning approximately two weeks of playing/learning time. Learning experiences within MHS will be facilitated through interactions within the MHS virtual environment in which students have the opportunity to explore and experiment with water systems, collect evidence relative to challenging water related problems, interacting with non player characters, and use collected evidence as the basis for building and critiquing arguments. Within the MHS curriculum, students progress through a series of six levels. Each level has been designed around a challenging problem or task that features progressively more complex ideas about water systems as well as more challenging argumentation competencies.

The MHS curriculum has been specially designed to align with the NGSS. Central to the vision of NGSS is the necessary linkage of disciplinary core ideas, crosscutting concepts, and scientific practices. As such, the MHS curriculum allows students to engage in science practices, while also building a more sophisticated understanding of water systems. MHS aims to integrate argumentation into the core design of the curriculum, while also recognizing the cognitive demands that argumentation places on students. It has been shown that argumentation can be a difficult practice for students to engage in (Driver, Newton & Osborne, 2000). There are many barriers to student mastery of scientific argumentation. Students tend to make claims that are unjustified as well as struggle with recognizing opposing arguments (Sadler, 2004). Sadler (2004) also found that students do not commonly use scientific evidence to inform arguments, and analyzing and evaluating arguments. Furthermore, Driver and colleagues (2000) found that (1) students struggle with construction of arguments, and (2) readily dismiss scientific evidence that contradicts their initial viewpoint. However, it has also been found that these initial barriers to mastery can be alleviated using a variety of pedagogical methods. Cavagnetto (2010) identified pedagogical practices that increase student argumentation mastery: these include immersion practice (Clark and Sampson (2007, 2008), creating cognitive conflict (Clark, D’Angelo, and Menekse, 2009), and explicit instruction of argument structure, (Venville, 2010). As such, even though there are substantial initial barriers to student argumentation mastery, they can be overcome using sound pedagogy. Studies focusing on incorporating immersion practice, explicit argumentation, and cognitive conflict instruction into a single intervention, especially through the means of a VLE, are lacking. As such, MHS intends to provide explicit instruction of argumentation structure within an immersive environment as a means to overcome the innate difficulties of students' engagement of scientific argumentation.

Throughout the MHS curriculum, students are constantly using their understandings of water systems to collect data from the game environment, which is later used by students to build and critique arguments. This approach allows learners to engage in this practice, while also developing a deeper understanding of water systems content knowledge. As such, the focus of this study is to examine the extent to which an NGSS aligned VLE such as MHS can support student learning of water systems content and scientific argumentation. We aim to investigate the following research question: (1) To what extent can a NGSS aligned virtual learning environment support student learning of water systems content and scientific argumentation?

Methods

Description of MHS

MHS is a two week instructional unit that engages students into a three dimensional VLE that allows students to build more sophisticated understandings of water systems while also engaging in science practice. From this perspective, MHS was designed to closely align with the NGSS since it covers both science content (DCIs) as well as science practices (i.e. scientific argumentation). Allowing students to engage in scientific argumentation was a key component to the MHS curriculum and through completing MHS students regularly argue with non-player characters about water systems ideas. The MHS curriculum is comprised of six units, and within each unit students engage in narrative problem solving that requires them to explore the environment to arrive at a solution. Each unit contains an argumentation scenario where the student must collect data from the environment, analyse that data, and use it as supporting evidence for their argument non-player characters within the game. For example, in the Surface Water unit of MHS, students are asked by another character in the game to find and deliver supply crates to their location. To solve this problem, students must use the river systems to float the supply crates back to the character’s location. In the game, each unit requires students to collect and analyze data from the environment in order to formulate an argument that addresses the problem.

As a means to facilitate argumentation MHS includes the claimer system, which is an interface that had been built specifically to allow students to create scientific arguments. The claimer system is a drag and drop system that allows students to build arguments by dragging selected argument components (i.e. claim, evidence, reasoning) into the center of the screen where the argument is formed (Toulmin, 1958). All of the evidence that is populated into the claimer systems is collected by students in earlier parts of the game. When students add components to their argument they can see their argument being built in real time. Another key component of the claimer system its ability to provide immediate feedback to players. For all possible incorrect permutations of claim evidence, and reasoning, students are presented with immediate feedback that explains how to improve their argument.

As students progress through MHS, the argumentation tasks become increasingly more complex and sophisticated. The design of the argumentation scenarios of MHS was influenced by the learning progression of scientific argumentation proposed by Osborne et al. (2016), which leverages cognitive load theory to accounts for the cognitive demands that argumentation places on students. Early units of MHS focused on specific argument components such as claim, evidence, and reasoning, while later unit include argumentation scenarios that require students to create a counter arguments to those posited by non-player characters within the game.

Sample

This study collected data from 633 middle school students across 10 schools in the Midwestern United States. Students completed pre/post testing surrounding a 10-day MHS intervention. The pre/post-test included both a water systems content assessment and an argumentation assessment. Both of these assessments were multiple-choice and were administered electronically via the online testing portal Qualtrics before and after students completed the MHS curriculum.

Instrumentation

Water Systems Assessment

The water systems content assessment contained 24 multiple-choice questions. the content of the assessment as a whole can be broken down into four areas: (1) groundwater, (2) surface water, (3) watersheds, and (4) water cycle. Questions pertaining to these broad areas include a variety of formats from recalling of factual information about water systems to interpreting a diagram of and applying water systems ideas to answer the items successfully . For example, with surface water there are questions that present students with a watershed map including rivers and streams and asks students to predict how a dissolved pollutant would spread through the watershed. In addition to these questions, there are questions that ask students more factual based questions related to the processes of evaporation or condensation.

Argumentation Assessment

The argumentation assessment is a scenario-based assessment that is grounded in the context of evaporation. Students are presented with a scenario where a student leaves home for a long summer vacation and leaves a bowl of water on the porch. Upon returning, the student notices that the water is gone. Based on the observation that the water is gone, the assessment engages students with a variety of arguments about what could have happened to the water. As such, the entire assessment is situated within the context of evaporation, and as student progressed through the assessment they worked through arguments related to the phenomenon of evaporation and explaining what happens to water once it evaporates. The assessment contains 12 multiple-choice questions that address the constructs in Sampson & Clark (2008), and also includes items that fall at different levels of the Osborne,Henderson, MacPherson, Szu, Wild, & Yao (2016) learning progression for argumentation. These include students' ability to identify critical components of an argument, align evidence to a given claim, and engage in critique of arguments. Within the assessment, there are four items relating to argument structure, four items that require students to align evidence to a claim, and four items that measure ability to engage in critique of an argument.

Data Analysis

We analyzed the water systems and argumentation assessments in terms of omnibus gains as well as gains along individual subscales. Subscales of interest on the water systems assessment were: (1) groundwater, (2) water cycle, (3) surface water, and (4) watersheds. Subscales of interest on the argumentation assessment were: (1) argument alignment, (2) argument structure, and (3) criticism of an argument. Statistical significance was evaluated using paired samples t-tests under the null hypothesis of no gain (alpha level = 0.05). Hedges G, an unbiased estimate of the standardized mean difference, was used to assess practical significance of the change in students' test score over time on a scale of standard deviations.

Results

Students made significant gains in both water systems understanding (Gain = 0.99, SDgain = 3.11, T = 8.03, G = 0.32) and argumentation (Gain = 0.24, SDgain = 2.25, T = 2.67, G = 0.11) (Table 1). The practical significance of the gain in content understanding meets the What Works Clearinghouse (WWC) (2014) criterion for substantive importance (G >= 0.25). Among the subscales for water systems understanding, students made significant gains along all four subscales, but only knowledge of surface water characteristics (Gain = 0.37, SDgain = 1.27, T = 7.62, G = 0.30) met the WWC criterion for a substantive change of 0.25 or greater. Among the argumentation subscales, the ability to analyze the structure of an argument was the only construct to change significantly (Gain = 0.12, SDgain = 1.42, T = 2.15, G = 0.085), but the significance of the gain was small.

Table 1. Gains in students' understanding of water systems and argumentation across the MHS intervention.

Construct	Pre	Post	Gain	T	G
Water Systems Omnibus Score	13.85(3.68)	14.84(4.02)	0.99(3.11)	8.03*	0.32
Groundwater	2.84(1.16)	2.95(1.21)	0.11(1.29)	2.06*	0.08
Water Cycle	6.01(1.77)	6.35(1.85)	0.34(1.63)	5.21*	0.21
Surface Water	1.79(1.14)	2.18(1.20)	0.39(1.27)	7.62*	0.30
Watershed	3.20(1.45)	3.36(1.51)	0.16(1.65)	2.48*	0.10
Argumentation Omnibus Score	6.85(2.16)	7.09(2.23)	0.24(2.25)	2.67*	0.11
Align	2.53(1.12)	2.61(1.12)	0.09(1.31)	1.64	0.07

Structure	2.10(1.18)	2.22(1.23)	0.12(1.42)	2.15*	0.09
Criticism	2.22(0.91)	2.25(0.86)	0.03(1.2)	0.67	0.03

* Significant at 0.05 alpha level

Discussion

Our data indicate that MHS was successful at supporting student learning of water systems content and scientific argumentation. While these gains were statistically significant, both exhibited small effect sizes. We view the design and development of the MHS curriculum as an iterative process, and the version of MHS that was used in this study was an early build that is still in development, and our team has used the results of this study to further develop new features to improve the learning outcomes of the curriculum.

MHS Improvements

We used our data to inform a number of changes to the early version of the MHS curriculum.including: explicit argumentation structure instruction, increased experience in critiquing the arguments of others, a reduction in the complexity of the argumentation system, variable feedback based on student performance and explicit descriptions of each argumentation context. We discuss these in turn.

While the MHS curriculum produced statistically significant gains in students argumentation structure ability, the effect size was very small at .09. In reflecting on the curriculum, we noticed no instances of explicit instruction for students, and the inclusion of this explicit instruction should help students better understand the components of an argument. In designing this explicit instruction, we chose to develop an additional feature called the Claim, Reasoning, Evidence identifier (CREi). CREi provides students with a complete argument that consists of three sentences, one the for each argument component. CREi randomly selects one of the sentences of the complete argument for students to identify as being the claim, evidence, or reasoning. An important aspect of CREi is the immediate feedback that it provides to students after choosing which argument piece the selected sentence entailed. We intended CREi to serve as a drill and practice area for students to gain experience and receive feedback classifying the main pieces of a complete argument. We expect that including this explicit instruction around argument structure, should increase the gains associated with argument structure ability for students that complete the MHS curriculum.

When looking at student gains in argumentation, we noticed that critique gains were the lowest of any argumentation dimension. With full acknowledgement of the argumentative demand critique entails, we point out that there were no opportunities for students to engage in argument critique in the early version of MHS. As such, we developed scenarios in which students engage in argumentation critique with each in-game non-player character at multiple points within the game. These critique scenarios leverage the Osborne et al. (2016) argumentation learning progression by first having students recognize missing argumentation structural components. Later students' critiques are centered around the proper usage of components (i.e. evidence or reasoning). By including these explicit critique scenarios we expect increases in student's overall argumentation competency, as well as their ability to critique alternative arguments.

When students were playing the game we noticed that there were a lot of students trying every possible permutation of claims, evidence and reasoning with little time in between submissions. This led us to believe that the argumentation scenarios presented within the CLAIMER system were too cognitively demanding and that students were not actually reading the feedback given to them. As such, we made alterations in an attempt to decrease the cognitive load on students and to get students to actually read the feedback.. To address the cognitive load issue, we reduced the complexity of each scenario so that they could have a maximum of two possible claims, five pieces of evidence and four possible reasonings. The previous version of the game had up to three possible claims, seven pieces of evidence and five possible reasonings. This leads to a large reduction of possible combinations, which hypothetically reduces the cognitive load for the student.

We also noticed that students were not utilizing the feedback within the CLAIMER system. To address this we altered two aspects of the system. First, the art team did voice over for all of the feedback text. So even if the students do not read the text for one reason or the other, it is at least read to them by a non-player character. Second, we made the feedback more user friendly by varying itbased on student performance. In our current system we initially give students generalized feedback (e.g. "Your argument doesn't make sense. Your reasoning does not explain how your evidence connects to your claim."). However if the player submits five incorrect arguments, we give them more specific feedback (e.g. "Your claim and evidence makes sense. Try using a reasoning that connects your claim with your evidence."). Note the nuance in the wording, with the generalized feedback any of the parts of the argument could be wrong, however with the specific feedback we tell the players which pieces are good and which ones to change. Ultimately this gives students more directed, usable feedback, allowing them to build an appropriate argument. We expect this to help students utilize the in-game feedback, thus allowing them to improve their arguments.

When looking back at the MHS curriculum, we noticed that the argumentation scenarios lacked well developed contextual background. It is well known that having a better understanding of the contextual background of an argument leads to higher argumentation competency (Sadler, 2004). With this in mind, we created previews for each argument that students complete within the game. These argument previews allow students to know the driving question of the argument, and the competing claims before any data are collected. Our goal with the argument previews are to provide students with a proper explanation of the driving question ahead of time so that when kids are collecting data and building their argument later on they are reminded and aware of why they are creating the argument. In addition to the argument preview, we also provide students with opportunities to ask questions about key science ideas related to the argument topic before they argue with the intention of allowing students to have a clearer understanding of the underlying science concepts.

Significance of Results

Based on the results of this study, we recognize that the curriculum could be improved to include more support for student learning of scientific argumentation. We have discussed ways in which we have made modifications and revisions to the curriculum to better support student learning of science content and practice. It is important to point out that despite the small effect sizes between students' pre and post assessment scores, the MHS curriculum represents a significant move forward for the use of 3D-VLEs in science education.

Most of the VLEs used in science education are shorter experiences for students and include much less curricular content. MHS is unique in that it provides a two-week long water systems VLE that is on the scale of a curricular unit. Previous VLEs used in science education tend to be the topic of one-to-two lessons, and not intended to be a main curriculum of an entire unit of instruction. Additionally, the MHS curriculum is unique in that it aligns to multiple dimensions of science learning described by the NGSS. The decision to focus on scientific argumentation as the main science practice in the game was made because engaging in argumentation also requires student to engine several other science practices. This includes the analysis and interpretation of data, and also generating explanations of science phenomena. With this in mind, it is also important to consider the innate difficulty of creating and critiquing arguments. Argumentation is a complex and cognitively demanding task for students to complete, and statistically significant gains in argumentation competency is promising given the modifications that have been made to the MHS curriculum. Even though the effect size was small, it is still important because MHS was able to to provide learning gains for particularly difficult topics such as argumentation. Furthermore, the MHS curriculum was able to obtain these significant gains using a non-traditional game based instruction that immersed players in a 3D world where students use their knowledge of water systems to engage in argumentation.

Conclusions

This study has allowed our team to gather information about the types of learning that the current version of the MHS curriculum can produce. We will further implement the changes and modifications discussed here and conduct another field test. In addition to learning gains, we will also be interested in the extent to which teacher treatment group impacts student learning outcomes. In our current data, we found intraclass correlations near zero for the teacher effect, meaning that a student's teacher has little effect on his/her likelihood of achieving learning gains from MHS. We will be interested in seeing if this result is replicated in additional field tests with the new improvements to MHS described here. Our goal for the MHS curriculum is to provide students with a engaging way to build more sophisticated ideas about water systems, and to be able to use what they know to both create and critique arguments.

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