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Geospatial Science Technology versus Traditional Tools for Inspiring STEM Learning: An Assessment Informed by Evidence-Based Learning Principles

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Abstract

In the United States, there is a gap between the availability of various STEM-related jobs and the number of trained individuals qualified to fill those jobs. Previous research has shown a link between STEM education and interest in future STEM careers. Traditionally, learning tools such as lectures and discussions have been used to promote STEM learning in the classroom. However, in recent decades, geospatial science (GSS) technology learning tools that capture, store, analyse, or visualize the characteristics and locations of real-world phenomena digitally have also been used for this purpose. Though many educational research studies have assessed the use of traditional and GSS technology learning tools separately for promoting STEM learning, few have compared these two types of learning tools against each other. Those that do have usually only compared digital mapping or geographic information system (GIS) tools against a single traditional tool to promote STEM learning. In contrast, within this study, we assessed the use of various GSS technology learning tools such as unoccupied aerial vehicles (UAVs), digital spectrometers, and an online mapping interface, as well as traditional learning tools such as discussions, videos, drawing boards, and dichotomous keys for inspiring future interest in STEM learning. We surveyed forty-three honors Biology classroom high school students after they received two weeks of environmental science instruction with both GSS and traditional learning tools. Survey results showed that 67% of students reported that, in aggregate, GSS technology learning tools inspired interest in future STEM learning more than traditional learning tools, and 33% of students reported that traditional learning tools inspired interest in future STEM learning more than GSS learning tools ($\alpha = 0.05$, *p-value* = 0.0222). However, student ratings of individual tools used within the study showed that most of the seven tools assessed were statistically similar for inspiring future interest in STEM learning, but UAVs were statistically more effective than all other tools for this purpose. Furthermore, student feedback about individual tools, reviewed in the context of evidence-based learning principles, provided us insights into the variations of students' survey responses, thus giving us potential opportunities to improve our instructional designs to better promote future STEM learning. Some insights gained from student feedback included the importance of helping students manage their cognitive load by limiting distractions when learning, providing adequate time and group learning when students are introduced to new technologies, and changing students' environments to help inspire learning.

Key Words: GSS, GIS, UAVs, Spectrometers, STEM Education, Geospatial Science Technology, Learning Tools, Evidence-Based Learning Principles, Instructional Design.

Introduction

Within this research, we looked to assess the effectiveness of Geospatial Science (GSS) technology learning tools versus traditional learning tools at the high school level for inspiring students' interest in future STEM learning. This work was completed to help us improve our future instructional designs in the context of evidence-based learning principles [1-4].

The Importance of STEM Education

STEM (Science, Technology, Engineering, and Mathematics) education is regarded as an important factor in building and maintaining a nation's workforce, economy, competitiveness, and security in the modern world. [5], [6]. However, in the United States, there are more STEM-related jobs in the government and private sector than trained individuals to fill those jobs [7], [8]. One way to help fill this gap may be through STEM education at the high school level because STEM education has been shown to promote interest in future STEM college degrees and careers [9], [10]. For instance, many students who enter into a major in STEM-related fields at the undergraduate college level have decided to do so while still in high school [9], [10]. Maltese and Tai [9] found that twelfth graders who showed interest in STEM fields before leaving high school were three times more likely to acquire a future STEM degree than those who had interests in other majors. Further, Wang [10] found that simply exposing high school students to both math and science courses promoted interest in future STEM fields.

The Use of Geospatial and Traditional Learning Tools

Previous research has explored the classroom use of geospatial science (GSS) technology and traditional learning tools for more effective STEM learning [11] – [20].

GSS learning tools, such as unoccupied aerial vehicles (UAVs) (also known as unmanned aerial vehicles or drones), handheld digital spectrometers, and geographic information systems (GIS), are used to capture, store, analyse, or visualize the characteristics and locations (coordinates) of real-world phenomena [17], [19], [20]:

- UAVs are autonomous aircraft that can be used to remotely sense the reflectance of light off the earth's surface with on board visible light cameras or infrared sensors. The imagery captured with UAV sensors can be used to map vegetation species or physical elevations over a study area [17], [19], [21] – [23]. For instance, Williams et al. [18] used UAVs to create digital elevation models to teach students about physical geography.

- Digital spectrometers are tools that measure the reflectance of electromagnetic radiation off of a surface vs. its wavelengths. Because of this capability, researchers often use digital spectrometers to identify plant species types and health at specific coordinate locations in Plant Ecology studies [24] – [26]. Digital spectrometers have also been valuable tools for engaging students in classroom learning related to forest health, plant biology, and the electromagnetic spectrum [11], [27], [28]. For instance, Rock and Lauten [11] utilized digital spectrometers to show middle and high school students how to measure the health of white pine tree needles within a STEM learning program called "Forest Watch."

- GIS software tools are used to process, map, and assess geospatial data. The proliferation of these tools in ecology since the 1970s has led to the use of GIS learning tools in classrooms beginning in the 1990s [15], [20], [29] – [41]. For instance, Henry and Semple [15] have used a home-grown GIS software called H2O MAPPER to teach students about water quality and land use for different watersheds in Michigan, and Solís et al. [20] used online mapping and GIS in high school tech camps to teach students about climate change. Today, online GIS web mapping tools created by state-level GIS data clearinghouses, such as the New Hampshire GRANIT coastal viewer, may also be helpful in promoting the learning of STEM topics [42].

Traditional learning tools differ from GSS learning tools in that traditional learning tools utilize standard teaching devices and methods such as videos, discussions, drawing boards, and dichotomous keys. These tools usually don't have locational coordinates associated with them [12] – [14], [16].

- Videos are recordings of sound and moving images used to transfer ideas and knowledge. Studies have shown that videos can be effective learning tools that increase student's test scores, improve study habits, and increase classroom attendance [43] – [45] as they can utilize both audio and visual channels to convey information [2], [16], [42].

- Discussions are conversations between students or between students and teachers [12], [47]. One manifestation of active learning is through the implementation of discussions and small working groups [12]. Facilitating these student interactions can help to foster the expansion of thoughts and ideas [47]. Veteran educators have reported that discussions can help students explore different perspectives, become connected to subject matter, develop synthesis skills, and integrate knowledge [48].

- Dichotomous keys are learning tools that utilize a series of binary choices to identify particular biological or physical components of the environment [13], [49]. STEM education often requires organizational skills that foster analysis and discrimination between differing elements and/or entities. Case study results have shown that programs using dichotomous keys can provide a relatable context, such as a particular plant species, for students to identify, organize, compare, and analyse information [13], [49].

- Drawing boards are large flat boards accompanied by marking instruments like pencils, pens, or markers. Using both words and pictures to convey information can promote learning by reducing the learner's cognitive load [2] – [4]. It turns out that student-generated graphical representation (e.g., drawing, graphing) can also facilitate student learning [50] by promoting observational skills [51], invoking prior knowledge [52], and constraining inferences [53]. One way to incorporate drawing into the STEM curriculum is via the use of drawing boards that can enable students to draw plans or concepts related to a learning topic.

Given the numerous examples of GSS technology and traditional learning tools being used within classrooms, it is notable that comparative studies between GSS technology and traditional learning tools are less widespread. Among those, Groshans et al. [54] showed that GSS technology GIS story maps were more effective at promoting geospatial relational thinking than traditional slideshow presentations. Additionally, Favier et al. [55] showed that GSS technology mapping learning tools were more effective than traditional tools, such as discussions and workbook exercises in secondary school classrooms for understanding water-related land use issues. Although these studies do compare GSS technology learning tools to traditional learning tools, they seem to represent a trend in current literature that primarily assesses just geographic information systems (GIS) mapping tools vs. traditional learning tools. Further, prior research seems to follow an additional trend where GSS technology learning tools were assessed for their ability to promote STEM learning while used within the classroom [18], [54], [56], [57], but not necessarily for their ability to inspire interest in future STEM learning.

The Use of Evidence-Based Learning Principles

The application of evidence-based teaching approaches can benefit student learning [1] – [4]. For example, Angelo [1] described a set of 14 evidence-based principles for use in improving student engagement and learning. Among his principles, Angelo promotes that active learning is better than passive learning, sufficient time and support are needed to learn skills and knowledge, timely feedback keeps students on track for learning course content, personally meaningful content can help students learn, and students' learning can be positively or negatively affected by the task and the environment [1].

Further, Mayer [2] – [4] promotes the use of the Cognitive Theory of Multimedia Learning (CTML) as a different set of evidence-based learning principles built upon the assumption that humans receive and process information via two sensory channels (dual-channel assumption). These channels include the auditory and visual channels, each of which can hold only a limited amount of information at a given time (limited capacity assumption). CTML principles provide guidance for instructors as they deliver material in a manner that maximizes learning. For instance, the Coherence Principle informs that the removal of unnecessary words, pictures, and sounds in multimedia lessons helps students learn better than including interesting but only tangentially related material; the Redundancy Principle informs that slides with graphics and narration or on-screen text help students learn better than when slides include graphics, narration and on-screen text; The Personalization Principle informs that students learn better when content is presented in a conversational style, and the Segmenting Principle informs that the use of smaller user digestible segments in multimedia lessons help students learn better than the use of longer materials [2], [4].

Hypotheses

Thus, based on our project goal, the findings and limitations of previous research literature, and the proven use of evidence-based learning principles to improve learning within classrooms, we hypothesized the following:

- Hypothesis H1: Traditional and GSS technology learning tools will differ in aggregate in their ability within a high school classroom to inspire students' interest in future STEM learning.

- Hypothesis H2: Traditional and GSS technology learning tools will differ individually in their ability within a high school classroom to inspire students' interest in future STEM learning.

- Hypothesis H3: Evidence-based learning principles can be used to help understand differences in the abilities of traditional and GSS technology learning tools to inspire interest in future STEM learning and provide context as to how we can improve our future instructional designs.

Methods

Within this research, our materials and methods consisted of: 1) Delivering STEM lesson plans using both GSS technology and traditional learning tools at the high school level; 2) Surveying students' perceptions of these tool types for inspiring interest in future STEM learning; and 3)

Reviewing the results of our research in the context of evidence-based research learning principles to improve our future instructional designs.

Participants

Eighty freshman and sophomore honors biology high school students from a medium-sized (enrollment ~1,000) coastal New Hampshire high school were invited to participate in the study during nine consecutive school days (week #1 Mon.-Fri., week #2 Mon.-Thur.). Of these 80 students, 43 (53.75%) were eligible to be included in the final project's assessment. Thirty-seven students (46.25%) of the original 80 were disqualified from the study because they did not provide the project with their parental consent or student assent forms or were absent during any part of the assessment. The use of human subjects in this research was approved by the University of New Hampshire Institutional Review Board for the Protection of Human Subjects in Research (IRB) (#8100).

Lesson plans

Because of the proximity of the project's high school to a large salt marsh, this study focused instruction on environmental science learning related to salt marsh and sea level rise topics. We designed and deployed lesson plans to include a variety of traditional and GSS technology learning tools. Evidence-based learning principles, as described above, were used to deploy the lessons throughout each of the nine days of the project to provide a pedagogical basis for comparability or repeatability of its assessment in future studies. Deployments of these lessons were completed with support from the student participants' regular teachers.

Lessons began with a 10-minute slideshow presentation following Mayer's coherence, redundancy, personalization, and segmentation principles [2] – [4]. This was completed by limiting presentations to one salt marsh science topic per day, ensuring that daily slide sets were segmented into easily digestible learning chunks, eliminating extraneous words, graphics, and sounds in presentations when possible, and delivering lectures in a conversational style with the use of personal pronouns, such as in the phrases "our saltmarshes" or "your environmental impacts" to help promote learning. Each presentation was followed by a 25-minute laboratory session in which students utilized a unique GSS or traditional learning tool per lesson, keeping in mind Angelo's active learning principle [1]. Environmental science topics and tools used included those in Table 1. Due to the limited availability of some learning tools, all laboratory sessions were completed in groups of three to five students, except for those involving the online mapping, because individual laptops were available to deploy these tools for everyone. Each class then concluded with a 15-minute discussion, when students and instructors discussed the science lessons and tools in coherence with Angelo's timely feedback principle [1]. Throughout the daily lessons we also adhered to Angelo's principle of fostering meaningful connections between the science topics and the salt marsh directly across the road from the school.

Table 1: Lesson Days, Learning Topics, Tools, and Classes of Tools

Day	Environmental Science Learning Topic	Learning Tool	Traditional or GSS Tech.
1	Importance of Salt Marshes	Video	Traditional
2	Marsh Vegetation Species ID	Dichotomous Keys	Traditional
3	Marsh Vegetation Zonation	Drawing Boards	Traditional
4	The Electromagnetic Spectrum	Spectrometers	GSS Tech.
5	Marsh Vegetation Health	Spectrometers	GSS Tech.
6	Marsh Vegetation Mapping	UAVs	GSS Tech.
7	Sea Level Rise	Online Mapping / GIS	GSS Tech.
8	Storm Surge/Marsh Migration	Online Mapping / GIS	GSS Tech.
9	Conservation/Marsh Protection	Discussion	Traditional

Instructional program assessment

Students responded to a simple Post-Instruction Perception Survey one week after the instructional program. This survey was used in three ways. First, the survey was used to collect a binary response from each student about whether traditional or GSS technology learning tools, in aggregate, were more inspiring to interest them in future STEM learning. Second, the students were asked to rate all of the tools individually for their effectiveness for inspiring interest in future STEM learning (1,2,3,4,5,6,7 where 1 = low and 7 = high). Third, the survey also included an opportunity for students to write open-ended feedback about their most and least favorite tools for inspiring future STEM learning.

Statistical analysis

First, we used a two-tailed, one-population, proportional, binomial statistics to measure whether there was a statistical difference in the proportions of students who reported traditional vs. GSS technology as being more inspiring for future STEM learning. The null hypothesis (H_o) of this test states that the proportions of favorable choices for each tool type are equal to 0.5, thus being equal to (not statistically different from) each other (traditional vs. GSS technology). The alternative hypothesis (H_1) states that the proportions of favorable choices for each tool type were not equal to 0.5, thus being statistically different (significant) from each other. Statistical *p*-values were calculated to measure the probability of how unlikely the statistic was within a 95% confidence interval ($\alpha = 0.05$).

Second we used both a Kruskal Wallis and a post-hoc Dunn's non-parametric test to measure whether there were any statistical differences in the student ratings between all seven learning tools as to their ability to inspire interest in future STEM learning. The null hypothesis (H_o) of the Kruskal Wallis test states that at least one tool is not (statistically) different from the others. The alternative hypothesis (H_1) of the Kruskal Wallis test states that none of the tools are (statistically) different from each other. The null hypothesis (H_o) of the post-hoc Dunn's test states that an individual tool is not (statistically) different from another. The alternative hypothesis (H_1) of the post-hoc Dunn's states an individual tool is (statistically) different from another. In the use of both of these statistics, p-values were calculated to measure the probability of how unlikely the statistic was within a 95% confidence interval ($\alpha = 0.05$).

Results

The results of our first survey question showed that overall, a greater proportion (67%) of our sampled students reported that GSS technology learning tools inspired their interest in future STEM learning more than traditional learning tools. While a smaller proportion (33%) of our sampled students reported that traditional learning tools inspired their interest in future STEM learning more than GSS technology learning tools ($p = 0.0222$) (Figure 1).

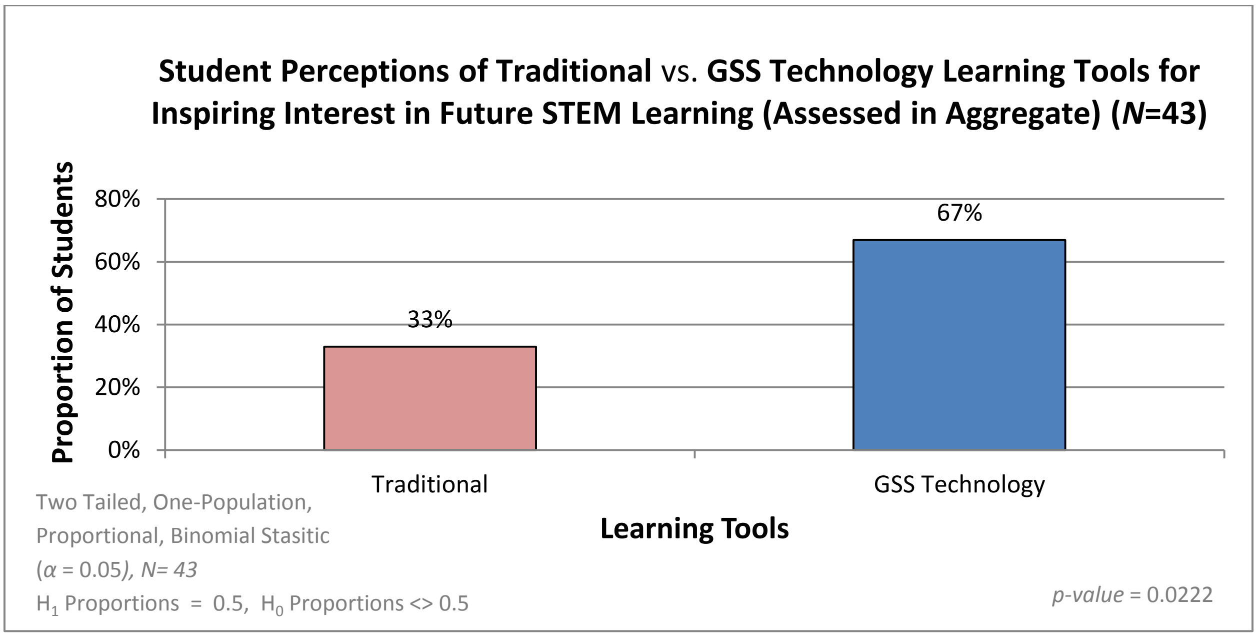

Figure 1: Post-instruction perception survey results showing that student perceptions of traditional vs. GSS technology learning tools to inspire interest in future STEM learning differed as a proportion of all students in aggregate.

The results of our second survey question showed various ratings of each tool's effectiveness for inspiring interest in future STEM learning from our sampled students. The results of our Kruskal Wallis test showed that at least one of the tools was statistically different from the others ($p = 0.00036$) (*Figure 2*). The graphing of student's mean ratings and the p-value pair results of the post-hoc Dunn's test showed that the Videos, Dichotomous Keys, Drawing Boards, Discussions, and Digital Spectrometer learning tools were found to be statistically similar to each other to inspire interest in future STEM learning (A). Further, Videos, Dichotomous Keys, Drawing Boards, Discussions, and Online Mapping learning tools were found to be statistically similar to each other for this same purpose (B). However, UAVs were found to be different and greater than all other tools to inspire interest in future STEM learning (C). (*Figure 2, Table 2*).

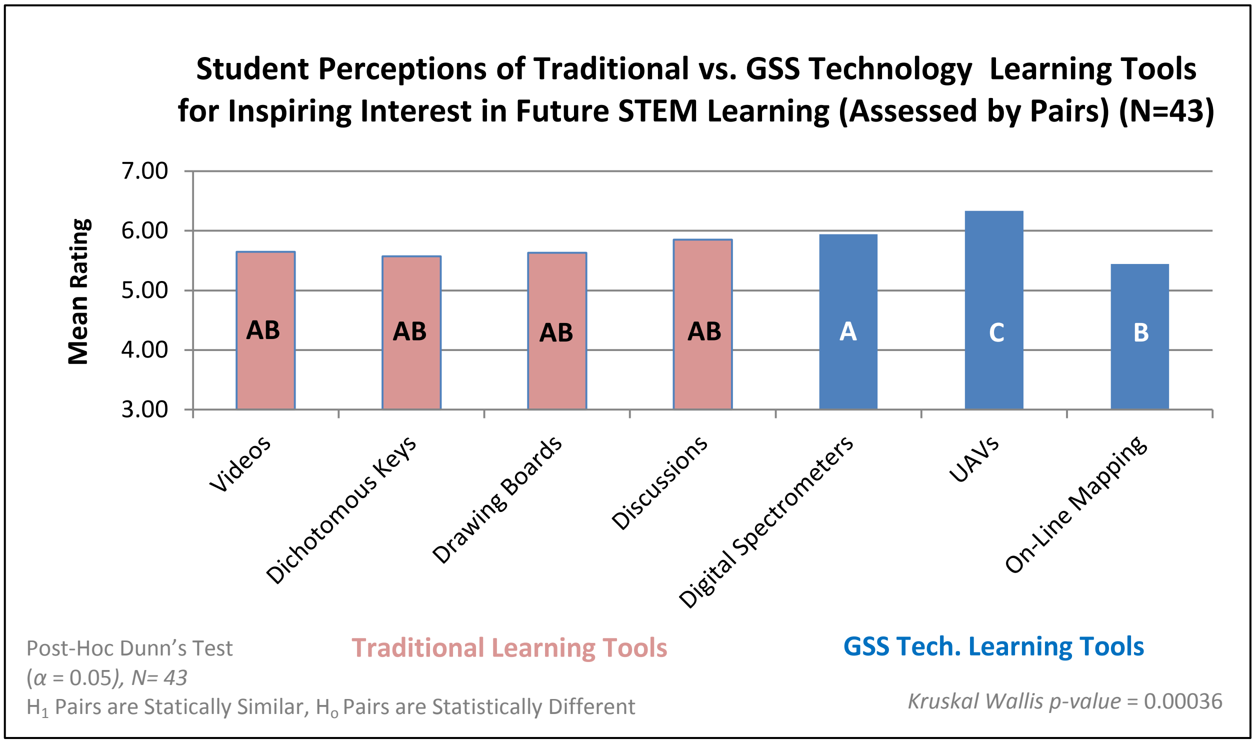

Figure 2: Post-instruction perception survey results showing student mean ratings of traditional vs. GSS technology learning tools for inspiring interest in future STEM learning as assessed by pairs.

Table 2: Post-Hoc Dunn's Test p-Values by Learning Tool Paris

Pair	Learning Tool	x1 Videos	x2 Dich. Keys	x3 Draw. Brds	x4 Discussions	x5 Digital Spec.	x6 UAVs	x7 On-Line Map.
x1	Videos		0.76190	0.92110	0.24520	0.13180	0.00033	0.62410
x2	Dich. Keys	0.76190		0.68760	0.14290	0.07030	0.00010	0.85160
x3	Draw. Brds	0.92110	0.68760		0.28770	0.15920	0.00048	0.55580
x4	Discussions	0.24520	0.14290	0.28770		0.73030	0.01520	0.09848
x5	Digital Spec.	0.13180	0.07030	0.15920	0.73030		0.03728	0.04582
x6	UAVs	0.00033	0.00010	0.00048	0.01520	0.03728		0.00005
x7	On-Line Map.	0.62410	0.85160	0.55580	0.09848	0.04582	0.00005	

Students' open-ended comments

Students' open-ended feedback provided a variety of positive and negative comments about each of the learning tools assessed within this study. Of the traditional learning tools, students reported that they had difficulty with the video. "My least favorite learning tool was the video. I found it difficult to understand because it wasn't as interactive." Conversely, students expressed positive comments about the discussions, drawing boards, and dichotomous keys traditional learning tools. One student expressed that he liked how the class was asked to reflect on what was learned during discussions and then followed up with the statement: "It helped me to stay on track and know what we were learning." Other students expressed the following about the drawing boards and dichotomous keys. "I liked the drawing boards because it helped me memorize names and zones;" "I liked the dichotomous keys because I got to see real vegetation types and learn a new way to identify them," students said.

Of the GSS technology learning tools, many students reported that their favorite part of the salt marsh lessons was the UAV demonstration. They were "cool" and "fast," "I liked going outside," and "I learned a lot." Students also reported that they were delighted to have held the UAV after its flight, even though they were not the ones who flew it to collect aerial images of ground vegetation with the UAV's onboard camera. Students also expressed positive comments about the spectrometers but some negative comments about the GIS mapping software. For instance, one student reported that: "The spectrometer really opened my eyes to new ways of doing things." Other students reported that although they learned a great deal about sea-level rise, storm surge, and marsh migration within the project lessons, they didn't find the interactive online mapping learning tools to be as effective as the other interactive learning tools for this purpose. Students reported that this was because the online mapping tools were the only interactive activity that was completed by each student independently instead of as part of a group. "It was important and informative but slow;" "I enjoy being part of a group instead;" "I didn't like doing the online mapping by myself;" "I got confused at times," students stated.

Discussion

Review of Traditional Versus Geospatial Learning Tools

The results of our research showed that within our study, in aggregate, GSS technology learning tools were reported to be more effective than traditional learning tools for inspiring interest in future STEM learning. Thus, our results supported Hypothesis H1 in our research. Further assessment of student post-instruction survey results for individual learning tools showed a more refined breakdown of student's opinions, with UAVs being the clear leader in inspiring interest in future STEM learning, but with other tools being statistically similar to each other with regards to their ability to inspire interest in future STEM learning. Thus, our results only partially supported Hypothesis H2 in our research.

Review of Student Open-Ended Comments

Students' open-ended feedback assessed in the context of evidence-based learning principles provided additional insights into the breakdown of student's perceptions of individual learning tools. For example, students responded negatively regarding the video used within our lessons because it was reported to be uninteresting and difficult to understand. As where the video was a passive form-of learning, the nature of the student's comments might be illustrative of Angelo's principles of the benefits of active learning and that motivation to learn can be positively or negatively affected by the task [1]. Also, although videos, in general, can be useful to promote learning [2], students noted that the video used in our assessment looked dated, had a shaky appearance, and contained a repeating flute soundtrack. These characteristics might have detracted students' attention away from the learning objective and a subsequent appropriate schema representation [58]. Thus, informed by student feedback and learning-based principles, we plan to use a more up-to-date video that contains less extraneous material in future lesson plans.

Students reported positive opinions about the use of drawing boards and dichotomous keys within our lessons because these tools were interactive and helped students to memorize vegetation growing zones and identify vegetation types. Likewise, students reportedly enjoyed the digital spectrometers because they offered a hands-on new way of doing things (characterizing plant types and their health spectrally). The nature of these comments might also be illustrative of Angelo's principles of the benefits of active learning and that motivation to learn can be positively affected by the task [1]. Thus, we plan to continue to utilize these active tools to help promote students' inspiration for future STEM learning.

Students also reported that they were pleased with being able to go outside during the lesson that utilized UAVs. Further, they were curious and eager to learn about how the UAVs moved. Angelo's principle about student motivation being positively affected by the task and the environment appears to be at play here as well [1]. Thus, we plan to continue to utilize this tool outside in our future lessons to help promote students' inspiration for future STEM learning.

Students reported less favorable responses regarding the GIS online mapping tools. They documented that the GIS online mapping tools were time-consuming and difficult to use independently during the brief classroom sessions. Angelo informs us that students need time, instructional support, and motivation to master skills [1]. The challenge of learning complex new technologies and course subject matter concurrently in a limited amount of time has also been recognized by Nicaise and Crane [59] when attempting to integrate the learning of web-design technologies into their lesson plans. They found that students expressed that the length of time required to learn how to design and build web pages left them with little time to learn the course content itself. Our finding that students expressed confusion at times when using the GIS online mapping tool might speak to how the tool's more complex interface might have slowed down the learning of lesson content. Thus, in future deployments of our lessons, we plan to continue to utilize this tool but incorporate increased classroom time, group learning, and students' prior knowledge in instructional design.

These above insights provided us with new knowledge about how we can improve our future instructional designs. Thus, our results support Hypothesis H3 of our research.

Future Opportunities for Our Research

We identified several opportunities during this research that we can use to potentially improve future similar studies. For instance, the above results were compiled from a population sampled from high school honors Biology students because we were invited into their classrooms for this research. However, this population might not be as representative of the high school population as a whole if sampled randomly. If trying to assess how STEM learning tools could potentially help all students, future studies could sample from the general student population instead of just the honors science population.

The future directions of this research can also include assessing other GSS technology, as well as traditional learning tools such as ESRI Story Maps, Google Earth browsers, global positioning system (GPS) units, traditional reading exercises, and student-implemented web searches. Furthermore, future research could benefit from assessing how a field trip to a salt marsh might increase inspiration in STEM learning. Also, because the results of our research show promise that GSS technology learning tools were more effective than traditional learning tools at inspiring interest in future STEM learning based on salt marsh environmental science topics, GSS technology learning tools could be assessed for prompting STEM learning in other adjacent school landscapes, such as forests, freshwater wetlands, and grasslands.

Challenges in Implementing GSS Technology Tools within the Classroom

Within our research, we have come to recognize some of the challenges inherent in implementing GSS technologies within a classroom. These include cost, access to needed local school information technology (IT) services and permissions, setup times, weather dependencies, and buy-in from the local school teachers and administrators. For instance, unlike traditional learning tools such as videos, drawing boards, dichotomous keys, or discussions that tend to have little to no cost associated with their implementation, GSS technology learning tools tend to incur higher costs for their purchase, use, and maintenance. The handheld spectrometers used within this project had a retail cost of approximately $550 per unit. To help alleviate the costs associated with the current project spectrometers, students shared the units per lab group composed of three to five students each. Also, the UAV used within this project had an approximate retail cost of about $1,500. However, lower-cost UAVs in the range of about $750 could be used instead. An additional option to lower costs associated with a UAV demonstration could have been implemented by soliciting a volunteer UAV pilot from a local college or university research center to perform the outside UAV aerial imagery capture part of our project.

The implementation of GSS technologies within our host school also required the use of some of its local services and permissions. For instance, the use of the school's pool of available laptops and access to the local internet was crucial for the implementation of the web mapping GSS technology learning tool within our project. Furthermore, access to the proper permissions to install a data visualization software on the school's pool of laptops was essential for students to understand the data collected with the spectrometer GSS technology learning tool. To overcome these challenges, we worked with our host school's teachers and IT group in advance of the project implementation to ensure proper access and permissions.

Furthermore, we have noticed that GSS technology learning tools tend to require a greater setup time than traditional learning tools at the start of a lesson. This can include the unpacking, powering up, connecting to the internet, and charging of batteries for laptops, spectrometers, and UAVs. In order to overcome these additional requirements for the use of GSS technologies, instructors allocated an extra hour at the start of each day to complete all necessary setup tasks associated with these learning tools.

An additional challenge associated with the implementation of GSS technology learning tools included that of weather dependencies for the safe use of the UAV outside. The UAV used within our project was not built to fly in inclement weather conditions. Thus, we kept a watchful eye on the weather forecast for the day that we planned to complete its demonstration outside. Though the weather conditions for the day that we completed the demonstration were sunny with no wind, we planned for the potential of flying the UAV outside on a different day of the project in the event of poor weather.

Finally, if other educators are looking to complete similar work as that listed in our research, we would like to emphasize the importance of support from your host school. Our work could not have been completed without the support of our host high school's administration and the enthusiasm and willingness of the teachers involved to learn new technologies. This fact runs in line with several previous research studies that identify the importance of administrative support and teacher interest in implementing Geospatial Technologies in k-12 classrooms [39] – [41], [60], [61].

Conclusions

GSS Technologies are becoming more relevant within education and society. With the new availability of low-cost spectrometers, much easier access to UAVs, and the proliferation of new free online GIS mapping tools, students and teachers are now poised more than ever to take advantage of GSS technologies for real-world STEM-based learning. This study has shown how GSS technology and traditional learning tools may differ in their abilities to inspire future STEM learning within a high school classroom, with unoccupied aerial vehicles (UAVs) being the clear leader for this purpose within our project. Our work also shows how assessing the use of these traditional and GSS technology tools in the context of evidence-based learning principles can help provide insights into improvements in our future instructional designs. Since previous research links STEM learning at the high school level to future careers in STEM fields, we have conducted this research to provide examples of how GSS technology and traditional learning tools can potentially help lessen the gap between STEM job openings and available STEM workers within the United States in future years.

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