Supporting Watershed Literacy with a Desktop Virtual Reality Exploration Game

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***Abstract*—A prototype desktop Virtual Reality (dVR) exploration game was developed as a curriculum enhancement activity for promoting watershed literacy with middle school students. It focuses on the spatial components, geography, and history of their local watershed. The dVR exploration game was implemented in the summer of 2021 in eastern USA during the COVID-19 pandemic with 35 learners aged 10–14 during summer school. Immediately before and after gameplay completion, the participants answered a 9-item watershed literacy measure assessing essential elements of watershed understandings. The preliminary findings revealed players' improved ability to identify their own local watershed and how it connected to the ocean by rivers, creeks, and human-made structures. The watershed literacy measure was found to be a valid and reliable instrument.**

Index terms—desktop virtual reality, exploration game, watershed literacy, middle school

I. INTRODUCTION

Water is a paramount element to provide sustainable resources for humanity, industries, and the environment [1]. Nevertheless, studies have demonstrated that both children and adults have a poor understanding of water resources and systems that are mostly responsible for unsustainable water usage worldwide [1], [2]. The watershed concept is also misunderstood by people of all ages [3]–[5] and this is especially the case with middle school learners [6]–[10]. The Environmental Protection Agency (EPA) explains that "a watershed — the land area that drains to one stream, lake or river — affects the water quality in the water body that it surrounds. (...) Because we all live on the land, we all live in a watershed — thus watershed condition is important to everyone" [11]. We contend that learning about one's local watershed history and its environmental features may enable students to better comprehend the spatial traits, ecological features, and the environmental issues of the watershed in which they live. Thus, we designed, developed, and prototype-tested "Watershed Explorers", a multidisciplinary VR exploration game aligned to the National Geography Standards [12], see Table I. The game focuses on promoting learners' understanding of the spatial components of the Lehigh River watershed, focusing on how the watershed has changed over time [13].

II. WATERSHED LITERACY

The role water plays in one's life is a learning goal in the USA [14]. Nevertheless, the topic of water is primarily focused on water as a natural resource and not so much as the medium of complex systems (i.e., watersheds). Environmental knowledge studies have reported that many adults and children fail to identify the correct concepts and understandings that define a watershed [3]–[5]. Thus, watershed-related concepts and understanding of its systemic functions remains unclear for many [8]. It is important to note that defining the term watershed is only one skill that watershed literate individuals need to have [15]. Additionally, watershed literacy skills include one's ability to identify their local watershed and its connections with the ocean while recognizing that both natural processes and human activities affect the flow and quality of water in watersheds systems [15]. Furthermore, understanding geographic contexts of a watershed may serve to guide the interpretation of anthropogenic events in the past [12].

III. GAME-BASED LEARNING WITH DESKTOP VR

The potential of using video games and game-based learning (GBL) for education is well documented in the literature [16]–[22]. Digital game-based learning (DGBL) is a branch of GBL that encompasses digital entertainment media meant to promote players' cognitive learning or skills with technology resources (e.g., computer games, mobile apps, and XR devices). Studies have demonstrated how DGBL can support the development of epistemological understandings [23], [24], positive attitudes and beliefs [25]–[28], as well as process skills and practices [29], [30]. VR learning games can engage learners in scientific practices, real-life problem solving, and reflection on their actions [31]. Among the motivations for VR use in education is allowing individuals facing cost prohibition [32], time constraints [33], inaccessible locations [34], risky activities, such as exploring cliffs and canyons [32], or hazardous training [35] to experience situations that would be otherwise impossible [36]. Desktop VR is an advantageous entry option for immersive learning since its virtual experiences can be delivered by computers, gaming devices, or any device with a Web browser and internet connection (i.e., WebGL interfaces).

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TABLE I. THE NATIONAL GEOGRAPHY STANDARD ALIGNMENT TO WATERSHED EXPLORERS

	Using geography to interpret the past	**Change in geographic contexts**	**Perception of geographic contexts**
up to 8th GRADE	▪ Identify physical landforms that affected overland travel during the expansion of the United States *(e.g., mountain ranges, gaps, and rivers)*. ▪ Analyze the significance of physical features that have influenced historical events *(e.g., the role of hydrologic and/or topographic features of the Lehigh River Watershed, and the Appalachians in the settlement of the United States)*. ▪ Explain how physical geographical features and levels of technology influence the course and outcome of battles and wars *(e.g., strategic localization of the Lehigh River in the industrial revolution, Bethlehem Steel's role in the first world war)*.	▪ Describe how the physical environment of a county or state was changed by processes of forest clearing, damming of rivers, or land leveling .▪ Describe the changes in the spatial organization of cities over the past *200* years *(e.g., the environmental effects of industrialization, river canals, and railroad systems)*.	▪ Describe how people's perception of the environment changed over time from limitless exploitation to sustainability *(e.g., pollution of rivers during industrialization)*. ▪ Explain how geographic perceptions impacted decisions of and actions by an individual, a group, or a nation *(e.g., the perception of land uses and its values leading to the creation of cement, the construction of river dams, locks, towpaths, canals, and later, railroad systems)*.
12th GRADE	▪ Analyze how geographic contexts (i.e., the human and physical characteristics of places and environments) can explain the connections between sequences of historical events.	▪ Analyze how technological changes in infrastructure have affected human activities in places, regions, and the environment *of the Lehigh Valley* over time *(e.g., the effects of processes of technological change, development of the railroad spurring migration and influencing changes in land-use patterns with access to markets)*.	▪ Describe the changes in perceptions about a group, place, or geographic feature and analyze the effects of those changes *(e.g., opinions about the role of the NJ Zinc plant in the Lehigh Gap area, attitudes towards and therefore treatment of superfund sites in the United States from late 1900's to today)*.

IV. THE WATERSHED EXPLORERS DESKTOP VR GAME

We developed "Watershed Explorers" using Unity real-time engine and built the game for WebGL platforms. The desktop VR game includes a GIS map interface of the Lehigh River watershed with labels, high-resolution 360 photos from the actual locations, 3D models of trail signs, historical imagery, and narrations regarding the environmental and historical significance of each explored area. "Watershed Explorers" was designed and developed with a series of design principles focused on local contexts and gaming features [13]. The intended audience for "Watershed Explorers" included a wide age range from adolescents to senior citizens.

The exploration game begins by providing players with the game's context, the main goal of the game, a pretest measure, and the game tutorial. Players start the game in the D&L museum conference room and meet four avatars that serve as virtual tutors and tour guides throughout the immersive exploration. Della-the-mule is the D&L museum mascot and coordinates the exploration team. Leni is the rivers and recreation specialist. Mira, the environmental educator of the group, describes the environmental importance as well as changes that occurred in the watershed area since the industrial revolution. Lance, a local historian, shares the main historical events of the Lehigh River during the past two centuries. After the avatars' introductions, a narrated fly over animation of the Lehigh watershed map illustrates the path of their exploration down the river.

In sequence, the avatars introduce the controls of this point-and-click exploration game in a tutorial playthrough mode. The game environment contains 360º high resolution photos enriched with videos, historical imagery, trail information signs, and narration regarding the historical or environmental importance of each visited area.

Next, players explore the nine locations along the Lehigh River. Each location has two or three photospheres (i.e., immersive 360º photos). To keep advancing in this linear narrative-based game [24], players need to explore every photosphere completely by collecting the historical photos, watching regular and immersive videos, and reading the local information signs by clicking on their respective icons. Before moving forward to the next location, players answer one multiple choice question that summarizes the main aspect of the area. After exploring the final photosphere, players return to the D&L museum to report on their findings. Players achieve their main goal by recommending three locations to receive improvements that would increase tourism and community engagement along the Lehigh River. They also complete a watershed literacy posttest measure and provided demographic information that included gender and age. Upon data collection completion, the D&L game avatars award players with the title of Watershed Explorer.

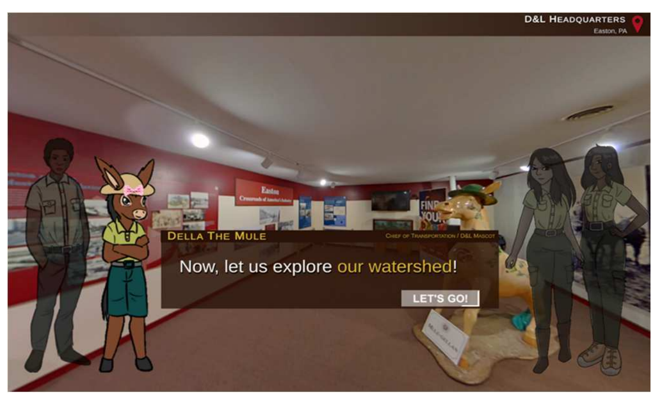

Fig. 1. Watershed Explorers avatars in the D&L museum conference room. From left to right: Lance, Della (highlighted), Lenni, and Mira.

V. Study Context and Design

This study investigated the efficacy of the desktop VR exploration game "Watershed Explorers" as a curriculum enhancement activity to understand its impact on middle school learners' understandings of watersheds by measuring changes in their watershed literacy scores. Implementation took place during the COVID-19 global pandemic in the summer of 2021. Participants had access to the study materials at https://go.lehigh.edu/explorers along with the game via a WebGL interface (i.e., a web-browser connected to the internet). The study's participants were middle school-aged students (10–14 years old), living in the Lehigh River watershed and surrounding areas. Sixty-six participants completed the pretest, from which 35 (9 female, 25 male, and 1 other) completed both the pretest and the posttest. The following research question guided this feasibility study:

To what extent does playing the VR learning game impact middle school learners' understandings of watersheds?

The participants completed a 9-item watershed literacy pretest-posttest content assessment measuring essential watershed understandings that individuals need in order "to be considered scientifically watershed literate" [15, p. 6]. Its nine closed questions included seven true/false and two multiple-choice selection items that assessed participants' ability to:

- Define the term "watershed" (items #3, #4, and #7);
- Identify their local watershed, how they are connected to the ocean via streams, rivers, and human-made structures, as well as the functions that occur in a watershed (items #5, #6, and #9);
- Recognize that both natural processes and human activities affect water flow and water quality in watersheds (items #1, #2, and #8).

The data collection instruments were embedded in the game progression. The game interface (front-end) displayed the data collection instruments as required tasks of the game (see Fig. 2). As players submitted their responses, a C# script forwarded their input data to an online Google Form (previously created by the researcher) that automatically stored each participant set of responses across the rows of a Google spreadsheet.

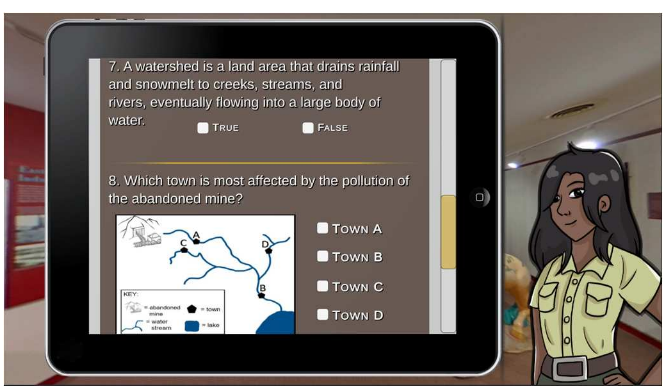

Fig. 2. Embedded data collection instrument. Item 7 and 8 illustrate the two different types of assessment questions of the watershed literacy measure.

A repeated-measures one sample *t*-test was conducted to check whether there was any difference between the students' pretest and posttest watershed literacy scores. Although the measure had different formats of test items (i.e., true or false, multiple choice), each item had only one correct response. Thus, a new re-coded dataset was prepared as a data treatment procedure that dichotomized participants' answers between incorrect (0) and correct (1). Total scores ranged from 0 to 9.

Four education technology and environmental education experts with experience in teaching and learning with VR technologies reviewed each measure to ensure face validity and content validity of the data collection instruments. After considering their feedback, we revised item prompts to better address the study's research question and improved the visual representation of the maps for items 8 and 9 in the watershed literacy content assessment.

Despite the limited sample size, we investigated the psychometric properties of the Watershed Literacy measure by conducting a Rasch analysis using the partial credit model since the items had different rating scales. Next, we conducted a Confirmatory Factor Analysis (CFA) to ensure that the three originally conceptualized subscales "Define", "Identify", and "Recognize" were valid. The Rasch analysis was conducted using MINISTEPS, a free version of WINSTEPS computer program [37]. SPSS was used for the CFA.

VI. Findings

The Rasch Analysis' item reliability coefficient was .87 with a separation coefficient of 2.59 (i.e., a reliable measure with at least two different types of items). Findings from item infit and outfit analysis suggest low likelihood for multidimensionality since all nine items were within the conventional mean square (MSQ) fit ranges of 0.70–1.30 for multiple choice questions of mid/low stakes tests [38]. See Table II.

TABLE II. Infit and Outfit Item Analysis of the Watershed Literacy Measure

Item Number	Infit-MSQ	Outfit-MSQ
1	1.11	1.18
2	0.94	0.96
3	1.22	1.30
4	0.89	0.84
5	1.04	0.96
6	0.86	0.79
7	0.92	0.83
8	1.00	1.14
9	0.94	1.01

Note. $N = 66$

Findings from the confirmatory factor analysis (Principal Components Analysis with Varimax rotation) aligned with our subscales. The 3 fixed factors requested to be extracted in SPSS accounted for 52.55% of the total variance (factor 1, 20.72%; factor 2, 18.64%; factor 3, 13.19%). Five items (#4, #5, #7, #8, #9) corresponded to the subscales as they were originally conceptualized and had factor loadings above .70 with little to no correlation with the remaining two subscales. Table III displays each set of items with their respective factor loadings.

We hypothesized that using the "Watershed Explorers" desktop VR game as a curriculum enhancement activity to promote watershed literacy would positively impact learners' watershed-related knowledge after playing the game. The mean difference between the pretest and posttest scores of the entire Watershed Literacy (WL) measure was not statistically significant. When comparing the pretest-posttest mean scores of the WL subscales, there was a statistically significant difference with a small effect size in the "Identify" subscale, $t(34) = 2.27$, $p = .030$, $d = .383$. There were no statistically significant differences for the "Define" and "Recognize" subscales. Table IV displays the descriptive statistics (mean, standard deviation, and mean difference) and pretest-posttest paired-sample *t*-tests for the entire WL measure and its subscales.

Next, we investigated the mean difference for each item. There was a statistically significant difference with a medium effect size in Item 9 "Which number corresponds to the Lehigh River watershed?", $t(34) = 3.51$, $p = .001$, $d = .59$. No statistically significant difference was found in items 1–8 in a pretest-posttest 2-tailed significance test ($p > .05$). Overall, the means of seven items slightly increased whereas the means of two items decreased. Table V displays the descriptive statistics (means, standard deviations, and mean differences) and pretest-posttest paired-sample *t*-tests for each of the means of the nine items of the Watershed Literacy measure.

TABLE III. RESULTS FROM A FACTOR ANALYSIS OF THE WATERSHED LITERACY MEASURE ESTS

Watershed Literacy item	**Factor loading**		
	1	*2*	*3*
Factor 1: Recognize that both natural processes and human activities affect water flow/quality in watersheds			
8. Which town is most affected by the pollution of the abandoned mine?	**.74**	.00	-.13
6. Watersheds include running water, still water, groundwater, and surface water.	**.68**	.51	.10
3. Topography does not define and separate the watersheds.	**.63**	-.16	-.16
Factor 2: Define the term "watershed"			
4. Watersheds consist of biological and physical components.	.09	**.74**	.10
7. A watershed is a land area that drains rainfall and snowmelt to creeks, streams, and rivers, eventually flowing into a large body of water.	-.06	**.72**	-.23
1. Everyone on Earth lives within a watershed.	-.21	**.41**	.38
Factor 3: Identify one's local watershed, how they connect to the ocean by waterways and built structures			
9. Check the number corresponding to the Lehigh River watershed.	.33	.07	**.75**
5. Smaller watersheds do not connect to each other forming larger watersheds.	-.25	-.05	**.73**
2. Watersheds are changed only by natural processes.	-.20	-.03	**.41**

Note. *N* = 66. Original (non-dichotomized) dataset. Factor loadings above .40 are in bold.

TABLE IV. WATERSHED LITERACY MEASURE'S ITEM ANALYSIS

	Pre		**Post**			**Paired *t*-test**		**Cohen's *d***
	M	***SD***	***M***	***SD***	***ΔM***	***t(34)***	***p value***	
Item 1	0.34	0.48	0.51	0.51	0.17	1.53	.136	0.258
Item 2	0.40	0.50	0.43	0.50	0.03	0.26	.800	0.043
Item 3	0.49	0.51	0.37	0.49	-0.12	-1.00	.324	-0.169
Item 4	0.66	0.48	0.77	0.43	0.11	1.07	.292	0.181
Item 5	0.49	0.51	0.66	0.48	0.17	1.36	.183	0.229
Item 6	0.71	0.46	0.66	0.48	-0.05	-0.53	.600	-0.089
Item 7	0.66	0.48	0.66	0.48	0.00	0.00	1.000	0.000
Item 8	0.51	0.51	0.54	0.51	0.03	0.24	.812	0.400
Item 9	0.11	0.32	0.43	0.50	0.32	3.51	.001*	0.593

Note. *N* = 35. *p < .01

TABLE V. WATERSHED LITERACY MEASURE AND SUBSCALES DESCRIPTIVE STATISTICS AND PAIRED-SAMPLE T-TESTS

	Pre		Post			Paired *t*-test		Cohen's *d*
	M	*SD*	*M*	*SD*	*ΔM*	*t(34)*	*p value*	
Entire measure	4.37	1.63	5.03	1.93	0.66	1.73	.093	0.292
Define subscale	1.80	1.02	1.80	0.90	0.00	0.00	1.000	0.000
Identify subscale	1.31	0.87	1.74	0.82	0.43	2.27	.030**	0.383
Recognize subscale	1.26	0.85	1.49	0.92	0.23	1.05	.300	0.178

Note. $N = 35$. ** $p < .05$

VII. DISCUSSION

This exploratory quantitative study investigated how middle school students' understandings of watershed changed after playing "Watershed Explorers", a desktop VR game used as a curriculum enhancement activity. Due to the COVID-19 global pandemic, the study implementation took place in summer schools. In the U.S., regular schools and summer schools have different goals, which impact their curriculum. Summer schools usually have students work on remedial activities to make up for any learning losses they had during the academic year. Although, the multidisciplinary game, "Watershed Explorers" was originally designed for informal learning, from adolescents (age 13+) to senior citizens, it was implemented with young learners (ages 10–14) from two summer school programs. It might be the case that some of the study participants had difficulties with the amount of reading. However, the young participants did benefit from using the desktop VR game as a curriculum enhancement activity to learn about their local watershed. These findings tend to indicate that VR integration into school curriculum may be a helpful learning tool. Therefore, our future plans also include developing a watershed curriculum learning unit using the VR game "Watershed Explorers".

The findings from the Watershed Literacy content assessment partially support our hypothesis that the use of the "Watershed Explorers" game as a curriculum enhancement activity can positively impact middle school students' essential understandings about watersheds. Players improved their ability to identify their own local watershed and its connections to the ocean by rivers, creeks, and human-made structures. This statistically significant learning gain in the "Identify" subscale was achieved despite the use of the desktop VR game as a curriculum enhancement activity. The unchanging scores of the "Define" subscale is corroborated by the literature as the concept of watershed is not considered common knowledge and is often misunderstood, especially among young learners [3]–[8].

There were some limitations to this study. First, despite the interest of school administrators and teachers, it was very hard to have students engage in this "no-stakes" learning activity during summer school. Second, the number of participants decreased between the pretest and posttest. Participant attrition occurred due to insufficient time to complete the entire game and network technology issues that occurred during gameplay. One teacher reported that a 50-minute class period was not always sufficient for some students to complete the whole experience in one sitting. It was also reported that three students experienced technical issues when completing the posttest. We believe that if the researcher were present during the implementation, time and technology related issues reported by the two teachers could have been addressed. Finally, using a curriculum enhancement activity is itself a limitation since we did not know the scope and sequence of the summer school curriculum of the participants. Future research should first interview teachers and analyze their adopted curriculum to identify where "Watershed Explorers" could fit best in a coherent local sequence for the school curriculum.

From a methodological perspective, the limited sample size number did not jeopardize this prototype implementation study given its exploratory nature (i.e., not intended for generalization). However, if the number of participants were larger, our Rasch analyses could have explored the difference between participants' ability levels as well as the role of guessing in the Watershed Literacy content assessment. This would further support a better psychometric measure for the next iteration of the instrument.

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