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Final Project: Using StoryMakAR in the Classroom

I. INTRODUCTION

For this final project, I designed a lesson plan for the students at Tecumseh Jr. High School to learn a topic related to their 8th grade science curriculum. Within the 8th grade science class, there are 150 students total. ~40 of those students are “accelerated learning” students and are capable of more than the other classes. I will be working with and 8th grade science tech at Tecumseh, who has worked there for over 15 years. Within the 8th grade science class, there are 135 students total. This Chemistry teacher has all her students broken up into groups of four students with 5 - 7 groups per class depending on class size.

In the science class, the students used an experimental Augmented Reality (AR) software called StoryMakAR, which combines physical prototyping, AR, and the Internet of Things to bring stories to life. StoryMakAR is accompanied by two additional applications for the computer and cell phone called DeviceMakAR and EventMakAR, which enable the students to program various electro-mechanical devices with little-to-no programming experience and import those devices into a story that they have written (see

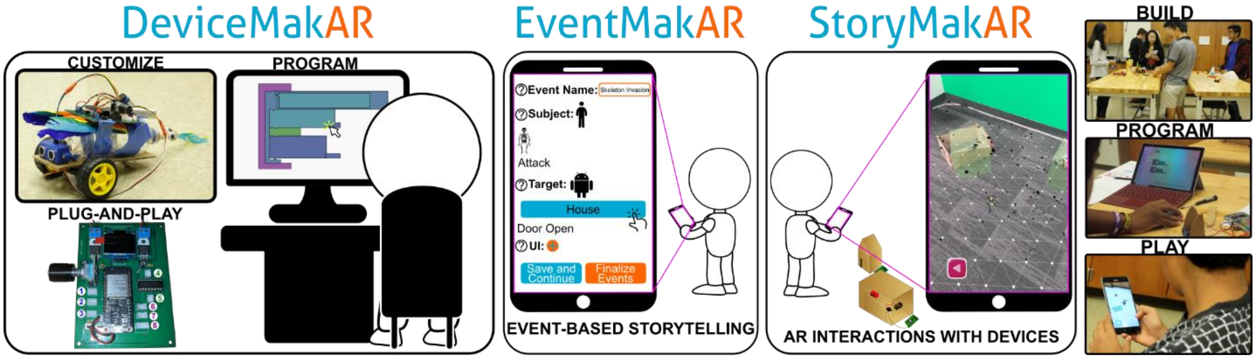

Figure 1: *Overview of StoryMakAR workflow (from left to right). (a) Users build electro-mechanical devices, program them using our drag-and-drop environment, DeviceMakAR, and control them with our plug-and-play MakAR Board. (b) Users create events for their story with EventMakAR. (c) Finally, using an AR-enabled cell phone, users control the physical story devices by using the virtual characters to create Virtual-Physical Interactions.*

Figure 1). Although the original intent of this project was to have the students use StoryMakAR, DeviceMakAR, and EventMakAR, we were unable to do so due to time constraints. Therefore, we adjusted the scope of the project to only have them use StoryMakAR and the MakAR Board (see Fig. 1) for this in-class lab assignment.

II. METHODOLOGY

The first step to this project is to conduct pre-study interviews with the 8th grade science teachers at Tecumseh Jr. High. The scope of this interview was to elicit critical criteria for integrating StoryMakAR into an 8th grade science curriculum. The teachers will have the best perspective on how the students learn, and how they might benefit from technology like this in the classroom. This study has been approved by the Purdue University Institutional Review Board (IRB) and is filed under IRB Protocol # 1903021906, *Augmented Reality Interaction with Physical Devices*. A copy of the IRB Approval, Child Assent Form, and Parental Consent Form can be found in Appendices I-III. The theoretical framework that I adopted for this study is the theory of *Constructionism,* which was first developed and proposed by Idit Harel and Seymour Papert in their 1991 book titled *Constructionism: Research Reports and Essays* (Harel, Papert, & Massachusetts Institute of Technology, 1991). Seymour Papert defined constructionism as follows:

> *The word constructionism is a mnemonic for two aspects of the theory of science education underlying this project. From constructivist theories of psychology we take a view of learning as a reconstruction rather than as a transmission of knowledge. Then we extend the idea of manipulative materials to the idea that learning is most effective when part of an activity the learner experiences as constructing a meaningful product.*

A full copy of the interview questions can be found at the end of this report in Appendix IV. From these interview questions, I have developed a series of codes that will be useful in analyzing student engagement and learning while using our system. After our initial codes are developed and our lesson plan is set, we will begin the study portion of the project. There will be four parts to this study.

1. Students received an introduction to StoryMakAR through a structured activity that gave the students control over various features of the system and help them learn how to use sensors and motors with Arduino.
    a. Sensors: Temperature Sensor, CO_2 sensor, color sensor, light sensor, Turbidity Sensor (see Figure 2).
    b. Motors: Servo, DC
2. Students will complete a lab assignment in class. The lab objective will be to learn *How to Tell if There Was Really a Chemical Reaction.* There are several ways to tell if a chemical reaction has occurred: (1) change in color, (2) emission of light, (3) change in temperature, (4) emission of gas, (5) formation of a precipitate. Each chemical reaction will require a different sensor and the students will have to collect information about each sensor.
    a. e.g. Add 1 dropperful of water (H_2O) to 1 tspn of potassium chloride (KCl) to observe a temperature change. Using the temperature sensor, the students will read values from the Arduino and record them in their lab manual.

3. Students receive a “chunk test,” which is administered by the school. Each 8th grade science class takes the same test (there are 4 classes in total). We will compare our classes success rate to the other three classes and show that StoryMakAR helps learn concepts in science.
4. I conducted post interviews with the four 8th grade science teachers after their students take the chunk test. The scope of this interview will be to see what the teachers plan to do differently, if anything, given the scores on the chunk test.

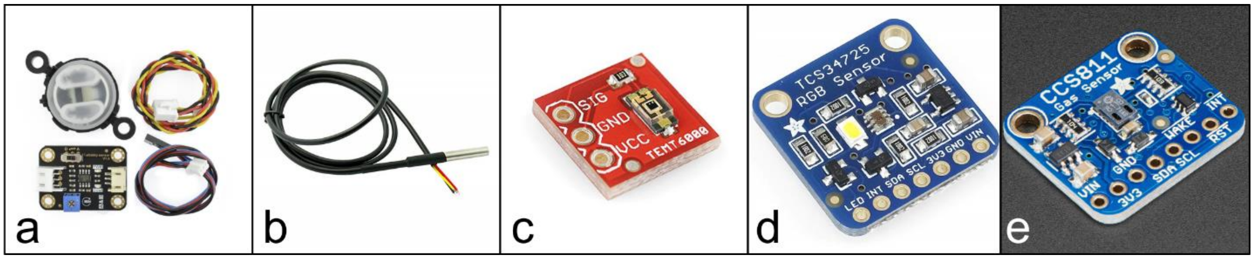

Figure 2: Various sensors that students used in this study: (a) Turbidity, (b) Temperature, (c) Light, (d) RGB Color, and (e) CO2 Sensor

LITERATURE REVIEW

In this report, I will also discuss how the methodology is employed by these references by answering the questions provided to us. The articles reviewed are the following: (1) The Table Mystery: An Augmented Reality Collaborative Game for Chemistry Education (Boletsis & McCallum, 2013), (2) Gears of our Childhood: Constructionism Toolkits, Robotics, and Physical Computing, Past and Future (Blikstein, 2013), (3) A Case Study of Augmented Reality Simulation System Application in a Chemistry Course (Cai, Wang, & Chiang, 2014), (4) When Makerspaces Meet School: Negotiating Tensions Between Instruction and Construction (Tan, 2019), and (5) Considerations for Teaching Integrated STEM Education (Stohlmann, Moore, & Roehrig, 2012).

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Prior Research Methods

Some of the researchers enact similar methods for learning than others. For instance, Boletsis and Cai both use augmented reality to help teach Chemistry to junior high school students. While Boletsis decided to create an AR game to help students learn about various elements on the periodic table and their properties, Cai et. al use physicals cards that represent different atoms (Hydrogen, Oxygen, Carbon, etc.) that the students can place in front of a cellphone camera to show a virtual model of that atom, then place those cards near each other to create a molecule (e.g. two Hydrogen cards and one Oxygen card placed near each other would show an H2O molecule).

After reviewing the state of various engineering toolkits, robotics kits, and physical computing form factors, Blikstein argues that the development of hobbyist technologies should be closely related to the needs of younger students by reducing barriers of entry and simplifying the process of integrating software and hardware for young students. Michael Tan continues this idea by developing four themes from running a makerspace: high playfulness, high authenticity, developing tacit knowledge, and connecting practices to representations, which all define the makerspace an environment that elicits learning. Lastly, Stohlmann et. al. utilize a hands-on learning approach through a Project Lead the Way (PLTW) course in an 6th to 8th grade middle school in a Midwestern state. Their goals were to help students understand the scientific process, engineering problem solving, and how technological systems work with other systems.

Although each author does not specifically mention constructionism as their theoretical framework, the methods that they employ in their research, as well as their interpretation of the results are aligned with constructionist ideologies. The students are given the opportunity to manipulate the materials that are given to them and become active participants in their own learning, which allows the students to build conceptual models on their own.

Stohlmann, et. al. justify their methods by calling on the work of Zemelman, Daniels, and Hyde (Zemelman, Daniels, & Hyde, 2005) who list ten best practices for teaching math and science:

1. Use manipulatives and hands-on learning,
2. Cooperative learning
3. Discussion inquiry,
4. Questioning and conjectures,
5. Use justification of thinking,
6. Writing for reflection and problem solving,
7. Use a problem solving approach,
8. Integrate technology,
9. Teacher as a facilitator,
10. Use assessment as a part of instruction.

Although not cited directly, other authors utilize these same practices. Su Cai, et. al. provide students with pre- and post-tests to evaluate their students' learning (number 6). They also call on the work of Harle and Towns whose research has an emphasis on visuospatial skills in chemistry to justify their use of AR to help students comprehend, interpret, and translate molecular representations (Harle & Towns, 2011). Boletsis and McCallum built their work on design principles for educational games presented by Squire et. al. (Squire et al., 2003) to justify the design rationale of their AR-based Chemistry game, while also employing the first, seventh, and eighth best practices from Zemelman, Daniels, and Hyde. Next, Michael Tan utilized an ethnographic case study method in order to justify his approach to teaching in a Makerspace. Tan also cites numerous sources whose results show the benefits of using Makerspaces as sites for learning. Finally, Blikstein conducts a comprehensive comparison of various microcontroller-based toolkits and physical computing devices from the past that serve as educational aids, including some that are still common today like Arduino and LEGO Mindstorms. Blikstein uses their platforms to highlight the impact that these devices have made for students and show how researchers and educational technology designers can create new technology that builds on these concepts to better prepare students for what is to come.

Setting the Stage for Future Work

The findings from these studies offer very valuable experiences to the field of HCI and to the theory of constructionism. Blikstein's idea of digital fabrication technologies as 'Logo, but for atoms' gives rise to the liberating potential of the democratization of the means of invention. This also shows how future physical computing devices should be designed with children in mind, which can impact the future of computing in new and exciting ways. Michael Tan's work with children in Makerspaces shows how students can receive a more robust learning experience by having access to a wide range of fabrication technologies (3D printers, laser engravers, Computer Aided Design software, etc.) could give them the opportunity to get hands on experience with engineering concepts like *tolerance, combined loading, destructive/additive manufacturing, stress, strain,* and so much more. Getting this hands on experience will be helpful for them in the future when they take engineering classes and learn the math behind these concepts since they will already have a conceptual model built from these hands-on experiences. Now, Boletsis and McCallum's findings offer a different type of contribution to my field because they are utilizing AR to help teach Chemistry. Through their gamification of the learning experience, they were able to show how making students active participants in their own learning can have lasting benefits; playing the Table Mystery game is more engaging and memorable to the students than traditional Chemistry learning methods.

Su Cai, et. al. also use AR to teach Chemistry, but instead of gamifying the learning process, they produce virtual models of atoms and molecules to help students visualize what the atoms look like and how they interact with one another. In this case, seeing is believing! This study offers insight to how AR can be used to teach in the classroom, but also its implications on high-achieving and low-achieving students. Lastly, Stohlmann, et. al. study how students learn through integrated STEM education, but also how teachers can be supported in the endeavor of integrating STEM education in their curricula. This aids me in my research because the results give me design considerations from the perspective of a teacher in the classroom.

Each of these works contributes to my understanding of constructionism and gives me different perspectives of integrating AR, physical prototyping, and other various technologies into the classroom environment. My methodology should align with each of these articles and take into consideration the data collection methods and analysis techniques as well.

Other Points of Interest

Another point of interest that emerged as a result is the use of computational thinking (i.e. thinking about computing) that emerged as an undertone in some of these articles. In the conclusion section of the article, Blikstein mentions the importance of simplifying programming languages to help young students learn the basics of coding. He hypothesizes that in order to have a more seamless integration of hardware and software, the use of programming jargon and syntax should be limited to its very basic limits so that students can be successful at focusing on the logic and functionality of the program. Next, the idea of gamification presented by Boletsis and McCallum interests me because of its high engagement for students. The design requirements for their game, *Table Mystery*, are (i) the game must have scientific-educational content, (ii) the number of players must be between 9 and 12, (iii) the gaming session has to last approximately 20-35 minutes, and (iv) the game has to take place inside a limited space where the periodic table is placed. Gamifying learning is a popular constructionist technique because it allows the students to think about the educational content in a fun and interesting way, rather than through simple readings and lectures. Lastly, Su Cai, et. al. used a mixed methods approach for their study, combining both quantitative analyses through questionnaires and a pre- and post-test, as well as coded interviews of students selected at random. This is useful for me because I plan to implement a mixed methods approach for my research study as well. All in all, this review assignment has allowed me to examine several works that follow constructionist theory and methodologies for use in classroom and extracurricular settings.

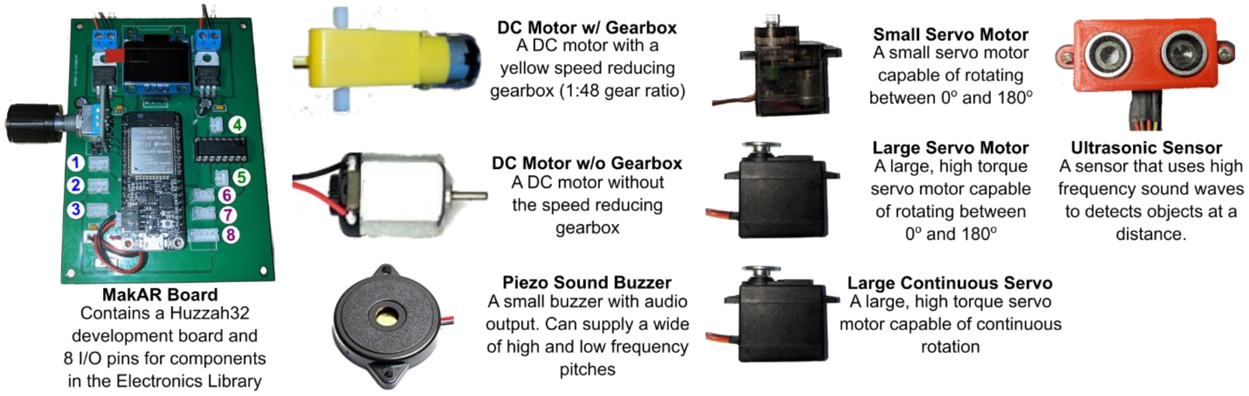
III. THE STORYMAKAR SYSTEM

In this experiment, I wanted to use a new system that I developed called StoryMakAR, a "plug-and-play" hardware platform with an integrated AR environment that brings stories to life. The StoryMakAR system is composed of (1) an electronics toolkit that includes a microcontroller hub device that connects to and dynamically controls input (sensory) and various output devices, (2) a block-based programming web application for programming Arduino ~\cite{Arduino},~\cite{ESP32} called DeviceMakAR, (3) an event planning application called EventMakAR to help students design the interactions between their virtual and physical content, and (4) a cell-phone application called StoryMakAR that wirelessly pairs to the electronic devices and turns them into Internet of Things (IoT) devices, and (5) a structure toolkit that is designed to help users quickly and easily assemble story elements. However, for this experiment, we will only focus on part 1.

Electronics Toolkit

The electronics that accompany the structure toolkit are modular by design and include a main device, and several, smaller sub-devices. We found that many off-the-shelf toolkits are hard for novices to learn. Based on our design goals, we designed a **plug-and-play** PCB that we call the MakAR Board. In order to deliver a true maker-based storytelling experience, our PCB design was required to include a microcontroller unit (MCU), several functional components for input and output, and a power source to power it all. We selected a Huzzah32 ESP32 Feather Board (Adafruit, n.d.) because of its small size, Bluetooth Low Energy (BLE) and WiFi capabilities, and its numerous in/out pins. Additionally, a small group of off-the-shelf electrical components, which are common to many maker-based projects were selected when designing the electronics toolkit (see Fig. 2 & 3).

We designed the MakAR Board to be plug-and-play; users should not be required to undergo a significant amount of training in order to connect their sub-devices to the main device (Figure 2). The MakAR Board gives the user access to 8 I/O ports. Ports 1 -- 5 are reserved for sub-devices that receive output commands, while ports 6 -- 8 are reserved for sub-devices that provide input information. Sub-devices with two, three, and four pins can be used with this board (Fig. 2 & 3). Once the MakAR Board is turned on and connected to WiFi, users can assign the Board a device type and select the occupied pins.



MakAR Board
Contains a Huzzah32 development board and 8 I/O pins for components in the Electronics Library

DC Motor w/ Gearbox
A DC motor with a yellow speed reducing gearbox (1:48 gear ratio)

DC Motor w/o Gearbox
A DC motor without the speed reducing gearbox

Piezo Sound Buzzer
A small buzzer with audio output. Can supply a wide of high and low frequency pitches

Small Servo Motor
A small servo motor capable of rotating between 0° and 180°

Large Servo Motor
A large, high torque servo motor capable of rotating between 0° and 180°

Large Continuous Servo
A large, high torque servo motor capable of continuous rotation

Ultrasonic Sensor
A sensor that uses high frequency sound waves to detects objects at a distance.

Figure 3: Our electronics Library, which consists of our custom designed MakAR Board (left) and seven electronics modules: 2 DC motors, 3 servo motors, 1 sound buzzer, and 1 sensor.

IV. RESEARCH METHODS

Research Subjects

This study involved a total of 135 students in Grade 8, including 58 boys, 69 girls, and 7 students who preferred not to answer. The experiment of the software's impact was conducted in a local Junior High school in Indiana. All students were required to sign a "Child Assent" form and were given a "Parental Consent" form to be taken home and signed. All student and teacher names will be reported as pseudonyms with (gender) when appropriate.

Experiment Description

This study mainly focuses on the use of the supplemental learning effect of IoT-based learning tools in an 8th grade Chemistry course. I had initially wanted to explore the use of AR in this context as well, but ultimately ran out of time due to unforeseen circumstances. The classroom that I was in was taught the content of *"How to Tell if There was Really a Chemical Reaction."* The StoryMakAR platform was developed before the beginning of this project; however, the development of the curriculum was done in conjunction with the teacher of this 8th grade Chemistry class, Jasmine. After the curriculum was set, some modifications to the MakAR Board had to be completed in order to use the variety of sensors that we planned to use for this experiment. I interviewed Jasmine after we had designed the curriculum together to gain her perspective on using technology in the classroom, her teaching style, and her expectations for how the students would react to the technology that we would be using. A copy of this interview transcript can be found in Appendix V.

The day before the students were introduced to the system, they were given a lecture on the different type of chemical reactions, namely *Single Replacement, Double Replacement, Synthesis, Decomposition, and Combustion.* This lecture was given by Jasmine and is the same lecture that she typically gives to her students when teaching this lesson. A copy of this presentation can be found in Appendix VI. After the lecture, the students were given a pre-survey to fill out, which gathered their demographic information and some other background information. Then, they were introduced to Augmented Reality, the Internet of Things, and the StoryMakAR system and allowed to play with the different physical devices and AR characters that I brought for them, which was all conducted by me. Students were then given the Lab Assignment to be completed in groups at their lab stations. The Lab Assignment consisted of several different chemical reactions that each showed at least 1 of 5 different chemical reactions: (1) change in color, (2) emission of light, (3) change in temperature, (4) emission of gas, (5) formation of a precipitate. Students were required to observe the chemical change by using one of the 5 sensors presented to them (Fig. 2) and then look at the chemical formula of the reaction to determine which of the 5 chemical reactions had occurred. A copy of this Lab Assignment can be found in Appendix VII.

Figure 4: Students at their lab tables working on their lab assignment.

Lastly, a "chunk test" was administered by the 8th grade science department, consisting of 5 questions related to the topic of Chemical Reactions. Our control group in this case will be the other three classrooms which did not have the technology that we developed, and were employing more traditional teaching methods (i.e. lectures, worksheets, and demonstrations). I believe that the difference in test scores between the three control groups and our experimental group will ultimately show the MakAR Board's learning effect. Although this chunk test is a part of my research study, I will not be reporting on the results of this test in this report because the date of the chunk test as determined by the 8th grade science department fell after the due date for this assignment.

Research Hypotheses

I propose two research hypotheses to be tested and examined by the interviews with the Jasmine and the experiment.

- Hypothesis 1: I expect Jasmine's attitude toward teaching science to have been influenced by her previous teaching experiences, but also for her to enjoy the experiment because of how hands-on it is.

- Hypothesis 2: I expect there to be a statistically significant improvement in students' scores on the chunk test after using this technology.

Teacher Interview: A Look into Constructionism

Comparing Old and New

Through this interview, the overall impression that I received from Jasmine was that she believes that hands-on activities yield better results for students to learn the topics in her class. This is backed up by classroom activities that I observed over the semester (e.g. rockets that move by mixing baking soda and vinegar), as well as the activity that she typically does to teach this same concept for chemical reactions. She explains this activity as follows:

I've done in the last couple of years, I've done this by the baggy lab where they actually get to th - the. There are premeasured um, uh, substances in, in little Ziploc bags and they have to add mineral water or vinegar or whatever. Um, and then have to write down their observations, but then they also have to tie it into one of the six, uh, types of chemical reactions, which I've already gone over beforehand. Okay. It's mostly more of an observation type thing.

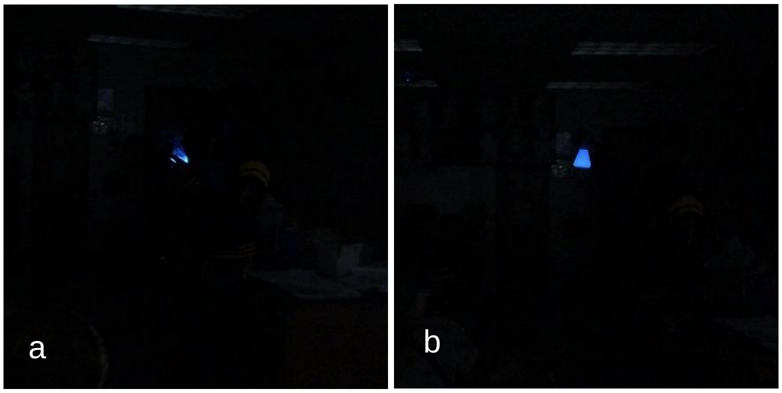


Figure 5: The students getting a demonstration of a chemical called Luminol, which produces a bright, blue light as its chemical reaction.

This statement is a large reason why she wanted to adapt my research project for this concept. Although it is a hands on activity where they get to mix some chemicals and observe the reactions, it's more observational than it is hands-on. She goes on to say that she’ll normally hear “surprise yells” because the students “like the bells and whistles” of the activity. Then, when asked if she anticipates a similar reaction to the activity, she said that the technology is “so new to them too, but then they're going to feel like real scientists.” This fall directly in line with the theory of constructionism because she believes that, not only will the students enjoy themselves, but they can think of themselves as being “real scientists” because of their previous assumptions of what a real scientist is. However, it could also be that the students are *reconstructing* their ideas of what a real scientist is through this activity.

Technology in the Classroom

At this particular middle school, the students are each given a ThinkPad laptop to use to complete homework assignments, take notes, and participate in various educational activities given to them by their teachers, and the school. The introduction of this technology comes with the opportunity to do some very creative things in the classroom and could be powerful when combined with constructionist theory. Because of this, I was curious about Jasmine’s approach to integrating technology into the classroom and I asked her about it. She responded by explaining that she doesn’t use very much technology at the lab tables outside of having the students look things up.

When asked about the ThinkPads, she said that she aims to make her students’ ThinkPads “a place where they can gather information and store information, but I'm not there yet.” She says she aims to get there by having them keep an “electronic science journal” where they can store and access information related to their learning. Doing this would also align with constructionist theory by allowing the students to build upon the things they’ve learned and reflect on how they interpret their knowledge in writing.

Jasmine also disclosed that this is the fourth year that the students have had laptops, but the first year that the students have had ThinkPads (previously the students were given Microsoft Surfaces). One of the pitfalls of giving the students these laptops is that the students don't really know how to take care of their electronic devices yet, which is what prompted the switch from Surface to ThinkPad. Also, technology is not perfect and, because of WiFi issues, incorrect licensing, updates, etc., students sometimes face issues with syncing and can get frustrated.

Overall, it seems that Jasmine's experiences with teaching 8th grade science have helped influence her teaching style by creating a learning environment that is more hands-on. My hypothesis 1 was spot on since Jasmine said that she thinks the students' self-efficacy would be higher from this experiment, but she hasn't been incorporating all of her ideas for technology integration like she said she wanted to. Furthermore, I believe this was a good pre-study interview for the experiment and look forward to seeing the results of the chunk test and the final interview with Jasmine.

V. CONCLUSION

This paper presents an extension to my research project, StoryMakAR, which was originally designed with Makers in mind, and has been adapted for the classroom. Additionally, I met with an 8th grade science teacher, Jasmine, who works at a local junior high school here in town in order to curate a lesson plan to fit into her Chemistry curriculum. I interviewed Jasmine after making this lesson plan with her in order to get her perspective on her teaching methods, using technology in the classroom, and how it's all connected to the theory on constructionism. Although StoryMakAR includes an AR component, we only focused on the use of the MakAR board and various sensors while conducting this study. My goal was to teach the students “How to Tell if There was Really a Chemical Reaction” so that they could perform well on a “chunk test,” which is administered to the students by the 8th grade science department. These results are forthcoming; however, based on the results of the interview and the success of the students in completing the assignments, I am expecting there to be a significant difference in the scores of our experimental group vs. the scores of our control groups.

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