Mission HydroSci: Meeting Learning Standards through Gameplay

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Abstract:
Mission HydroSci (MHS) teaches water systems and scientific argumentation toward meeting Next Generation Science Standards. MHS is a game-based 3D virtual environment for enacting transformational role-playing, wherein students must learn new knowledge and competencies in order to achieve the game missions. MHS was developed for middle school science as a replacement unit of about 6 to 8 hours using analytics and a teacher dashboard to support teachers supporting students.

Introduction
Mission HydroSci (MHS) is a game-based 3D virtual environment for teaching and learning key concepts and knowledge of water systems and building competencies in scientific argumentation in ways that support meeting Next Generation Science Standards (NGSS Lead States, 2013). Meeting these new science education goals for middle school students requires rich learning contexts for exploring substantive science ideas through engagement in scientific practices. Our goal is to meet these educational goals for all learners by using online learning to serve those in distance education and rural communities as well as more traditional and well-resourced classrooms, and to use gaming to engage and support students who typically do not see themselves as successful science learners.

MHS is a research and development project funded by grants from the U.S. Department of Education. The grant support has enabled a team of researchers, science educators, learning and game designers, creative arts professionals and software developers to build MHS through an iterative process (Laffey, et al. 2105; Laffey, et al. 2016). The process started with envisioning a powerful fit between emerging technological capabilities and the requirements of teaching and learning to NGSS. Next came conceptualizing a complete system to engage and teach students a robust curriculum and then building and testing each component of the system. The building and testing process has included prototyping, creating design documents such as requirements specifications and storyboards, building initial versions, which can be taken to usability testing and then refined. Once we felt a substantial portion of MHS was playable and met our requirements specifications for teaching and learning activities to implement the curriculum as a game, we conducted usage testing in live classrooms. The usage testing taught us about the practical challenges of using a game in classrooms as well as identifying many areas of game play that needed improvement. Our intention and obligation to the funding sources is to undertake a field test using a randomized control trial (RCT) to rigorously evaluate the impact of MHS game play. The RCT will be undertaken in Winter, 2019. However, to test the feasibility of conducting a large field test in classrooms we undertook a preliminary field test in the Spring of 2018. This report and showcase describes MHS and presents some insights about the use of MHS in classrooms from interviews with 12 teachers who participated in the 2018 feasibility testing.

Rationale for MHS
While MHS is a research project with goals of understanding and testing the potential impacts of a gameplay approach on teaching and learning and of developing game play strategies that map to teaching and learning approaches, it is also a product development project aspiring to build a game that middle school science teachers will use to meet important learning objectives in their science curriculum in ways that align with the NGSS. MHS targets general and earth science courses by meeting learning objectives for understanding water systems and building competencies in scientific argumentation. The MHS game provides an active learning environment for meeting these learning objectives by engaging students in a narrative about needing to investigate water resources and use scientific argumentation to complete missions critical to the survival and accomplishments of the members of their scientific enterprise. The enterprise is set on an earth-like planet in the future as the science cadets (our player and a set of non-player characters who serve as guides, partners and sometimes antagonists) explore mysteries and prepare for survival on the planet. Along with the narrative game play MHS includes learning progressions for water systems science and scientific argumentation, a visually exciting environment, substantial interaction and feedback, and applies transformational role playing as an approach to integrate learning with game play.

The theory of transformational play (Barab, Gresfali & Ingram-Goble, 2010) shows how specific design strategies can optimize the potential of games and gameplay to lead to desired learning outcomes.
The design strategies to enact transformational play include the student taking on the role of a protagonist who must use subject matter knowledge to make decisions and take action during play, and having these actions and decisions transform the problem-based situation. In turn the student’s understanding of the subject matter is transformed and so is the student’s identity. Virtualization and role playing experiences in MHS are intended to make realistic actions possible and bring the consequences of actions to dynamically impact the world and the learner.

Building competence with scientific practices, such as scientific argumentation, requires learning a progression of competencies, thus multiple practice settings and iteration with feedback must be provided. The game experience helps sustain the student through the many activities as well as makes it OK and natural to fail and try again. MHS is a first person narrative adventure with a sustained learning experience of 6 to 8 hours of instructional time for gameplay and 1 to 2 hours of supplementary classroom or discussion board activity for the teacher to clarify, supplement, and extend the learning from the gameplay.

**Game Play**

**Unit 1**

Unit 1 introduces students to (1) gameplay including game controls, characters and narrative, (2) scientific argumentation as a process of using evidence to judge between competing claims and (3) the argumentation engine that will be used to conduct arguments during game play. The design task of unit 1 is to help the player get off to a good start, but also to set the stage for engaging at one’s own pace, so as to learn how to succeed in the game and not just to move through the game. The tutorial nature of some of the starting tasks are counter balanced by interesting and fun visuals, learning about interesting NPC characters, and an exciting start to the game.

The unit starts with the player awakening on a space station orbiting an alien but earth-like planet. The player is introduced to ARF who will be an assistant for the player’s exploration and activities. ARF is presented as a buddy, given an avatar of a dog, and a high form of artificial intelligence to assist the player. The player also meets Dr. Toppo who is the mission leader and sets up challenges for the player throughout the game. After learning some basics of how to navigate and play MHS as well as being introduced to other NPC’s and tools to be used throughout the game, the space-craft if rocked with an explosion and our player must escape the station and fly to the alien planet.

![Figure 1: Meeting Dr. Toppo and ARF on the spacecraft and the explosion.](image)

**Unit 2**

Unit 2 teaches players about topography and using a topographic map as well as understanding watershed and how the relative size of the watershed is related to the amount of water flowing through it. After crash landing on the alien planet our player practices some of the skills they learned in unit 1 while collecting scrap to repair a broken hoverboard and tracking down the communication equipment which they will need to move rapidly on the large terrain and find the rest of their team. In order to find the team they must use a topographic map and respond to clues and feedback framed using topographic terminology. Once they have located the team, our player is assigned the task of finding which watershed is larger and thus best for setting up the base camp for the expedition. After traveling to key waterfalls and gathering evidence our player engages in an argument where she must use evidence to support the claim of which watershed is largest.
Unit 3

Unit 3 teaches about surface water with the learning objectives of having the player be able to predict the spread of a dissolved material through a watershed and identify the direction of water flow based on a map of a watershed. This is enacted narratively through one of the NPCs, Sam, who needs to set up her camp but her supplies are scattered all over the terrain. Our player must find the supplies and figure out which waterways to use in order to float them back to Sam’s camp. Upon completing the task, our player returns to the base only to find that Sam’s base is polluted and she asks our player to solve what’s causing the pollution by tracing the source of the pollution. The player does this by throwing sensors into the nearby river and eventually will find wreckage from the space station explosion. Our player works their way up the river and then must create a good argument using reasoning to connect evidence with a claim in order to get the pollutant removed. Next, our player discovers that the aliens had left irrigation devices to support growing food in gardens, which will be extremely important for the success of the expedition. Unfortunately, the pumps are old and need to be replaced. By succeeding at solving the first of the dungeon-like puzzles the player unlocks new pumps and then must use their knowledge of surface water flow to pick which irrigation systems to restart.

Unit 4

Unit 4 teaches about groundwater with objectives of understanding water tables, predicting rates of infiltration based on permeability of the soil type, and explaining the movement of water from the surface to the ground system. Our player is sent off to explore recently discovered ancient alien ruins and finds a drill that the aliens apparently used to access underground water. The drill isn’t currently operational, so the player must solve the second puzzle in order to restart the drill and access the water table. This provides a source of water for the expedition but also has the downside of flooding the new bunker facility that Riley, another NPC, had just built. Our player must then explore the bunker to identify if the flooding was caused by drilling or by Riley having built the bunker in the wrong place. Our player must go through the bunker collecting soil samples in order to build a model of how the underground water
will flow and the permeability of the different soil types. By doing this the players collects evidence for
which claim is correct and subsequently answers if it was player or Riley’s fault for the flooding. Our
player must construct 2 complete arguments with claims, reasoning and evidence to sort out fault. Next our
player must engage in an engineering task to identify which fountain to flood in order to send water to the
base camp.

Figure 4: Finding an alien village in the desert and using their drill room to access underground water.

Unit 5

Unit 5 teaches about the movement of water through a cycle focusing on state changes that occur
in atmospheric water. The learning objective is for students to understand the energy required for
atmospheric phase changes. The player arrives on an tropical island at the request of one of other other
cadets, this time Bill. Bill wants to show the player a process that he just discovered, but first the player
must solve another of our puzzles. This puzzle requires students to transport seaside water by changing its
phases from solid, gaseous and back. By doing this, the player also gains a better understanding the
relationship of humidity and temperature. After successful completion the player follows Bill to learn about
his new process. He’s stumbled across the means to produce salt by “destroying” the water. Unfortunately
for the player, an emergency occurs in which the player is trapped without access to drinking water. The
player must then figure out how to make drinkable water with only saltwater available to them. Bill doesn’t
believe that this is possible and the player must convince him through argumentation. After successfully
creating drinkable water, the player survives the emergency. Afterwards, the player is asked to recreate the
process by which drinkable water is created but on a much larger scale.

Figure 5: Helping Bill create salt from seawater and collecting evidence from the humidity meter to
convince Bill that drinkable water can also be created from seawater.

Unit 6
Unit 6 is the culminating experience for our player. There is a planet wide emergency taking place and it’s up to the player to figure out what is going on. It seems that water levels are dropping dramatically and if the player can’t solve the issue, the planet will no longer be viable for habitation. The player travels back to the previous Unit’s locations and takes measurements has to how the water levels in each having changed. The player finds that the Sam’s river levels are dropping, Riley’s lake is drying out and the humidity levels on Bill’s island are lowering. No one believes your findings though and you must convince them that the evidence you’ve collected leads to something extra-natural. Due to the fact that levels are dropping planetwide, it must be something regarding the alien’s advanced technology that must be causing it. Having convinced the group, the player engages on a fantastical voyage that culminates with them transporting to outerspace in order to save the planet.

Figure 6: Concept art of the alien walkway needed for teleportation to the planet’s moon and the control room for solving the final puzzles to save the planet’s water.

Argumentation

A key innovation of MHS is the development of an argumentation engine that does not rely upon preselected evidence sets and structures (Griffin, et al. 2016). Reliance upon fairly simple multiple choice formats can lead to naïve argumentation strategies which are not generalizable to scientific argumentation outside the game context, such as using a process of elimination without reasoning from evidence. The MHS argumentation system uses pseudo openness and regular expressions to create logic rules for how different components can combine. The argumentation engine also allows us to input a number of argument scenarios from simple, such as merely stating a claim, to more complex, with multiple evidence items and reasoning statements.

We created a user interface with similarities to a solar system with the claim represented as the sun, reasoning statements as planets, and evidence statements as moon-like entities for the full system. This new structure reimagines the visual representations of connections between claim, evidence and reasoning while still adhering to its underlying model. Players are given the largest possible tree structure without pre-set drop-zones; allowing students to fill out their solar system as much or as little as they wanted. The system therefore allowed us to facilitate pseudo openness and used a simplistic implementation of regular expressions to create logic rules for how different components can combine. We then created a priority list of all the possible player feedback; so that if a player’s argument matches two of our logic rules; we can display the most desired feedback. Further, MHS implements support for understanding and making arguments throughout the game play, not just while in the argumentation engine. We highlight claims, reasoning and evidence when encountered, provide narrative for framing an argument such as discussing driving questions, and provide game activities to help players distinguish between claims, reasoning and evidence as well as activities to help players practice critiquing arguments.

Our implementation of support for learning argumentation in MHS follows the empirically-based learning progression suggested by Osborne and colleagues (2013). Their work offers a progress map with levels incorporating construction and critique of scientific arguments. MHS follows this progression by starting with having students make claims, moving to providing evidence to support claims, and then...
having students create full arguments. Next students are asked to provide a counter argument to a faulty claim as well as having several chances to critique arguments throughout the game play.

Figure 7: The argumentation engine from unit 5 where the player is convincing Bill that drinkable water can be made from seawater. At this point the player has some pieces of evidence, which are not relevant and will get feedback to make a stronger argument.

Dungeon-like Puzzles

Units 2-5 introduce concepts and have students use their new knowledge to solve a problem, typically to help one of their space cadet buddies. We also wanted students to have the opportunity to use the knowledge, such as about soil permeability or water evaporating and condensing, in a context where they could easily fail and then try again. Adding puzzles to MHS provided an opportunity for putting knowledge into practice, alternative explanations, providing natural feedback, allowing players to fail and retry, and adding fun. We developed a puzzle schema, which we call dungeon-like puzzles wherein players have to move through a dungeon-like space to reach some objective. Movement through the space requires solving mini puzzles in each room or floor to advance to the next. For example a player may have to use knowledge of soil permeability to regulate water flow to fill a waterway to float resources from one room to a next, or use knowledge of evaporation to move water from one area in the dungeon to a next.

Figure 8: First dungeon puzzle where the player must figure out how to move the power cube to another room for opening the water flow and the second dungeon showing the locked pumps the player needs the flowing water in order to access.

Learning Analytics & Teacher Dashboard
We employ Learning Analytics to provide monitoring and awareness for teachers and to create potential for an adaptive system for student learning and assessment. The analytics track individuals’ specific choices, and then analyzes those discrete choices against a backdrop of learning outcomes and argumentation competencies; thus assessment is built into playing the game. The analytics populate a teacher dashboard to visualize student activity and progress. The dashboard for visualizing student activity is designed from a performance support framework to optimize acting upon insights such as recognizing when a student is falling behind or getting off track.

![Teacher Dashboard Image](image.png)

Figure 9: The teacher dashboard shows a column of students and a grid for their progress through the quests and tasks of MHS.

**Some Key Feedback**

As part of a last design research phase before preparing MHS for an impact study, in the Spring of 2018 we asked 12 teachers to implement a partial version of MHS in their classrooms. The test included 8 days of game play for the kids and followup interviews with teachers. We learned a lot from this test which confirmed that MHS could be feasibly implemented in classrooms and that teachers were generally quite enthusiastic about using MHS with all of them volunteering to be part of any further testing we conducted.

The MHS implementation had a number of bugs and glitches because MHS was not complete nor fully tested against all the operating systems employed by schools for our test. In addition we also found that many of the computer systems students used were under-powered for the MHS implementation. This teaches us that we need to invest in performance optimization of the game, do more complete testing before our impact study and carefully screen schools as well as assist them in using appropriate computers. The state of MHS during the spring 2018 test led to more work on the teachers, school tech support, and our team as we addressed bugs, glitches and slow downs which impacted the teaching and learning experience.

While the MHS implementation included some frustration, the students proved to be highly engaged. Some comments from the teachers reflect on the classroom experience and kids being focused and engaged in MHS play:

Response: I mean, it made my classroom management for the last ten days great actually. They’re all engaged and usually when you have a normal class setting, you’re gonna have kids doze off or going out, or so, no. Twenty-five kids working on it for a good 40 minutes of class period.

Response: Oh, it was actually pretty exciting to see some of my students that normally may not be as engaged kind of a little more excited about that. So it was mostly like my boys that are gamers that you could definitely tell that they were excited about. I would say that we had almost 100% engagement while playing the game almost every day that we did it. It was kind of also interesting to watch some of the kids help other students. They were more eager to help and show their
knowledge of like, “Oh, you just have to do this.” … And so there was just a lot of excitement that came with playing the game.

Response: The days went fast. Like even the kids said like the normal 47-minute class didn't feel like 47 minutes. It flew by because everyone was moving and talking and working.

Typically we think of a single player learning game as simply an individual learning experience or even potentially isolating. However a number of teachers reported on their classrooms during game play as being very social places. One of the comments below reflects a positive social atmosphere that contrasts somewhat with the teacher’s experience of how middle school students often interact.

Response: It was very collaborative. I liked that, and they were leaning over and helping each other, and they seemed to be excited and engaged.
Response: I mean, like some people would say something, “I can’t figure this out.” And they'd get up and go over there and say, “Go over there, go here.” Yeah. I’d say I wish it happened more in my normal class but no, in the normal class, I know a lot of kids that are gonna say, “I don’t understand.” But when they’re sitting there staring at the game, they say I don’t get it, and nobody says, “Oh, whatever, you’re dumb.” They went and kind of helped them, so, I guess it gave them more of a comfort level and then, those that were done I guess had a feeling of accomplishment, hey, I know how to do this, I’ll show you. … there were kids helping kids that usually wouldn’t help kids back in a normal classroom setting.

One area needing substantial improvement is the student use of the argumentation engine. We designed, developed and usability tested the argumentation mechanisms, but in the wild, actual classrooms, we found a substantial number of players trying to brute force their way through the tasks. Some students had over 50 trials on a single argument. Scientific reasoning and argumentation is difficult for middle school students so this starts as a challenge, but perhaps the students found the argumentation tasks too tedious in the flow of the game, lacked confidence in their ability to succeed at the tasks, or required more reading and thoughtful activity than the players wanted to invest. Subsequent to this testing we have done substantial revision to leading up to the argumentation tasks, support within the tasks, improved feedback, and improved support for the teacher as she/he seeks to help the students. One teacher summed up what she saw in her classroom.

Response: They got frustrated when they reached the argument stage of course. They wanted to answer now. They didn’t really want read to find the answer, so, that was – I think that was the frustration level.
Response: It just became like a manipulation guessing game. Well, I have this reasoning, let me try evidence one, two, three, and four. Oh, that doesn’t work, let me try one, two, three, and five. Oh, that doesn’t work, let me try one and two.

While argumentation needed improvement to meet our expectations for student learning, teachers reported that students were learning from the game play:

Response: I had a girl who for two years I've been trying to teach about why the oceans are salty and things like that. And all of a sudden, she's like, "Oh, no way! It's salty because water's evaporating." And I'm like, "Really? You got it from there from an argument in a game?" Like it was just so cute to see them get so excited because they learned something.
Response: I think it was a fun way to learn science. I think it just made it a lot more interactive than me standing up and lecturing, and [students] taking notes.
Response: this is coming from a perspective from somebody who understands the scientific content. Once I saw them figuring it – figuring out things in the game, once I realized, “Ah, this is what they’re supposed to do here.” It’s a great way to teach that concept,

Response: A lot of them were playing the game as if they were actually the character and I guess it was almost like first person. First person experience and that they were actually trying to solve the problem as if they were the ones who were trapped or whatever, and you feel like, so they actually had a reason to try and kind of be in control of their own learning, whereas when I give them certain assignments that they’re not that impressed with especially if they’re on paper. They’re like, why
are we doing this? What does this have to do with me? That kind of thing. Why do we need to know this?
Response: I wish there was more games like this because it really engages students and it – I think it’s more authentic and I think it makes them think more like a scientist.

Teachers also reported that the game play enabled students who were not typically high achievers to engage, achieve and even become leaders in the classroom.

Response: I had students who, like for the first time that they've been with me, seventh graders, and I've had them for two years at that point. They said this was the first time that they felt like they got to use their strengths to show that they actually knew science. I thought that was kind of touching.
Response: Yeah, that was actually really neat cuz I mean, the cool thing about the game was that some of the boys that maybe aren’t so good at paperwork really – I mean, they took off with this and were like the leaders, and so they got to help other kids when they were having problems, or they finished ahead of other people that normally, they’re never the first ones to finish or – so it was really cool to see some of these kids that normally, aren’t the leaders. They became the leaders and that was neat. And then some of the girls that aren’t really gamers but are more textbook learners weren’t – I mean, they’re used to having everything come easy. I think this was a little hard for them because they just don’t play video games very much.
Response: Yeah, one of them is gifted but he’s also autistic and has severe – it’s like his social skills and being engaged sometimes. And he has a hard time communicating on paper but he’s super, super sharp, and so that really – he was able to really shine during this. So that was really awesome actually. He ended up being a really – a leader which was really cool because it gave him a chance to go around and talk to other kids too, so. But he helped me.
Response: I could definitely say that and not only just the SPED kids, but some of my – the normal, I hate to say normal, but yeah. Normal kids but that were really kinda low and never seemed to really get anything. As a matter of fact, one of those girls, she was the first to finish and then she was bee bopping around, guiding people and stuff and typically, she’s the girl that when I call on her, I cringe because I know she’s gonna get it wrong.

Gaming seemed to bring out non-typical school responses. Typically high performing students did well in MHS but some struggled as they found gaming to emphasize different approaches than they were used to and enabled other students in the class to shine. Differences were also noted between boys and girls as well as across grade levels, but not all the differences were consistent from teacher to teacher.

Response: I had some kids that were so into it, it was pitiful. They were just – they were chomping at the bit and I had some kids that, “This is stupid. I wanna do bookwork.”
Response: These students in our seventh grade that participated definitely interacted vocally but more just in their reactions and our eighth graders interacted vocally and physically in a sense that they would go to the person next to them and they would help them out, explain things, and kind of verbally talk through the problems whereas our seventh grade was kind of more like, “Whoa, look how funny that person looks.” And they just kind of found like, “Oh, you have to meet them in the corridor or in the walkway through the mountain.” And so it was kind of interesting to see that big of a change between the two grades since I mean, they’re in the same setting.
Response: You could go through and when you’re going through and you’re setting the sensors in the river, the kids that really do a lot with their just studying stuff, they would set one or two sensors and expect all the data to flow in, and the guys sitting next to them were like, “No, you gotta go all up and down the river. Go in the little inlets and all that and see where it is.” So they would be helping out in that respect whereas the ones that were really like I said, the book learners, they would expect they push this button once and all the data to flow into their mind.

Next Steps

As noted in the introduction the MHS team is planning a substantial field test of MHS for the winter/spring of 2019. To reach the field test we have prioritized several objectives. First, we need to
achieve technical soundness, optimization to perform on as low a performance computer as possible, and clear direction for what systems will work. Second, improvements across a range of quests and tasks to better achieve learning outcomes. Third, making argumentation a better fit to the rest of the game play and providing support for students who are likely to struggle with the competencies. And fourth, support for low readers by adding audio for dialog, low gamers by adding better feedback, clearer graphics, more tutorials and simplifying some game mechanisms and activities, as well as support for high gamers by enriched graphics, rewards and side quests. More information about MHS can be found at MHS.missouri.edu or by contacting the authors.

References


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