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Level up! Gaming as a Tool to Support Science Education

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Level up! Gaming as a Tool to Support Science Education

Summary
Videogames are a popular medium in our society and have an enormous mass appeal, reaching audiences that number in the millions. Even though games are mostly viewed as leisurely pastimes, they can incorporate many effective pedagogical practices and have an enormous potential to deliver STEM education to millions of users simultaneously (Mayo, 2009). Unlike other media, games are highly interactive and have many attributes that could be adapted as pedagogical tools (Annetta, 2008). Given their popularity, many educators have made attempts to incorporate gaming in their classes to support student learning and engagements (Pennington et al, 2014; Bowling et al, 2013; Chuck, 2011; Takemura and Kurabayashi, 2014). This is particularly true in STEM fields, where playing games as education tools has led to significant improvements in test results, student motivation, and knowledge retention (Boeker et al, 2013; Sadler et al, 2013). This workshop aims to familiarize participants with the basis of gaming as used in scientific education and to guide them on the path of designing and implementing a game in their own teaching. Through the course of the workshop, the participants are introduced to several games and are encouraged to think of ways to incorporate these, or similar games, into their own curriculum.

Keywords
gaming, game-based learning, science education, motivation, engagement

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Level up! Gaming as a Tool to Support Science Education

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SUMMARY

Videogames are a popular medium in our society and have an enormous mass appeal, reaching audiences that number in the millions. Even though games are mostly viewed as leisurely pastimes, they can incorporate many effective pedagogical practices and have an enormous potential to deliver STEM education to millions of users simultaneously (Mayo, 2009). Unlike other media, games are highly interactive and have many attributes that could be adapted as pedagogical tools (Annetta, 2008). Given their popularity, many educators have made attempts to incorporate gaming in their classes to support student learning and engagements (Pennington et al, 2014; Bowling et al, 2013; Chuck, 2011; Takemura and Kurabayashi, 2014). This is particularly true in STEM fields, where playing games as education tools has led to significant improvements in test results, student motivation, and knowledge retention (Boeker et al, 2013; Sadler et al, 2013). This workshop aims to familiarize participants with the basis of gaming as used in scientific education and to guide them on the path of designing and implementing a game in their own teaching. Through the course of the workshop, the participants are introduced to several games and are encouraged to think of ways to incorporate these, or similar games, into their own curriculum.

KEYWORDS: gaming, game-based learning, science education, motivation, engagement

LEARNING OUTCOMES

By the end of this workshop, participants will be able to:

- understand the benefits of playing games in order to promote a relaxing and engaging learning environment;
- become familiar with useful resources for applying game-based learning activities in science courses, such as websites hosting on-line games or game repositories;
- use provided resources to generate a new game or adapt an already existing game to fit their course-specific demands; and
- recognize some of the challenges associated with gaming in the classroom, such as devising the appropriate assessment strategies for student learning.

REFERENCE SUMMARIES

Boeker, M., Andel, P, Vach, W., Frankenschmidt, A. (2013). Game-based e-Learning is more effective than a conventional instructional method: A randomized controlled trial with third-year medical students. *PLOS One 8*(12): 1-11.

A game is a system in which players engage in artificial conflict, defined by rules that result in quantifiable outcomes. A driving reason for educators to include such games in their curricula is the high motivational value of gaming. The authors in this study observed that educational games often lose this "gaming character" due to the incorporation of educational content, and thus end up losing their fun and motivational capacity. The authors developed a game called *Uro-Island*, which combines elements of adventure gaming with educational content aimed at medical students (e.g., urine analysis using phase contrast microscopy). The students exposed to the game achieved higher scores on exams assessing this material and were more confident in their knowledge, as compared to students that studied the material in a more traditional lecture-and-script style. Significantly, the students playing the game reported having more fun, being more motivated, and showing preference for game-based

learning. This study is a good example of the motivational power of fun activities during the learning process, which is something that this workshop emphasizes.

Franco, J. (2012). Online gaming for understanding folding, interactions and structure. *Journal of Chemical Education 89*: 1543-1546.

Foldit is an online platform that presents protein structure as a game. It recently gained popularity because gamers used the platform to solve the 3D structure of an HIV retroviral protease, and thus contributed to the effort of designing antiviral drugs. The author of this article proposes that the challenging yet entertaining format of the game, coupled with the fact that gamers are involved in solving "real-world problems", are great motivational tools for teaching protein folding, structure and interactions. The author proposes an integrated approach to teaching molecular biochemistry using this game. In his curriculum, the students received traditional lectures on protein folding and were required to use this knowledge to solve "puzzles" on Foldit as a homework assignment. The success of this approach was demonstrated via increased student engagement and improved test scores of students that played the game in addition to listening to the lecture material. The facilitator of this workshop will briefly demonstrate game-play on this online platform as an example of an engaging educational game.

Hudson, J.N, Bristow, D.R. (2006). Formative assessment can be fun as well as educational. *Advanced Physiological Education 30*: 33-37.

Formative assessment has been described as "the safety net in self-directed learning", meaning that it provides students a measure of their current state of knowledge while their learning is still taking place. Assessment is also important to educators since it enables them to modify the material to better suit the needs of the students. The authors of this study used a modified version of the popular television game show "Who Wants to Be a Millionaire" to test knowledge and to provide feedback to first year medical students in a fun and relaxed way. The students were organized in groups and presented with multiple-choice questions of increasing difficulty, followed by a discussion of why the answer they provided was right or wrong. The authors note that the competitiveness of this game was a major driving factor to engage students in the activity, and it promoted teamwork and sharing of knowledge among students. The participants in the study generally reported positive outcomes, increase in their knowledge base and motivation to learn the material better in order to improve their performance on the quiz. This study can be used as a model in the workshop to design a similar game quiz to pre-assess the participants on their knowledge of gaming as an educational tool and to introduce them to the topic.

Sadler, T.D., Romine, W.L, Stuart, P.E., Merle-Johnson, D. (2013). Game-based curricula in biology classes: Differential effect among varying academic levels. *Journal of Research in Science Teaching 50*(4): 479-499.

This study expands on the topic of games as learning tools, by developing and applying a game-based curriculum and exploring its effect on students of varying academic levels. The game used in this study, *Mission Biotech*, was designed to support genetics and molecular biology education. Game-play is based on the workings of a molecular biology labs and provides levels of varying difficulty. For example, in level 1 students are required to collect all the materials necessary and then perform a virtual DNA extraction. The authors used multi-level assessment (immediate, close, proximal, and distal) to measure the effects of the game on the students' knowledge, retention, and material application. Interestingly, it was found that students in the lowest academic levels benefited the most from playing the game, as their assessment scores showed the largest improvements among the groups. The game-based curriculum

presented here is used as a model in this workshop, demonstrating how videogames can be incorporated into more traditional curricula.

Squire, K. (2011). *Video games and learning: Teaching and participatory culture in the digital age*. New York, NY: Teachers College Press.

This book is part of a growing body of pedagogical texts advocating the use of videogames in education. The author tries to dispel the myth that videogames are just mindless pastimes and provides compelling evidence, through case studies and personal experiences, of the effectiveness of gaming in engaging students to learn difficult materials. The focus of the book is mainly on the so-called "participatory culture", defined as a pedagogy that demonstrates social, interactive, learner-centered and even learner-driven approach to education, and how videogames can be designed to embody these characteristics. What makes this book particularly interesting is the fact that, in additional to pedagogical theories, the author offers insightful critiques on existing educational and commercial games, offers design principles and tips for the development of new games, and provides strategies on integrating games in existing curricula. Even more importantly, challenges for assessing the effectiveness of learning through playing games are discussed. The concepts presented in this book are revisited several times in this workshop, and participants are encouraged to further explore them on their own.

CONTENT AND ORGANIZATION

Duration (min)	Subject	Activity	Purpose
2	Introduction	The facilitator introduces himself or herself and the topic of the workshop to the participants, and outlines the workshop structure and the learning outcomes.	Initial engagement of the participants. Familiarize the participants with the topic and the structure of the workshop so that they know what to expect as the workshop progresses.
10	Pre-assessment	The participants play an adaptation of the game show quiz *Who Wants to Be a Millionaire*. The facilitator organizes participants into small groups and each group gets a chance to answer one question. The question refers to gaming in popular culture and in the classroom. Sample questions: 1. Which game of the following has ~10 million players? **A. League of Legends** B. World of Warcraft C. Pandemic	Introduce the topic of the workshop in a more practical way. Try to make the game fun and challenging. The facilitator should record the answers and note down re-occurring themes. This will help to explore personal attitudes and preconceived notions towards gaming. These issues can be addressed later on during the workshop.

		D. Immune attack 2. What is River City? A. Any city located on a river **B. An ecology-based educational video game** C. The newest version of SimCity D. A board game 3. Playing videogames can strengthen which of the following? A. Your finger muscles **B. Your reflexes** C. Your hand-eye coordination **D. Your memory** 4. Playing video games can have a negative effect on which of the following? A. Your problem-solving skills B. Your mood **C. Your physical health** **D. Your social skills**	Several sample questions are provided, and facilitators can add more or modify the provided questions based on their own knowledge and preferences when it comes to gaming. The questions can have more than one correct answer (in bold), which can be used to encourage discussion. Depending on class size, the game can be set up competitively, and the groups can collect points based on the correct answers they give.
20	Lecture on the Current Use of Videogames in Education	The facilitator starts the lecture by asking the participants if there was anything that they liked or did not like about playing the game, and if they learned something new regarding gaming. Drawing from current educational research, the facilitator defines the concept of gaming, how it has been used as a teaching tool so far, and some advantages and disadvantages. The facilitator emphasizes some of the benefits of videogames such as strengthening of cognitive skills (memory, spatial navigation, reasoning), problem solving skills, mood improvement and relaxation. The facilitator briefly goes over an example of a curriculum that incorporates gaming to teach a scientific concept, as outlined in Handout #1 (Appendix A).	Gives the participants an insight of how gaming has been used in the classroom so far and gets them thinking about ways to incorporate it into their own classes. Makes participants aware of the advantages of using games as education tools, but also stresses the disadvantages that they might encounter when incorporating such activities in their teaching. The lecture can loosely follow the questions of the game played previously and can address some of the issues that the participants had with the concept of playing games as a way of learning.

10	Demonstration of the Game *Foldit*	The facilitator briefly introduces the game *Foldit*, the mechanism of game play and way of earning points/solving puzzles/getting your name on the Hall of Fame.	Provides a first-hand experience with a popular game based on scientific principles. If participants have a laptop they are encouraged to try the game on their own (or, time permitting, they can try the game on the facilitators' computer). *Foldit* is chosen for the demonstration because it is a game based on complex scientific concepts with a high motivational capacity, but at the same time it presents several challenges for educators that want to incorporate it into their curriculum. The purpose of choosing this specific game is to further encourage the participants to be creative in incorporating a game in their teaching. (It is at the facilitator's discretion to choose a different game if desired).
5	Break	Coffee break or try to play *Foldit*	Participants can take a small break, or they can try playing the game on their own.
5	Tips on Ways to Develop an Educational Game	This part of the workshop goes through the content outlined in Handout #2 (Appendix B), questions on how to design successful educational games and tips from educators that have already done so.	Start the participants thinking about what concepts are difficult to explain in their discipline and how to approach game design to address this. The handout also contains examples of how others have solved this problem, and some tips on better

			game design (see Kelly et al, 2007). The participants are encouraged to think about balancing the fun and motivational capacity of a game, and its educational content.
20	Game Development	The facilitator gives the participants time to answer the questions on Handout #2 (Appendix B) and start thinking about a game that they would like to adapt/develop to suit their educational needs. Participants can work individually or in small groups. Facilitator circulates among the participants, answers any questions that might arise and provides feedback.	Allows the participants some time to integrate the ideas presented so far and begin designing a game to apply to their own teaching. This time also allows the participants to ask for clarification on any concept they might struggle with.
10	New Game Demonstration and Feedback	The facilitator asks the participants to divide into groups of two or more, depending on the size of the class. If participants have been working together to design a game, they should pair up with another person. Participants should share their ideas with their partner and discuss game design, content, challenges and benefits that they think their game will have. The participants should discuss the following questions: - What course(s) are you teaching? - What active learning activities are you using in your course? - How familiar are you with video games in general? - How does the game you have designed/want to design contribute to your course content and the activities already used? - What are some of the benefits and negative effects of video games you can foresee in your specific course?	Receive feedback on ideas about incorporating a specific game/type of game in a class. This section allows the participants to share their ideas in a safe and supportive environment, and to receive (and offer) constructive criticism. The facilitator can put the discussion questions on the board to help the participants structure their discussion in the most productive way. The participants are encouraged to use this feedback to improve their game design/provide new ideas for different games.

5	List Available Resources	A very brief talk going through some resources available to educators who want to use an educational game to supplement their teaching. These resources are listed in Handout #3 (Appendix C).	Familiarizes the participants with some pre-developed games that have been used as educational tools. The participants are encouraged to go through the list on their own time and to do additional searches for other available games. Facilitator also points out that teachers can use these games in their class, or they can develop their own games using these resources as models.
3	Conclusions and Summary	The facilitator summarizes key concepts presented so far, the nature of gaming, benefits of gaming in science education and some challenges in introducing games in a learning environment. The facilitator invites participants to think about assessment strategies that could be applied to game-based learning (traditional testing assessment vs creative assessment such as keeping game score etc.). The facilitator responds to any questions and comments that may arise.	Provides a take-home message about what gaming is and how to use it to further education. It also invites the participants to start thinking not only about game design, but also about how to evaluate their students when they incorporate gaming in the curriculum.
Total Time: 90 minutes			

PRESENTATION STRATEGIES

As the primary objective of this workshop is to show science educators that playing games can be not only fun but also educational, the facilitator should try to engage the audience with the game-based activities, as well as to teach them something new about gaming. Gaming is a very prevalent pastime in present times; however, this workshop has been designed under the assumption that many science professors and teaching assistants do not have an experience with gaming in the educational sense. In addition to providing theoretical knowledge, a large portion of this workshop is dedicated to practical activities involving gameplay. The facilitator should have a firm grasp on the present literature involving gaming as a teaching and learning tool; however, it is also strongly suggested that he/she should play several educational games in preparation for leading this workshop. This preparation would provide the facilitator with firsthand experience of educational gaming, and would make him/her more comfortable demonstrating particularly fun parts of the game and answering questions from the audience.

The workshop is designed to provide the facilitator with a certain amount of flexibility. For example, one type of game played in class can be easily substituted for another, depending on the facilitator's preference, the size and the dynamics of the class.

The participants will be encouraged to bring laptops to class; however, this is not a requirement for attendance, and the facilitator should be prepared to accommodate participants that cannot play the games on their own computer. The room in which the workshop would be held should have a computer with Internet access and a projector in order to present a PowerPoint presentation and to demonstrate game play in front of the whole class. In order to bring across the point that games are fun and motivational way to learn, it is very important that everyone gets to participate and to have fun in the workshop. The facilitator should be prepared to draw everyone's attention to gaming as a fun activity, to try to give everyone an opportunity to play the game (time permitting), and to create a relaxed environment for learning.

ADDITIONAL REFERENCES

Several additional references, mostly describing interesting games that could be used as learning tools, are listed in this section. They represent a valuable tool for participants that are interested in including game playing in their classes. The workshop facilitator can adapt some of these games for the workshop activities (for example, *Interactive Hangman* can be played instead of *Who Wants to Be a Millionaire* in the first section of the workshop).

Annetta, L.A. (2009). Video games in education: Why they should be used and how they are being used. *Theory Into Practice 47*(3): 229-239.

Bowling, K.B., Klisch, Y., Wang, S., Beier, M. (2013). Examining an online microbiology game as an effective tool for teaching the scientific process. *Journal of Microbiology and Biology Education 14*(1): 58-65.

Chuck, J-A. (2011). Hypothetical biotechnology companies: A role-playing student centered activity for undergraduate science students. *Biochemistry and Molecular Biology Education 39*(2): 173-179.

Corredor, J., Gaydos, M., Squire, K. (2014). Seeing change in time: Video games to teach about temporal change in scientific phenomena. *Journal of Scientific and Educational Technology 23*: 324-343.

Kelly, H., Howell, K., Glinert, E., Holding, L., Swain, C., Burrowbridge, A., Roper, M. (2007). How to build serious games. *Communications of the ACM 50*(7): 45-49.

Mayo, M.J (2009). Video games: A route to large-scale STEM education? *Science 323*: 79-82.

Pennington, B.O., Sears, D., Clegg, D.O. (2014). Interactive hangman teaches amino acid structures and abbreviations. *Biochemistry and Molecular Biology Education 42*(6): 495-500.

Takemura, M., Kurabayashi, M. (2014). Using analogy role-playing activity in an undergraduate biology classroom to show central dogma revision. *Biochemistry and Molecular Biology Education 42*(4): 351-356.

APPENDIX A: Handout #1 - Sample Curriculum

A sample curriculum incorporating the game *Mission Biotech* in a standardized instructional sequence teaching DNA structure, the Polymerase Chain Reaction (PCR) and transcription (adapted from Table 2 of the article below)

Sadler, T.D., Romine, W.L, Stuart, P.E., Merle-Johnson, D. (2013). Game-based curricula in biology classes: Differential effect among varying academic levels. *Journal of Research in Science Teaching 50*(4): 479-499.

Lesson	Primary focus	Instructional activity
Week 1*	Introductory lecture, biotechnology tools, processes and safety	Students identify equipment and familiarize themselves with safety processes
2	DNA structure, location and function	Lecture on DNA structure, location and function
3	Introduce *Mission Biotech* game, demonstrate game controls	Student players familiarize themselves with aspects of the game
Week 2	Game DNA extraction in *Mission Biotech*	In the first level of the game, student players collect materials and equipment, and extract DNA
2	Laboratory DNA extraction	Extract plant DNA using standard lab procedures
3	DNA structure and PCR	Mini-lecture and video, small group questions, and whole class discussion
Week 3	Game PCR	In the second level of the game, student players extract DNA, collect materials for PCR, and perform PCR
2	PCR process	Small group activity: Simulate PCR process, make predictions about results. Whole class discussion
3	PCR process and analysis	Analyze the results of the game PCR
Week 4	PCR analysis	Students work in small groups to analyze and explain PCR results
2	Reverse transcription	Mini-lecture: introduce reverse transcription In the third level of the game, student players perform reverse transcription and PCR
3	Reverse transcription and analysis	Small group activity: analyze and explain reverse transcription results; whole class discussion

*This curriculum is designed as a 4-week module with 3 hours of instructional time/week.

APPENDIX B: Handout #2 - Designing a Game to Suit Your Needs

These are some questions to get you thinking about how to go about designing your own game or modifying an existing game. The example answers have been adapted from the article below, dealing with the design of the game *Immune Attack*.

Kelly, H., Howell, K., Glinert, E., Holding, L., Swain, C., Burrowbridge, A., & Roper, M. (2007). How to build serious games. *Communications of the ACM 50*(7): 45-49.

Question	Example answer	Answer based on your courses
What is a problem/concept in your discipline that students struggle with?	- The workings of the human immune system	
What game format would be most useful to bring this concept closer to students? Eg. Question-and-answer style, Adventure game, Role Playing game...	- A battlefield metaphor - immune cells combating bacteria. The player collects and trains different immune cells to avoid pathogen attack - The game is a combination of discovery-style gaming where players explore new environments and collect objects, and a strategy-style game where different immune cells are positioned to fight off pathogen attacks	
What are the learning objectives your game strives to accomplish?	- Comprehend pathogen strategies - Identify and understand the components of the immune system - Analyze and apply the concept of "self" vs. "non-self" recognition - Synthesize concepts of cell development and maturation - Identify and apply chemical compounds that deter pathogens	
Have you heard of an existing game that might suit your needs and teaching style?	- Most available games in this field are dealing with disease spread and containment on a larger scale (e.g., *Pandemic*)	

Question	Example answer	Answer based on your courses
What is your budget for designing/implementing a game?	- Limited budget	
What type of team would you need to execute the creation of this game?	- Research team (as opposed to a commercial game developer): programmers, artists, cinematic and sound experts, immunologists, experts in educational technology	
What is the motivational capacity of this game?	- Contains different levels of increasing difficulty - Players have to perform increasingly complex set of tasks to complete each level - Game design is very appealing and resembles commercial games	
What is the educational capacity of this game?	- Game-play and design are realistic - Players observe and control what happens in the human body - The game provides some introductory text materials that the players need to understand to excel in the game - Incorporates a database where players can watch videos and learn more about different aspects of the immune system	

APPENDIX C: Handout #3 - Sample of Available Educational Games

The names and links for several interesting educational games, as well as sites hosting game collections, are provided here. Some sites, such as The Educational Arcade, also host game design apps and demos.

Foldit: Solve Puzzles for Science
https://fold.it/portal/

EteRNA: Played by Humans. Scored by Nature
http://eterna.cmu.edu/web/

EyeWire: A Game to Map the Brain
https://eyewire.org/signup

PHYLO: DNA puzzles
http://phylo.cs.mcgill.ca/

Immune Attack
http://immuneattack.org/

Atlantis Remixed
http://atlantisremixed.org/

The Education Arcade: MIT Scheller Teacher Educational Program
http://education.mit.edu/projects

Science Game Center: Video Games that Teach Science
http://www.sciencegamecenter.org/

Surge: Scaffolding Understanding by Redesigning Games for Education
https://sites.google.com/site/surgeuniverse2/

Games Learning Society
http://www.gameslearningsociety.org

Web Adventure: Explore Science - One Game at a Time
http://webadventures.rice.edu