An Immersive Virtual Reality Game Designed to Promote Learning Engagement and Flow

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***Abstract*— An immersive game-based Virtual Reality (iVR) module for secondary students to learn about locations in their watershed with a primary focus on their city was designed and developed. A design model and associated theory that focuses on elements that lead to engagement and learning with iVR game-based experiences is described. A series of design principles that were used in the iVR environment are discussed. The iVR game was implemented in an urban school in the eastern USA with 54 economically disadvantaged adolescents ages 16-18 who typically are unengaged in traditional school-based learning environments. After game completion, the participants completed a 10-item survey measuring elements of flow and a 12-item survey designed to measure attitudes toward learning with VR games, immersion and presence. The findings revealed that all students experienced a flow state when they played the VR learning game. Almost all users (98.1%) had positive attitudes towards using the VR game. Student responses noted that they experienced high immersion and presence. In addition, students responded with favorable attitudes towards learning with iVR games in school environments.**

Index terms—virtual reality, learning game, engagement, flow

I. Introduction

Engagement is critical to learning in STEM education. This is especially true for high school students who are typically underrepresented in STEM-related fields. In the United States, traditionally underrepresented individuals in STEM-related fields include individuals from non-dominant racial, ethnic, and economic cultural backgrounds such as low-income, Black, Latino, and English-learning populations [1]. In U.S. high schools, many students from these populations are unengaged learners who are not concerned with achievement in school, avoid challenging work, and often do not complete learning tasks [2]. The level of engagement with adolescents in urban school settings can vary with traditional teaching and learning experiences that include didactic, lab, and field experiences. Classroom learning environments have many distractions that include off-task talking, cell phone use, and gaming on laptop computers. In secondary urban classrooms, many learners are not engaged or motivated to learn. They are satisfied to "just get by", and are at-risk for dropping out of school [3]. To address this, we designed and developed an immersive Virtual Reality (iVR) game for secondary students to learn about locations in their watershed with a primary focus on their city.

We use the term iVR to refer to an interactive computer-generated experience that takes place within a simulated environment using VR headsets to generate realistic images and sounds and handheld controllers that allow interactivity to simulate a user's physical presence in a three-dimensional, virtual environment. A person using iVR is able to move and look around in an artificial world and interact with virtual features or items in a classroom environment without distractions. While we recognize that VR experiences that are delivered via desktop computers have been referred to as immersive in the published literature, we contend that non-headset VR experiences are highly susceptible to distractions in U.S. classrooms with unengaged learners.

iVR gaming environments present several characteristics of great appeal to learners. Features such as active control of the user experience, naturalistic, yet safe environments, and realistic representation of real-world situations that increase engagement and learning. iVR games can provide a sense of authentic immersion and presence of being physically at specific geographic locations [4]. In an iVR game environment, authentic imagery, content, data, animations, video, and narration are incorporated to provide learners with a highly immersive learning experience. Since iVR technology allows for such supports in an immersive environment, it can be designed to provide improved access to STEM-related content for both non-native English speakers and those with mobility disabilities or transportation issues who are physically unable to visit less accessible locations. Furthermore, iVR technology makes it possible for learners to experience geographic locations or situations that are dangerous.

Game-based iVR learning activities are inherently interactive. Games have potential to advance multiple science learning goals, including motivation to learn science, conceptual understanding of science topics, science process skills, and identification with science and science learning [5]. Games can spark high levels of engagement, encourage repetition and practice, and motivate learners with challenges and rapid feedback [6]. Studies have demonstrated the potential of digital games to support learning in terms of conceptual understanding [7,8], process skills and practices [9], epistemological understanding [10], and players' attitudes, identity, and engagement [11]. In the literature, games have been described in terms of being interactive [12], directed toward a clear goal that is often set by a challenge and their ability to promote high levels of engagement [13] and learning [14]. A review of fifty research articles conducted by Pellas, Kazanidis, Konstantinou, and Georgiou of 3-D multi-user virtual worlds found that game-based and narrative contexts promoted student engagement [15].

II. iVR Learning Model and Theoretical Framework

Our iVR learning model (Figure 1) focuses on elements that lead to engagement and learning with iVR game-based experiences. Engagement can be defined as one's focus, participation, and persistence within a task, and therefore related to adaptive or self-regulated learning [16]. Engagement is what happens during a task, a result of the interaction between the learners and the characteristics of both the task itself and the supporting environment. Dorph, Cannady, and Shunn [16] discussed three dimensions of engagement: (1) behavioral engagement that focuses on what a person involved in a learning activity would look like or be doing (e.g., actively participating in a learning task or doing off-task behaviors); (2) cognitive engagement that focuses on thought processes or attention directed at processing and understanding the content in a learning task; and (3) affective engagement that includes one's emotions that are experienced during a science activity. Research suggests that a combination of these three aspects of engagement supports students' learning [17] and all may be enhanced by iVR.

Our project draws primarily from three theoretical frameworks (a) Malone's theory of intrinsically motivating instruction [18], (b) flow theory [19], and (c) science learning activation theory [13]. These three theories of motivation and engagement form the basis for our design of iVR game-based learning activities to promote user engagement and learning.

Malone's theory of intrinsically motivating instruction [18] argues that intrinsic motivation is created by three qualities: challenge, fantasy, and curiosity. Challenge depends upon activities that involve uncertain outcomes due to variable levels, hidden information or randomness. Goals should be meaningful to the learner and learners need some form of performance feedback to tell whether they are achieving their goal. For an environment to be challenging, the outcome must be uncertain. Fantasy should depend upon skills required for the instruction. For example, in an iVR environment, this might involve a learner "flying through" a watershed to visit different locations in various points in time. Curiosity can be aroused when learners believe their knowledge structures are incomplete. According to Malone's theory, intrinsically motivating activities provide learners with a broad range of challenge, concrete feedback, and clear-cut criteria for performance. Thus, to engage a learner's curiosity and learning, feedback should be both surprising and constructive.

Flow is an optimal psychological state in which a person performing an activity is fully immersed in a feeling of concentrated focus and enjoyment in the process of the activity [19]. People experience flow when engaged in an activity that is appropriately challenging to one's skill level. Recent research in the area of serious education games have reported specific flow components such as challenge [20], time transformation [21], positive affect [22], and motivation [23] with players in game environments. In addition, players' sense of time loss was found to be associated with the game's complexity, use of multi-levels, missions, multiplayer interactions, and narrative [21]. Other game-based studies reported that players engaged in scientific practices with a forensic science augmented reality mystery game achieved a substantive flow-like experience through a sense of discovery and desire for higher performance [24, 25].

A main component of science learning activation theory [17] contends that the activated science learner is fascinated by natural and physical phenomena. A learner can have emotional and cognitive attachment or obsession with science topics and

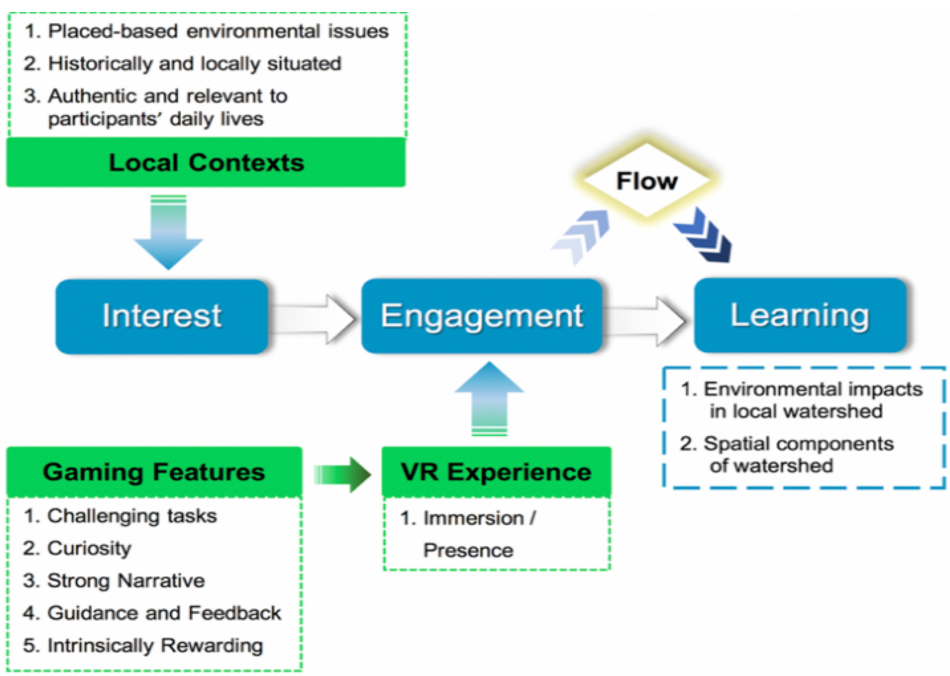

Fig. 1. Immersive VR learning model

tasks that serve as an intrinsic motivator towards various forms of participation. This includes aspects pertaining to curiosity [26] and interest or intrinsic value in science out of school [27]. It also includes positive approach emotions related to science, scientific inquiry, and knowledge. Past research has found each of these constructs to be associated with engagement during science learning [28].

III. The iVR Game

We designed our watershed VR environment using Unity and built the game for Oculus GO headsets. The VR space includes a map-based interface using 3D map with labels, models of objects, topography, and terrain. We used the Oculus Standard Development Kit input module and customized some C# scripts to enable the learner to "fly" through the VR environment using the headset and the controller. The final product includes navigational and map aids; UI elements such as buttons, pictures, and text; highlighted key vocabulary text; and attention to accessibility (for example, avoiding green and red interface elements, which are problematic for color-blind users).

We use a series of design principles to assist diverse learners within the VR environment.

1. *Design for diverse populations.* Environments should be developed in ways that expressly draw on participants' cultural practices, including everyday language, linguistic practices, and local cultural experiences [29]. Contexts should help learners identify with science in personally meaningful ways and promote connections between their personal lives, experiences, and science knowledge [30].
2. *Use of multiple and varied representations.* Promote deeper understandings and sense-making of concepts through concrete, sensory, and immersive experiences [29]. Use effective combinations of imagery, 3D visualizations, animation, highlighted text to enhance learning and transfer [31].
3. *Engage learners in challenging tasks.* Distinct challenges within a learning game keep learners engaged and challenged. Designing for the right challenge-skill balance promotes engagement and an intrinsically rewarding experience for the learners [25].
4. *Provide a strong narrative.* A game designed for non-traditional use requires a strong narrative content to generate excitement, interest, or enthusiasm for science learning [32]. Narratives as "mystery" that use a question, problem, or mission can enhance learner motivation [33].
5. *Provide supportive guidance and motivational feedback.* Guidance in the form of advice, feedback, prompts, and scaffolding can promote deeper learning [34]. Providing guided exploration and metacognitive support also enhances learning for transfer in informal settings [32]. Support is also enhanced by different forms of engaging and monitoring feedback types such as badges or mission checklists [35].

In the iVR game, students are first introduced to the game's contextual challenge. They are volunteering to help out at the Lehigh Gap Nature Center (LGNC) to get equipment and arrive to a locked door. The key has been lost at one of nine locations in the watershed. They must go to visit all locations with a drone and correctly identify each one to retrieve the key. Then the location game begins. Instructions are given on how to use Oculus GO controller and headset to move in the VR environment, use the navigational tools, and interpret map indicators (Figure 2). When the player selects a target location, a pop-up panel appears with the question "What is this place?" on the left side, four-choice buttons on the right side, and in the center, an embedded window with a top view of the camera provides a better reading of the map (Figure 3). If an incorrect answer is chosen, visual and textual hints focusing on scientific or socio-environmental aspects of that location appear, prompting the player to try again. For example, if a student is unable to identify the wastewater treatment plant, the hint states, "This facility is between the Lehigh River and the Little Lehigh Creek" and the adjacent creek in the iVR map environment is highlighted (Figure 4). When the correct answer is selected, an icon specific to that location appears on the badge board (Figure 5). After completing the board with all nine icons, the key is always found at the last location, regardless of order they were identified. The user's last mission is to return to the LGNC and open the door.

Fig. 2. Image of iVR game displaying navigational tools and three locations.

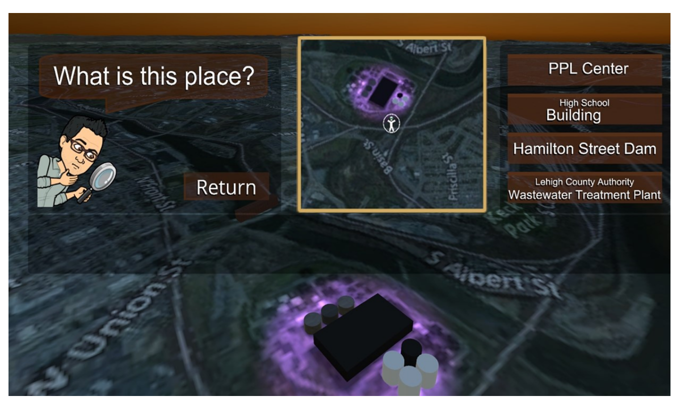

Fig. 3. Pop up panel prompting user to identify the location.

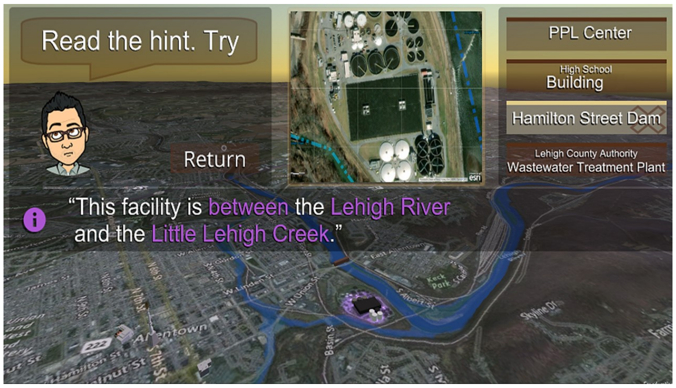

Fig. 4. Pop-up panel displaying a geo-contextual hint and activation of corresponding map layer.

IV. Study Context and Design

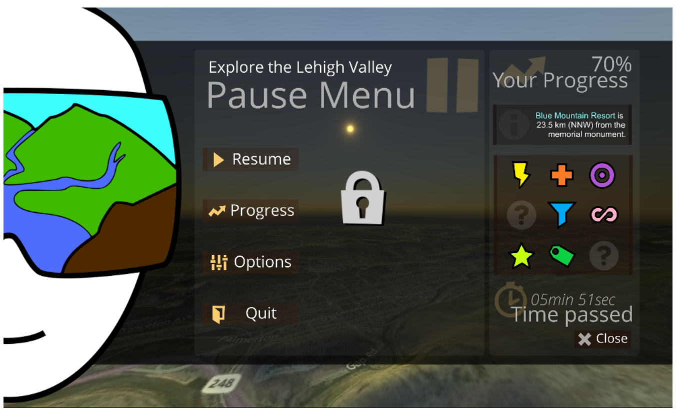

Fig. 5. Badge board displaying seven icons that correspond to the locations that have been identified. Elapsed time is also displayed

The prototype version of the iVR game was implemented with 54 adolescents ages 16-18 in an urban school environmental science class in the eastern USA. At this school, all students are economically disadvantaged and receive free breakfast and lunch. We conducted a feasibility study to see if students were engaged with the iVR learning experience and if they achieved a state of flow during their experience. In addition, we were interested in understanding students’ perceptions of learning with VR games.

The participants completed a 10-item flow survey measuring elements of flow as outlined by Csikszentmihalyi (1996). Each level of the Likert-scale had a different numeric value with “I strongly disagree” equal to 1 and “I strongly agree” equal to 5. Total possible scores ranged from 10 to 50. The survey derived from the Short Flow State scale (S FSS-2) and the Core Flow State scale (C FSS-2) developed by Jackson, Eklund, and Martin (2010) and has been used twice by Bressler and Bodzin [21, 22]; Cronbach's alpha for the instrument in our feasibility study was 0.80. The users also completed a 12-item Likert-scale measuring Students’ Perceptions of Learning with VR Games survey designed to understand attitudes toward learning with VR games, immersion and presence, and usefulness. Total possible scores ranged from 12 to 60. Cronbach's alpha for the instrument in this study was 0.915.

Despite the limited sample size, we tried conducting an exploratory factor analysis in SPSS (Principal Axis Factoring with Promax rotation). Two factors came up, with 6 items in each, explaining a total of 64.53% of the variance (Factor 1- 54.26%; Factor 2 - 10.27%). The individual items for each of the two factors did not correspond to the subscales that were originally conceptualized.

V. Results

The findings revealed that all students experienced a flow state when they played the VR learning game. The total flow measure mean was 41.67 with a standard deviation of 5.67. The total score responses ranged from 31 to 50. Table 1 displays the flow results and Table 2 reports the VR learning perception results.

Almost all users (98.1%) had positive attitudes towards using the VR game. The total perceptions of learning with VR games measure mean was 53.46 with a standard deviation of 6.47. The total score responses ranged from 33 to 60. The student responses noted that they experienced high immersion and presence. In addition, student responded with favorable attitudes towards learning with iVR games in school environments. Table 2 displays the means and standard deviations for each item about learning with VR.

TABLE I. Flow Survey item responses

Description of Item	Mean	SD
I was challenged, and I felt I could meet the challenge.	4.13	0.94
I did things naturally without thinking too much.	4.15	1.02
I had a strong sense of what I wanted to do.	4.46	0.69
I felt I was on track towards my goals.	4.43	0.77
I was totally focused on what I was doing.	4.56	0.66
I felt in control of what I was doing.	4.17	0.96
It felt like nothing else mattered.	3.72	1.12
I lost my normal sense of time.	3.70	1.14
I really enjoyed what I was doing.	4.43	0.76
I was in the zone.	4.37	0.71

TABLE II. STUDENTS' PERCEPTIONS OF VIRTUAL REALITY FOR LEARNING ITEM RESPONSES

Description of Item	Mean	SD
I enjoyed using the Virtual Reality (VR) game.	4.76	0.47
I felt that the Virtual Reality game helped me learn.	4.33	0.82
I would like to use VR games for learning in the future.	4.57	0.75
I believe using VR games in school is a good idea.	4.65	0.59
Using VR games makes learning more interesting.	4.61	0.63
I felt like I really was there during the VR game.	4.26	0.94
My seeing and hearing senses were fully used while in VR.	4.13	1.01
I felt the Virtual Reality game held my attention.	4.42	0.80
I felt I could move better in the game the longer I played.	4.41	0.81
I believe VR games can be helpful for learning.	4.59	0.66
Using VR games can improve my learning in school.	4.39	0.76
Learning to use Virtual Reality is not a problem.	4.59	0.66

VI. CONCLUDING REMARKS

We designed, developed, and implemented an iVR learning game in an urban school with a population of economically disadvantaged learners who typically are unengaged in traditional school-based learning environments. Our learning model focused on elements that lead to engagement and learning with iVR game-based experiences. In this project, we used the opportunities afforded by iVR, such as providing abstraction (e.g., 3D spatial markup to illustrate differences in watershed features) to direct learners' attention and support learner engagement with exploring the local environment. Learning with game-based iVR provided a learning experience that was highly immersive, and immediate and personal by situating the learning in the learner's lived experience. Adolescent learners demonstrated high levels of engagement and flow.

There are two main limitations to this feasibility study. First, while our immersive VR learning model includes interest and learning as important components of model, we did not measure these constructs in this feasibility study. This study was designed specifically to investigate learners' engagement with the iVR game and to determine if a flow state was achieved and to also understand the perceptions and attitudes of learning with VR games with urban high school students that includes many unengaged learners from a population of students typically underrepresented in STEM-related fields. In our next study, we intend to measure both interest and learning to fully test our immersive VR learning model. Second, our study was implemented with a small size of 54 high school students. One possible reason for the inconsistency in the exploratory factor analysis is that the small N for the factor analysis could have given an unstable factor structure. With a large N (e.g., over 100 participants), the factor structure might change.

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References

[1] R. J. Burke, "Women and minorities in STEM: a primer," in *Women and minorities in science, technology, engineering, and mathematics: upping the numbers*, R. J. Burke & M. C. Mattis. Eds. Cheltenham, UK: Edward Elgar, 2007, pp 3–27.

[2] J. Sanacore, "Turning reluctant learners into inspired learners," *The Clearing House: A Jour of Educ Strategies, Issues, and Ideas,* vol. 82, no. 1, pp. 40-44, 2008.

[3] N. Protheroe, "Motivating reluctant learners," *Principal,* vol. 84, no. 1, pp. 46-49, 2004.

[4] C. Jennett, A. L. Cox, P. Cairns, S. Dhoparee, A. Epps, T. Tijs, and A. Walton, "Measuring and defining the experience of immersion in games," *Intern journ of human-computer studies,* vol. 66, no. 9, pp. 641-661, 2008.

[5] National Research Council, *Learning science through computer games and simulations*, Washington, DC, USA: The National Academies Press, 2011.

[6] D. B. Clark, B. Nelson, P. Sengupta, and C.M. D'Angelo, *Rethinking science learning through digital games and simulations: Genres, examples, and evidence*, Washington, DC, USA: 2009

[7] S. A. Barab, T. D. Sadler, T. D., C. Heiselt, D. Hickey, and S. Zuiker, S., "Relating narrative, inquiry, and inscriptions: Supporting consequential play," *J. of Sci Edu and Tech,* vol. 16, no. 1, pp. 59-82, 2007

[8] E. Klopfer, H. Scheintaub, W. Huang, W., D. Wendel and R. Roque, R, "The simultion cycle: Combining games, simulations, engineering and science using StarLogo TNG," *E-Learn and Dig Med*, vol. 6, pp. 71–96, 2009, doi:10.2304/elea.2009.6.1.71

[9] Y. B. Kafai, M. Quintero, and D. Feldon, "Investigating the "'Why'" in Whypox: Casual and systematic explorations of a virtual epidemic," *Games and Culture,* vol. 5, pp. 116–135, 2010, doi:10.1177/1555412009351265.

[10] K. D. Squire, and M. Jan, M., "Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers," *J of Sci Edu and Tech,* vol. 16, pp. 5–29, 2007, doi:10.1007/s10956-006- 9037-z.

[11] S. A. Barab, B. Scott, S. Siyahhan, R. Goldstone, A. Ingram-Goble, S. Zuiker, and S. Warren, "Transformational play as a curricular scaffold: Using videogames to support science education," *J of Sci Edu and Tech,* vol. 18, pp. 305–320, 2009, doi:10.1007/s10956-009-9171-5.

[12] J. J. Vogel, D. S. Vogel, J. Cannon-Bowers, C.A. Bowers K. Muse, and M. Wright, "Computer gaming and interactive simulations for learning: A meta-analysis," *J of Edu Comp Res,* vol. 34, pp. 229–243, 2006.

[13] L. A. Annetta, J. Minogue, S. Y. Holmes, and M.-T. Cheng, M.-T., "Investigating the impact of video games on high school students' engagement and learning about genetics," *Comp & Edu,* vol. 53, no. 1, pp. 74-85, 2009.

[14] C. Girard, J. Ecalle, and A. Magnan, A. (2013), "Serious games as new educational tools: how effective are they? A meta-analysis of recent studies," *J of Comp Ass Learn,* vol. 29, no. 3, pp. 207-219, 2013.

[15] N. Pellas, N. Konstantinou, I. Kazanidis, and G. Georgiou, "Exploring the educational potential of three-dimensional multi-user virtual worlds for STEM education: A mixed-method systematic literature review," *Educ and Inform Tech*, vol. 22, no. 5, 2235-2279, 2017.

[16] R. Dorph, M. A. Cannady, and C. D. Schunn, "How Science Learning Activation Enables Success for Youth in Science Learning Experiences," *Elec J of Scie Edu,* vol. 20, no. 88, pp. 49-83, 2016.

[17] J. A. Fredricks, P. C. Blumenfeld, and A.H. Paris, "School engagement: Potential of the concept, state of the evidence," *Rev of Edu Res,* vol.74, no.1, pp. 59-109, 2004.

[18] T. W. Malone, "Toward a theory of intrinsically motivating instruction," *Cog Sci*, vol. 5, no. 4, pp. 333-369, 198.

[19] M. Csíkszentmihályi, *Flow and the psychology of discovery and invention*, New York, USA: Harper Collins, 1996.

[20] J. Hamari, D. J. Shernoff, E. Rowe, J. Asbell-Clarke, T. Edwards, and B. Coller, "Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning," *Comp in Hum Behav*, vol. 54, pp. 170-179, 2016.

[21] R. T. A. Wood, M. D., Griffiths, and A. Parke, "Experiences of time loss among videogame players: An empirical study," *CyberPsyc and Behav,* vol. 10, no.1, pp. 38-44, 2007

[22] C. K. J. Wang, A. Khoo, W. C. Liu, and S. Divaharan, "Passion and intrinsic motivation in digital gaming," *CyberPsych & Behav,* vol. 11, no. 1, pp. 39–45, 2008.

[23] W.-H. Huang, "Evaluating learners' motivational and cognitive processing in an online game-based learning environment," *Comp in Hum Behav,* vol. 27, no. 2, pp. 694-704, 2011.

[24] D. Bressler, and A. Bodzin, "A mixed methods assessment of students' flow experience during a mobile augmented reality science game," *J of Comp Ass Learn,* vol. 29, no. 6, pp. 505-517, 2013, doi: 10.1111/jcal.12008.

[25] D. Bressler, and A. Bodzin, "Investigating flow experience and scientific practices during a mobile serious educational game," *J of Sci Edu & Tech,* vol. 25, no. 5, pp. 795-805, 2016, doi: 10.1007/s10956-016-9639-z.

[26] J. A. Litman, and C. D. Spielberger, "Measuring epistemic curiosity and its diversive and specific components," *J of Person Assess,* vol. 80, no. 1, pp. 75-86, 2003.

[27] A. Baram-Tsabari, and A. Yarden, "Characterizing children's spontaneous interests in science and technology," *Int J of Sci Edu,* vol. 27, no. 7, pp. 803-826, 2005

[28] S. Hidi, and K.A. Renninger, "The four-phase model of interest development," *Edu Psych,* vol. 41, no. 2., pp. 111-127, 2006.

[29] National Research Council, *Learning Science in Informal Environments: People, Places, and Pursuits*, Washington, DC, USA: The National Academies Press, 2009.

[30] A. Calabrese Barton, "Reframing "science for all" through the politics of poverty," *Edu Pol,* vol. 12, pp. 525-541, 1998.

[31] R.E. Mayer, *Multimedia learning (2nd ed.),* New York, USA: Cambridge University Press, 2009.

[32] National Research Council, *Learning science through computer games and simulations*. Washington, DC: The National Academies Press, 2011.

[33] K. A. Wilson, W. L. Bedwell, E. H. Lazzara, E. Salas, C. S. Burke, J. L. Estock, K. L. Orvis, and C. Conkey, "Relationships between game attributes and learning outcomes: Review and research proposals," *Simul Gam,* vol. 40, pp. 217-266, 2009.

[34] R. Azevedo, and Aleven, V. (Eds.), *International handbook of metacognition and learning technologies*, Amsterdam: Springer, 2010.

[35] J. Pirker, M. Riffnaller-Schiefer, L. M. Tomes, L. and C. Gutl, C., "Motivational active learning in blended and virtual learning scenarios: Engaging students in digital learning", in *Handbook of Research on Engaging Digital Natives in Higher Education Settings*, M. Pinhiero and D. Simoes, Eds. Hershey, PA, USA: IGI Global, 2016, pp. 416 – 437.