GAME DESIGN AS A PEDAGOGIC TOOL: THE FUTURE OF STEM EDUCATION

University of Chicago

JUNE 1, 2022

AHIT KAAN TARHAN
tarhan@uchicago.edu

Table of Contents

Abstract

As our daily lives become more integrated with science & technology, our education systems need to ensure that all students are gaining the essential scientific literacy and critical-thinking skills to navigate the diverse technological landscape that defines the 21st century. Although STEM education has been at the forefront of global initiatives to prepare students to life, recent systemic reviews show that current pedagogic methods focus separately on individual subjects and fail to impart the necessary integrated systems thinking for students to design solutions for complex contemporary problems ailing our world. Game design processes employed as pedagogic tools can be the answer to contemporary issues in STEM education. As a unique blend of artistic and engineering processes, game design is an iterative design process that requires research, synthesis, dialogue, collaboration, interdisciplinary integration, and systems thinking to implement solutions for the construction of a desired experience. These affordances fit the bill for a design-based, student-centered, constructionist, hands-on learning experience that is desired by educators on both the national and international levels. Thus, game design could be the pedagogic tool necessary for STEM education to adapt to the needs of the 21st century and the future.

Keywords

Constructionism, constructivism, STEM, STEAM, educational games, affordances, procedural rhetoric, game design process.

Acknowledgements

I would like to thank Professor Patrick Jagoda, for giving me inspiration, hope, and guidance since the day I met him, and specifically for the opportunity to be involved in game design research.

I would like to thank my colleagues Denise Fischer and Caroline Sullivan for their suggestions, feedback, and discourse on game design.

I am incredibly fortunate to have worked alongside amazing game designers as part of the Weston Game Lab at the Media Arts, Data, and Design Center at the University of Chicago. Their camaraderie, support, and insight formed the foundation of a community of scholars, designers, and friends I will miss working with. Thank you, Alvin Shi, Amory Schmidbauer, Steele Citrone, Bruno Pasquinelli, Isaac Berman, Charlie Cooper, Alexander Joh-Jung, Kailin Wu, Christos Menemenlis, Daniel Steinberg, Pau Olieveres, Charlie Kupets and Jacob Briggs.

Special thanks to faculty and staff at the University of Chicago that have given me advice, on research, pedagogy, and life, for which I am grateful: Ashyln Sparrow, Professor Anne Henly, Dr. Sunanda Prabhu-Gaunkar, Sanskriti Chitransh and Roell Schmidt. Without their insights, it would not have been a smooth journey.

Finally, I would also like to thank my family and friends, who kept me going. Specifically, I am thankful for the patience of my mother and grandmother whilst I was involved heavily with games, the constant analysis and discussion of game mechanics supplied by my husband, and his patience in always being the first editor of my thoughts and words.

Games for Education

Games have become a colossal cultural phenomenon, perhaps even the defining trait of the 21st century for younger demographics. More than a third of the world population plays video games (Yanev, 2022). That number reaches a staggering 97% for teen in the US, with half of them playing every day (NW et al., 2008). Games penetrate all socio-economic levels of society, allow for never-before-seen magnitudes of participation across the globe, and allow for unparalleled agency over the art form for participants. Thanks to the increased access to internet (France-Presse, 2021), gaming is a rapidly emerging phenomenon in developing countries. Whether digital or analog, single or multiplayer, games are widely distributed to a large international audience thanks to global shipment routes and bustling online marketplaces such as *Steam, GOG,* and *Epic Games*. Due to their interactivity, games give players agency over the narrative they co-create and consume. Due to their replayability, games offer a truly staggering number of affordances to the player. With the advent of streaming platforms such as *Twitch*, *YouTube* and *Discord*, games can be played by dynamic communities. Thus, compared to more mature media of fine arts, and even performative arts, games are a uniquely democratic medium. The transcendence of gaming could prove to be the cultural zenith of the 21st century.

But games have existed since antiquity, from the fertile deltas of North Africa and the Middle East to the vibrant coasts of Asia and the marble halls of the ancient Mediterranean; so why have games and gaming garnered so much attention in the last few decades? It's not because gaming has suddenly become a central part of human culture, but due to the normalization of computer-assisted activities, games and gaming have come to the forefront of media (Tekinbas & Zimmerman, 2003). People have played games for millennia, but an 18th century newspaper might not have felt the need to write about these games, dismissing them as mere entertainment. On the contrary, these days contemporary journalism follows sociocultural, aesthetic, and economic impact of games, across platforms such as *IGN*, *Metacritic*, *Kotaku* and *GameSpot*, just to name a few. This heightened interest in the value of games both for entertainment purposes and those that go beyond it have also channeled new lifeblood into scholarly efforts to understand games and related phenomena.

Educational sciences stand to uniquely benefit from this heightened interest in games, with games being utilized as pedagogic tools. After decades of utilization, we can learn from the success of games in an educational context and apply those insights to develop new pedagogic methods and tools to come to the need of contemporary education. Of particular interest is STEM education, due to the common affordances of the scientific process and game design. This paper will systematically review underlying theories of learning employed in educational games and how affordances serve as the mechanism by which games facilitate learning. Finally, game design as a design-based constructionist approach to learning will be positioned as a pedagogic tool that can tap into the benefits of games while avoiding their limitations, to serve as the future of STEM education initiatives.

Educational Games

It is vital to have both theoretical and practical understanding of how games work, how they are made, and how they can capture the attention of an ever-increasing portion of the world population. We are perhaps headed towards the golden age of gaming, brought on by the emergence of technologies that can support a critical population of gamers and by renewed vigor in having a deeper understanding of this fascinating cultural phenomenon. That entails a large enough population to create demand for new games, new modalities of gaming, and renewed insight about games, which is in turn met by a supply of more games, better technologies to support them, and research efforts in understanding their impact. But we are not there yet; there is still much to investigate about the art and science of games. Game designer Jane McGonigal proclaims that a hurricane is coming, a social cataclysm caused by an exodus to the virtual world; it will be the biggest one yet, defining the 21st century, bigger than TV, cars, radio, anything (McGonigal, 2011). The tremendous momentum generated by the increased demand for games and related phenomena has the potential to catalyze advancement of many fields, namely science, education, and the science *of* education.

The cultural explosion of games is occurring over a backdrop of daily scientific developments that necessitate a deeper understanding of science for each new generation. Teens from each generation are not simply more likely to play games for ever-increasing periods of time, but they are also more likely to face daily challenges that require a better understanding of the underlying scientific concepts and technological savviness. Thus, education is uniquely situated as a field to benefit from the momentum generated by games, due to the overlap between the two demographics of "those that play games" and "those that attend educational institutions." Teens and children play games more than any other age group (NW et al., 2008). Unsurprisingly, games have been extensively utilized in all tiers of education in the last few decades, through gamification of tasks or as creative pedagogic tools. But not all educational games or games used in an educational setting rely on the same theory of learning.

Game designer and scholar Simon Egenfeldt-Nielsen categorizes educational games based on the theories of learning that underlie them: those that rely on behaviorism, constructivism and constructionism (Psych & Egenfeldt-Nielsen, 2007). Behaviorist games rely on the implicit claim that one learns "by practicing skills and contents through reinforcements and conditioning." Gamification of tasks in a classroom, quiz games or digital flashcards employ behaviorism. These are popular, because they require minimal guidance on the instructor's part and thus remain to be old-school and didactic. Eric Klopfer succinctly identifies the problems with gamification, which concentrates "only on applying games in traditional school settings with traditional methods and outcomes" but "the resemblance to a game is meaningless when the activity is nothing more than answering multiple-choice questions and when success is measured solely as the percentage of correct answers given expressed as a 'score' and presented with a fun animation" (Klopfer et al., 2009, p. 2). Not only is this approach prone to issues commonly raised with educational games, but it also lacks any of the benefits of educational games that "focus on the habits of mind and dispositions needed to collaborate, innovate, problem-solve and communicate effectively in a knowledge-based economy" (Klopfer et al., 2009, p. 1).

Constructivist games go a step further, placing the learner at the center of their gameplay (Psych & Egenfeldt-Nielsen, 2007). Based on famous development psychologist Jean Piaget's theory of cognitive development, they rely on the implicit belief that learners construct their own knowledge by interacting with their environment (McLeod, 2019). Games that allow the manipulation of dynamic systems without a singular correct answer to the problems presented by the game employ constructivism. Learners build upon prior knowledge, and any new uptake must be consolidated with existing ideas. Open-world crafting games such as *Minecraft* and *Terraria* are wildly popular constructivist games that players may not think of as learning experiences. Games like *Astroneer* and *Satisfactory* make their physics engine an explicit part of the game, while *Don't Starve* and *Raft* require players to understand the dynamics of the ecosystem they inhabit. Constructivist games rely on players to interact with their environment to learn the rules of the game, which are in turn based on the physical and natural sciences.

Constructionist games sound similar to constructivist games, but their focus shifts from the learner to the setting; the artefacts generated by a game provide the platform for exploring new material, both individually and in collaboration (Psych & Egenfeldt-Nielsen, 2007). Some multiplayer games, role-playing games (RPGs) and alternate reality games (ARGs) employ constructionism. These games are relatively few in numbers, especially those with explicitly educational aims, and their potential is only beginning to be understood. These games will be discussed more in detail later, as their underlying theory of learning is similar to that of game design as a pedagogic tool.

Affordances as Mechanism

Although educational games have underlying assumptions about how individuals learn, these are usually implicit extensions of the beliefs held by the game designer with regards to theories of learning. The mechanisms by which players become learners are not explicit in the context of educational games. To bring about a paradigm shift in the way games are thought about in an educational context, one must first dissect the rich affordances of educational games and the mechanism by which games can become educational.

Affordances are “players’ sensed possibilities for action within game environments,” the vocabulary for which has been adapted by game designers and scholars from ecological psychology (Jones, 2018). Kurt Squire delineates six core affordances employed in educational games: the ability to visualize, parametrize, simulate, change perspectives, test hypotheses and critically analyze (Squire, 2003). As games develop, future affordances may require entirely new categories to describe them, but these core affordances are nevertheless important in constructing an understanding of what shape an affordance may take.

Many games offer new visualizations of problem spaces: from two-dimensional conceptual maps that relate variables to three-dimensional models that allow for spatial relationships between objects to be developed. Games such as *SimEarth* and *CellCraft* allow players to manipulate variables in systems, such as oxygen or glucose levels, temperature, or pressure, and see how parametrization of variables can lead to desired outcomes. *Hidden Agenda*, *Mysterium* and *Dixit* encourage players to consider the perspectives of other players in order to gain the mutual understanding necessary to succeed in these games.

Hugely popular franchises such as *SimCity* or *Sid Meier’s Civilization* series allow players to simulate a variety of social scenarios and observe the emergent system behavior over time. These games also allow players to test implicit hypotheses such as “increased taxation will lead to civil unrest” or “ambient oxygen saturation could improve cellular respiration rates”. This leads to critical analysis of complex scenarios, where players must evaluate the accuracy or reliability of the ruleset with which they are presented. If increased public transportation routes lead to increased citizen happiness in *SimCity*, or if a lack of access to amenities reduces population growth rates in *Civilization VI*, what message is the game designer trying to relay? Unpacking these implicit biases and questioning the rules of the game add a new layer of affordances to playing games. All of these affordances turn players into learners, allowing them to practice with and hone skills that are useful for scientific reasoning.

The mechanism by which affordances become learning modalities is best explained by a term coined by game designer and scholar Ian Bogost: “procedural rhetoric”. Though not posited as a mechanism by him, it nevertheless allows for some interdisciplinary clarity to seep from game and media studies to that of educational sciences. Bogost claims that “games are unique as a medium in their persuasive modality”, by which he means that the voice of the game designer comes across not just through the images, narrative or soundscape of a game, but also through its gameplay (Bogost, 2010). He argues that videogames, which we can generalize to other game media as well, have rule-based symbolic processes that are carried out or manipulated by players and that this interaction modality, the act of playing a game, becomes the primary way of uptake for the message of the game by its audience. The voice of the game designer can thus be carried by the medium specific element of a game: its rules, mechanisms, and affordances. Just as a lecture or a book can allow for new knowledge to be conducted from source to learner, games can relay information to players through affordances. In a way, games allow players to learn by practice, by trial-and-error, and learning from the consequences of their own actions. This pathway of communication between the designer and the audience could explain how the affordances of games can functions as vectors for learning.

Videogames are not the only genre of game to be employed for educational purposes. There are many analog card-, board- and table-top games that have educational goals or have scientific themes that lend them well to inclusion in classroom or curricula. Some of the newest efforts to make such analog games have the explicit mission of employing procedural rhetoric as their primary vector of learning. The STAGE lab at the Pritzker Institute of Molecular Engineering for example, is designing games to teach quantum mechanics and quantum computing, by imbuing their games with mechanics that give their players quantum affordances. That means “first-hand experience with the concepts of wave-particle duality, measurement, superposition, randomness, tunneling, interference, coherence, quantum fidelity, and entanglement” (STAGE, 2022). They are not the only one: the famous puzzle-platformer *Portal* and its sequel *Portal 2* also rely on procedural rhetoric to familiarize its players with scientific concepts: this time good old Newtonian mechanics. The players must understand how objects accelerate, what inertia is, and the rules that govern objects in motion to solve the puzzles presented in each level. By slowly developing mastery over these affordances while playing, the players become learners and gain an intuitive understanding of classical mechanics.

That people can learn from affordances is exemplified by the existence of what Schrier calls “knowledge games” (Schrier, 2016). Talking about the phenomenon of citizen science, where normal people are enlisted in data collection, manipulation, and analysis to solve scientific problems, she notes how bird watching, folding proteins and sifting through images of distant galaxies can become “knowledge games”. A famous example is University of Washington’s *Foldit*, which is an online puzzle game about protein folding. Players first learn the affordances of proteins, by folding them correctly and developing and understanding of what conformations a particular string of amino acids are likely to take. Then, they test their understanding by trying to find solutions to unresolved protein folding problems. Scientists have been able to use the insight of the players to correctly identify folding patterns of certain proteins, which serves as resounding proof that games can teach complex scientific thinking modalities by lieu of affordances. Schrier notes that people “could identify biases, observe and record emotions, analyze specimens, solve puzzles, make estimations, describe social interactions, make ethical decisions, probe simulations, launch hypotheses, experience consequences, and provide points of view on issues and policies. Game players could be collectors, contributors, purveyors, and interpreters of scientific, humanistic, social, and psychological data and evidence” and that there is no limit to what subject games can become pedagogic tools for (Schrier, 2016).

Dialogue as an Affordance

The player-generated components of the game can be thought of as an extension of the game, and the dialogue and discourse a game generates can be used for educational purposes. Not all games have a dialogue component, and most dialogue is usually intra-diegetic to the game world. There is a newer strain of games, called alternate reality games (ARGs), that utilizes this otherwise forgotten affordance in the service of pedagogy, blurring the line between what is part of the game and what is not.

ARGs are "multiplayer roleplaying games that use the real world as their primary platform and incorporate a range of media, including video, audio, email, mobile technologies, websites, live performance, and social networks" (Gilliam, Bouris, et al., 2016). Thus, they can be situated as employing constructionist theories of learning, where the players become learners by interacting with the artefacts of the game and with other players. One example is *The Source*, designed by The Game Changer Chicago Design Lab (GCC Design Lab) to spark STEM interested and learning among traditionally underrepresented youth populations (Gilliam, Bouris, et al., 2016, p. 14). The game takes place over the course of five weeks, where an unfolding narrative of Adia (a 17-year-old African American girl living on the South Side of Chicago who asks the players' help to solve puzzles left by her estranged father) is utilized to guide participants through various STEM related mini-games, puzzles and activities.

Because these games mimic reality, the affordances of the players are those they have in their daily lives as individuals: utilizing search engines, editing images, recognizing patterns in sets, empathizing with other individuals, etc. The affordances are not as simple as "the pawn can take a single step forward" in chess, or "your character can move in the cardinal directions when you press the arrow keys" in many videogames; nevertheless, they exist! By becoming aware of these affordances, players get a chance to practice these skills. Thus, the procedural rhetoric of the game can be thought of as amplifying and drawing attention to STEM skills that players already have: the ability to collect data, analyze sources of information or come up with interventions to achieve social change.

The success of this new generation of games as educational tools stems from their recognition of affordances as vectors for learning and their integration of learning goals as core affordances in games. The GCC Design Lab, in collaboration with University of Chicago faculty, has developed many such games and found them to be successful in generating interest and motivation in various STEM, health and sexuality related topics (Gilliam, Jagoda, et al., 2016; Macklin et al., 2018). They have found, based on post-game student surveys and interviews, that youth learned as much from each other as they did from the core game material, with one student player of *The Source* saying, "I like working by myself a lot when I'm at school because I don't have any distractions or anything. But now it’s good to get help from others when you don’t know what to do. And I mean, I like communicating with other people and things like that” (Gilliam, Bouris, et al., 2016, p. 17). Thus, they have identified a hidden core affordance that is often left implicit in games: dialogue.

The participants in an ARG, the players of a boardgame, or the viewers of a videogame that is being streamed all have the opportunity to communicate with one another. They can strategize, discuss game mechanics, offer each other advice or critique, and thus benefit from each other’s experiences. Games can curate a community that constantly generates discourse. The social environment that a game sustains can be thought of as an integral part of the game. From a play-centric approach, game designer and scholar Tracy Fullerton argues, games can be thought of as the sum of the emergent game-play as much as they can be thought of as the set of rules written by the game designer (Fullerton, 2014).

Another interdisciplinary insight comes from literature, specifically from the post-structuralism movement. Though new among artistic media, games are not impervious to the assassination of the game designer: the principles of the *Death of the Author* can be applied generously to games just as well as it can be applied to any media (Barthes, 1977). The voice of the game designer can be amplified through emergent gameplay that is intended, or it can be muffled through unintended emergent gameplay. Either way, the game exists on a spectrum between two extremes: what the designer intends and what the player experiences. The player-generated components of the game can thus be thought of as an extension of the game, and the dialogue and discourse a game generates can be used for educational purposes. ARGs are great examples of games that utilize this otherwise forgotten affordance in the service of pedagogy. Educational videogames and boardgames that are educational often fail to capitalize on this affordance, perhaps due to the difficulty in seeing past the need for a rigid definition of a game, or the attribution of emergent gameplay to the realm of things over which a designer has no control over. But game designers could, and should, make explicit efforts to catalyze dialogue about their games, for communication and collaboration are vital skills to foster, not least because they are integral to the STEM community.

Contemporary Needs of STEM Education

With a growing understanding of the mechanism by which games can become educational and employed as pedagogic tools, the field of game design can respond to the contemporary needs of educators. Of particular interest is STEM education, due to growing demands for scientifically literate professionals in society and the excellent way in which most educational affordances lend themselves to learning cognitive processes that underscore scientific thinking. STEM education has been at the forefront of global initiatives in education research, and recent reviews highlight how reforms and new approaches are necessary to both attract and retain students in STEM fields, as well as develop core competencies required for scientific-engineering thinking. These new approaches can learn from and build upon the pre-existing literature denoting the success of educational games. Game design as a pedagogic tool has specific affordances that would fit into STEM education's needs better than educational games could, and to understand this subtlety, one must first understand what the contemporary needs of STEM education are, and how "playing games" alone cannot satisfy them, but "designing games" could.

The common view among STEM educators and researchers is the need for new pedagogic tools to galvanize student interest and retain it. A review of 237 studies over the period of 2010-2015 in 25 high quality educational journals yields a critical result: the implementation of new pedagogical practices are necessary to increase student interest and motivation, develop 21st century competencies, and improve student achievement (McDonald, 2016). Another review by Krapp and Prenzels also finds *pedagogy* to be the most influential factor in determining the science interest of students, and that consolidating efforts to promote "student-centered, inquiry-based pedagogical practices embedded in contextualized settings" would increase students' interest in STEM subjects (Krapp & Prenzel, 2011). The key to renewing student interest thus seems to lie in evolving away from the standard didactic classroom approaches. This in agreement with McDonald's findings: in order for "… STEM pedagogical practices to be effective, it is critical that teaching approaches are altered from traditional, teacher-centered pedagogies to active, student-centered pedagogies to support student learning" (McDonald, 2016, p. 538). Contemporary STEM education needs clearly needs less didactic and more constructionist pedagogic tools.

Constructionist games, like ARGs and other holistic educational interventions, are proving themselves to be apt at retaining student interest, but they cannot be applied as a blanket solution. One of the main problems that educators have with new methods is the difficulty of integrating them into a pre-existing curriculum. Though educational games can be beneficial on a case-by-case basis, their strength comes from their topic-specificity. But there is no pre-existing educational game that fits the specific needs of a STEM curriculum. There is also the need for a more integrated approach to teaching STEM topics. Research finds that in "schools that do teach the four STEM disciplines often do so in a disjointed manner, failing to integrate STEM in a unified way" (McDonald, 2016, p. 532). Thus, new pedagogies must have broad applicability and the ability to integrate multiple fields. Some new game initiatives, like those of The Game Changer Chicago Design Lab, also struggle with this, with one student saying: "[the ARG] started off engineering, then it somehow got to STIs, and then it went to, what was it, like, those don't correlate" (Gilliam, Bouris, et al., 2016, p. 17). This is where game design, used as a pedagogic tool, could offer the benefits of educational games while being applicable in a wider variety of curricular settings and not suffering from an inability to integrate diverse topics.

With the evolving understanding in the educational arena that hands-on self-directed activities are much more beneficial for everlasting learning compared to didactic instructional modes, there is a growing need for pedagogies that can facilitate constructionist learning. Games are already being utilized for educational purposes, in fact, the status-quo of *games* and *gaming* in an educational context has become centered around educational games (Squire, 2003). However, as learning scientist Burke succinctly states it: "There has been considerable interest in examining the educational potential of playing video games. One crucial element, however, has traditionally been left out of these discussions— namely, children's learning through making their own games" (Kafai & Burke, 2015). That is because a formal understanding of what game design is, and how it compares to the artistic and scientific processes, remains elusive for educators.

Honey, Pearson and Schweingruber point out that "designers of integrated STEM education initiatives need to be explicit about the goals they aim to achieve and design the integrated STEM experience purposefully to achieve these goals. They also need to better articulate their hypotheses about why and how a particular integrated STEM experience will lead to particular outcomes and how those outcomes should be measured" (Honey et al., 2014, p. 8). By understanding the game design process, one can better contextualize the initiatives that have employed it as pedagogic tool and learn from them to construct one's own STEM education initiatives.

Game Design Processes: Theory, Pedagogy & Practice

Much like art-making or learning, game design is not a uniform universal process. It is malleable, depending on the needs of the game designer and their goal; be a collective or individual effort, span a production cycle of years or a few hours, can be streamlined or experimental, be found in an industrial or educational setting. With such a diverse array of cases to study, dissect and analyze, "a Babel of competing methodologies" have emerged in the field of games design, as had happened for art criticism and artistic scholarship (Tekinbas & Zimmerman, 2003, p. ix). Thus, there are many lenses one can evaluate game design processes with. To posit game design as a pedagogic tool in STEM education, it is important to demarcate the constituent behavioral components of game design processes and the underlying cognitive domains they activate, such that parallels with the scientific process and modes that catalyze learning can clearly be identified.

Everyone brings their own biases about what the game design process entails for them, and such subjective perspectives can be helpful in constructing a personal mental image. However, one must be mindful of the plethora of game design processes that have existed throughout time and across cultures and acknowledge that this diversity and dynamism of the process allows it to elude stagnation and obsoletion. In fact, understanding the diversity of game design processes is the first step in employing them towards an educational goal. As individual learners have different preferred modalities of epistemic growth, the flexibility of the game design process should be embraced as a panacea for learning.

Theory

Though a comprehensive ontology of a "game" is beyond the scope of this paper, a framework for thinking about what a "game" is useful to have for understanding how games are made. A long-standing framework for understanding game design and guiding research by Hunicke et al. focuses on affordances as the core content of the game. At the core of their framework "… is the idea that games are more like artifacts than media. By this we mean that the content of a game is its behavior and not the media that streams out of it towards the player" (Hunicke et al., 2004, p. 2). The "game" should thus be thought of and evaluated as not just a set of rules and mechanics, but also the dynamic behavior it elicits from players, the affective response it invokes in them and the affordances it gives the players. The framework is named *MDA* after the three components it delineates: mechanics are the rules of the game, dynamics are the behavioral system the rules generate, and aesthetics are the responses evoked in the players. For some games, the affective response could be "having fun", however, for serious/educational games, the emotions can be much more complex (Hunicke et al., 2004). In an ARG that aims to spark STEM interest in its players for example, the affective response could be feeling emboldened, confident, or curious about STEM subjects. The MDA framework allows us to see games as complex artefacts that aim to curate affordances for their players by using mechanics, which in turn generate affective responses. This is a helpful starting point for thinking about games as experiences, and game design as the act of curating an experience, rather than simply producing a collection of media to be consumed.

It will not go unnoticed that amongst this talk of interacting with games, and behavior that games elicit, a word begging to be used is missing: "play". The word is rich in history, and scholarly interest in attempting to define and understand it never subsides (Caillois, 2001; Jagoda, 2020; Myers, 2008). Though the English language allows for a distinction between "play" and "game", many languages do not: in German "man spielt ein Spiel", in French "on joue un jeu", in Turkish "oyun oynuyor". Games can be thought of as a subset of play; in freeform play such as running around in a playground and interacting with toys or a roleplaying game that only has certain mechanics nailed down (Tekinbas & Zimmerman, 2003). Playing can also be thought of as a subset of the game as an artefact; the experience of playing a game is one way of interacting with a game, as games can be viewed, analyzed, tinkered with, theorized about (Tekinbas & Zimmerman, 2003). Thinking about "games" and "play" as separate can be helpful for certain theoretical approaches, but this is not always a necessary distinction.

A behavior-focused, "play-centric" approach to game design by Tracy Fullerton, game designer and educator, allows for a working definition of the word "play" together with a "game". The play-centric approach to game design centers around curating a playing experience for the players, which can be defined as the sum of realized affordances. Thus, the game is what is played, and any emergent playing behavior is considered part of the game. The game designer can be thought of as the curator at a gallery, and the art in display as affordances, or the game designer as a chef at a restaurant, and the menu items as affordances. The metaphors can be extended to many scenarios, but the main message is the same: "… if games are spaces where meaning is made, game designers are the metacreators of meaning, those who architect the spaces of possibility where such discovery takes place" (Fullerton, 2014, p. 13). For the purposes of this paper, if games are a collection of affordances, game design is the process of curating said set of affordances.

So how does a game designer go about curating affordances? The process is similar to reverse engineering a device. Fullerton's advice is to "Ask yourself, why do you play games?". She believes that understanding your own answer, and the answer of other players, is the first step to game design. Thus, there is an explicit focus on the curated experience for the audience. Game and play are intricately intertwined: games only exist, so to speak, when played. Her answer as to why we play games is "… to learn new skills, to feel a sense of achievement, to interact with friends and family, and sometimes just to pass the time" (Fullerton, 2014, p. 1), but an educator's answer might be to teach concepts, have the players experiment with ideas learned in class and feel confident in their ability to apply new skills to solve problems. The demographic, the audience, the consumer, the player, the choice of word to describe those that have played/are playing/will play a game has powerful implications for the game design process. It requires the designer to think like the player, place themselves in their shoes.

The MDA approach systematically highlights this reverse engineering approach: from a game designer's perspective, mechanics are designed to give rise to dynamics, which leads to desired aesthetics. That is the inverse of a player's perspective, where aesthetics and affordances generate play dynamics, which allow players to understand the underlying mechanics and assumptions. In a game like *Portal 2* for example, jumping down a ledge allows the generation of momentum. This *affordance*, combined with the ability to place portals in three-dimensional space, leads to the *dynamic behavior* of placing portals below a ledge to jump into, which preserves the momentum of the player's character. Then, when a second portal is placed at a different location, the player character emerges from the second portal with the same velocity that they had entered the first portal with. Eventually, this leads to the understanding of the underlying classical mechanics, which are incidentally the core *mechanics* of the game. A designer thus designs opportunities for a player to reach conclusions by using affordances. In order to successfully design affordances, a designer must understand the rules that govern them.

This is where game design becomes critical from an educational standpoint: a designer learns about the mechanics and rules that govern a system in order to curate affordances within it. If games teach, as educational games do, then the designer is both the teacher and learner. In order to teach, the game designer learns, and "through the iterative design process, the game designer becomes a game player, and the act of play becomes an act of design. Learning to play a game critically, seeing where it excels and where it grinds to a halt, and being able to implement changes that will push the game toward meaningful play are all core game design skills" (Tekinbas & Zimmerman, 2003, p. 12). This is because game design processes are essentially design processes and include key steps that allow many opportunities for learning to take place: research, synthesis, dialogue, collaboration, interdisciplinary integration, and systems thinking.

Much like the artistic and scientific processes, game design begins with research to review pre-existing literature and content material. Game designer and academic Scott Rogers suggests doing a lit-review to begin with, so as to not re-invent the wheel: "Sometimes when you are trying to think of an answer to a problem, it's a good idea to look at other games and see how they solved it" (Rogers, 2014, p. 39). Like the scientific and artistic processes, game design requires one to understand the concepts they want to implement in a game, but also how the field has dealt with such concepts. This might entail doing further research into topics covered in a classroom setting, such as applications of mathematics, limitations of physics, economics of chemistry, subtleties in language, or different accounts of history. The research presents a dual learning opportunity: by interacting with games that utilized similar content matter, one can learn how the content has been presented.

Content and information alone do not add up to much of course, synthesis of the content is necessary to come up with creative insights. Design processes necessitate this to come up with new artefacts. Proponents of STEAM education, which incorporates the "A" for the arts into STEM, have long argued that the artistic process offers many opportunities for science learning and synthesis of knowledge (Perignat & Katz-Buonincontro, 2019). Their main premise is that the personalized artistic process allows for constructionist learning, where students interact with concepts, objects and try to construct mental schemas that make sense for them. When designing a game about biology, for example, a student might be trying to decide the color of the card for the chloroplast vs the mitochondria. They might choose complementary colors of green and red, to highlight the complementary processes of the photosynthesis and the Krebs Cycle. Perhaps they will decide to give them different hues of the same color, to highlight the fact that both are organelles with double membranes. Maybe the game will not even include a chloroplast component if the focus on the game is on the human body. To make decisions about why certain game elements should take the form they do, how certain mechanics function or whether something should be omitted requires a working understanding of the relationship between the concepts at hand. Thus, synthesis of the knowledge that is learned is essential to game design processes.

The decision about a small component of the game might spark debate, or lead to healthy discourse, where game designers can learn from one another. Dialogue between designers is an inadvertently emergent property of any design process. Argumentation and reasoning, core competencies for scientific reasoning, regularly take place in the game design process through the evaluation of mechanics and playtest results. Intra- or interpersonal discourse such as "should we keep the mechanic, is it giving the result we want, why or why not?" requires constant reasoning, debate, and persuasion. The team needs to be able to find common ground and reach a conclusion with regards to the design path they want to follow. Speaking of a team, game design is usually a collaborative process. Though individuals can design games on their own, "people from other disciplines than game design—programmers, artists, testers, writers" bring a lot to the table (Rogers, 2014, p. 36). The game design process offers many academic and creative affordances to designers: from coding to writing, from image generation to data collection, it allows for teamwork and even necessitates it.

Along with diverse affordances, perspectives and different individuals contributing to the game design process comes the need for interdisciplinary integration. Game designers must attempt to look at problems from the perspectives of multiple disciplines. As Tekinbas & Zimmerman eloquently puts it: "as products of human culture, games fulfill a range of needs, desires, pleasures, and uses. As products of design culture, games reflect a host of technological, material, formal, and economic concerns. It would be ineffective (and even silly) to try and view such a complex phenomenon from a single perspective. To do so would be to miss most of the design problem entirely" (Tekinbas & Zimmerman, 2003, p. 5). Game designers must reason why certain mechanics are representative of system, how to represent rules, what aesthetic elements to employ to curate a particular experience. The answers for each question may differ based on the perspective of the designer and what kind of experience they are trying to curate. The colors assigned to mitochondria in a game might aim to generate different meaning depending on whether the designer has a feminist or queer-theory approach, evolutionary or Intelligent Design perspective, a capitalist or environmentalist agenda. Within a team, this also means looking at the problem from the perspective of one's collaborators and trying find common ground.

On top of the metacognitive awareness about different perspectives of approaching problems, integration also entails systems thinking that is required for designing games. Games can be viewed as integrated systems of objects/particles interacting with one another according to a set of rules/mechanics (Tekinbas & Zimmerman, 2003, p. 55). Even thermodynamic formalisms can be applied to thinking about games as system; open systems having some form of free exchange with their environment, whereas closed systems do not. The system in this analogy is the game, and the environment is the emergent behavior and cultural phenomena that it generates. Resource management board games such as *Wingspan* and *Everdell*, or classical strategy games such as chess or Go can be modelled as a closed system when they are being played by artificial intelligence. This allows for optimal strategies to be established, and the AI to find the best move possible with certain constraints. Thermodynamically, this is reaching equilibrium. Another example is blackjack, which can be treated mathematically to have a complete statistical picture of the game that allows for a player to always make the least-risky decision in each scenario. Games with social components can be viewed as open systems. Boardgames such as *Settlers of Catan*, *Monopoly*, trading-card games such as *Magic the Gathering*, video games such as massively-multiplayer online role-playing games (MMORPGs) such as *World of Warcraft* or *Star Wars: The Old Republic* and multiplayer online battle arenas (MOBAs) such as *League of Legends* and *Dota 2: Defense of the Ancients* all have open & closed systems. There are certain rules and systems that are rigid, such as the code of the game or official rules, but the way the games are played, the *meta*, is always changing. The games can be played in ways never imagined or intended by the designers, or certain players can add/remove some of the rules while playing at home, called *homebrewing*. ARGs, role-playing games, installation art or performance art that includes game-elements can be thought of as open systems, with the purpose of generating player- or location-specific affordances. Thus, designing a game is designing a system, requiring foresight about mechanics. In some cases, foresight is impossible, and one must simply playtest the game. Testing is essential; it is a simulation of the system the designer has built, to see how it fares the real-life stress of being played. If there are any bugs, glitches, or points of failure, they will have to be fixed, and the game will have to iteratively be playtested again.

Several scholars have recently attempted to demarcate the components of a game design process. Fullerton's play-centric approach that positions affordances and emergent behavior as core parts of a game (Fullerton, 2014) is supported by the theoretical MDA approach's framework for games as designed experiences (Hunicke et al., 2004). Roger's industrial approach highlights research and collaboration (Rogers, 2014), and Tekinbas & Zimmerman's consolidation of diverse methodologies prevents subtleties such as games-as-systems from being glossed over (Tekinbas & Zimmerman, 2003). Together, they highlight the pedagogically relevant steps that one might take in a game design process: research, synthesis, dialogue, collaboration, interdisciplinary integration, and systems thinking.

Pedagogy

The aforementioned steps are integral to many processes and have long been recognized by educational sciences. The resultant design-based learning (DBL) is being employed by educators as "an inquiry-based learning approach focusing on the generation of novel and creative artifacts, systems and solutions" (McDonald, 2016, p. 539). Design-based learning is becoming ever more mainstream. In 2015, the US transitioned from the *No Child Left Behind* (NCLB) policy for K-12 general education to *Every Student Succeeds Act* (ESSA). ESSA "encourages states and districts to use federal funding to help teachers expand the use of UDL [Universal Design for Learning]" which encompasses DBL (Lee, 2019). This approach to teaching and learning is based on three principles: engagement, to make skill building feel like a game; representation, to offer knowledge in multiple media formats; and expression, to give students more than one way to show what they know, such as doing a group project or designing a game (Lee, 2019). Game design fits into this definition perfectly and is poised to be employed more often for design-based learning.

Game design processes are uniquely positioned in between the artistic and scientific processes. Employing game design projects in STEM education can help answer many of the needs of contemporary STEM education: "instrumental to the development of engineering literacy is the construct 'engineering thinking', which encompasses engineering design processes and engineering habits of mind (including competencies such as systems thinking, collaboration and creativity)" (McDonald, 2016, p. 535). Systems thinking, collaboration and creativity are all essential components of the game design process, hence it makes sense to utilize game design as a means of engaging the cognitive domains that underlie the engineering mindset.

Game design processes are iterative, they require playtesting, hypothesizing and going back to the drawing board. Thus, employed in STEM settings, game design can simulate true-to-life design cycles and offer opportunities for learning as Professor of education Roger Bybee states: "orchestrating learning experiences where students have to engage in cycles of design and redesign that require constructing of grade-appropriate mathematical and science understandings may be powerful opportunities for deep learning to occur in the classroom and extend far beyond" (Bybee, 2013).

Though games as pedagogic tools have been recognized and are abundant in popular media, game design as a pedagogic tool remained a niche concept relegated to the realm of experimental ventures. The potential for game design to serve as a better context for teaching as opposed to simple educational games was first recognized by Papert's seminal grant proposal to the NSF: the 1987-1990 NSF grant given to Seymour Papert at the MIT Media Laboratory's Epistemology and Learning Group outlines the philosophy of the research group and defines critical vocabulary. Their goal was the utilization of constructionism as a new opportunity for elementary science education:

> The word constructionism is a mnemonic for two aspects of the theory of science education underlying this proposal. From constructivist theories of psychology, we take a view of learning as a reconstruction rather than as a transmission of knowledge. From a rich body of educational experience, we take the view that learning is particularly effective when it is embedded in an activity the learner experiences as constructing a meaningful product (for example, a work of art, a functioning machine, a research report or a computer program). (Papert, 1986, p. 2)

They then frame game design as a constructionist activity, which "goes beyond (while including) the idea of hands-on". They highlight the social and affective components of game design as beneficial to stimulating and motivating students. This is in line with the identification of collaboration and dialogue as important steps of a game design process (Rogers, 2014), as well as the need for more engaging pedagogy for student engagement and retention in STEM fields (Krapp & Prenzel, 2011; McDonald, 2016).

The definition of game design as a constructionist pedagogic tool, different from educational games and gamification in educational contexts, is essential if it is to be adopted by educators. ARGs were identified as constructionist approaches in employing games in an education context. But most educational games operate in the constructivist regime, giving information out “on demand” and “just in time” as opposed to information presented in schools, allowing the students to interact with games on their own pace (Gee, 2003). There exists criticism in employing constructivist approaches in education, which applies to educational games as well (Kirschner et al., 2006).

The first branch of the criticism relates to the lack instruction in constructivist approaches, which is detrimental to the development of fundamental principles for novice learners. If one knows nothing about the mathematical or scientific themes employed in a game, such as the notion of atoms, cells, derivatives, or light as both a wave and a particle, then it might be difficult to parse all of the knowledge contained in the game. The critics cite controlled studies that uniformly support the idea that “even for students with considerable prior knowledge, strong guidance while learning is most often found to be equally effective as unguided approaches” (Kirschner et al., 2006, p. 83).

The second branch of the criticism is concerned with the liberal and misguided application of constructivist pedagogy, as in the case of an educator relying completely on a constructivist activity for teaching: Constructivist activities entail sifting through information, interacting with nodes of knowledge at one’s own pace, assimilating new information and incorporating it into a pre-existing framework. When too much time is required to search for information, as is the case in some discovery-based techniques, the learner’s attention and memory capacity are unavailable for construction of knowledge. This can be viewed as a weakness of videogames and gaming for educational purposes. Too much time is spent in with components of games that do not lead to immediate learning outcomes. Interacting with aesthetics over mechanics, the visuals and narrative over the affordances, may reduce the learning benefits of educational games or even distract from learning outcomes: “not only is unguided instruction normally less effective; there is also evidence that it may have negative results when students acquire misconceptions or incomplete or disorganized knowledge” (Kirschner et al., 2006, p. 84).

The rebuttal to criticism about constructivist educational approaches can take the form of game design as a pedagogic tool. It is superior to playing educational games because it removes the distractions of in-between time. By collaborating and debating about content, mechanism and aesthetics; by hypothesizing, testing and analyzing the game-play; the content matter is always in focus. By giving students the affordances of thinking at a systems level and integrating different perspectives to solve problems, game design ensures that learning takes place consistently. It allows for an instructor to serve as a guide when the learners are novices. The teacher could function as a research adviser, a source of feedback who offers guidance, resources, and critique, and allows the children to learn by themselves, while also stepping in to offer corrections when misunderstandings occur or serving as a conflict resolution arbitrator for younger children.

Situating game design as a constructionist activity, as Papert does, distinct from constructivist approaches in education, is critical to employing it as a pedagogic tool, as some have already done.

Practice

While games for education are being extensively employed and studied, game design has been used as a pedagogic tool in relatively few settings. These take on the form of stand-alone extracurricular programs in the US (Macklin et al., 2018) and abroad (Akcaoglu, 2014), as well as in the classroom connected to a curriculum (Kafai, 1995). There is need for more research and documentation with game design as a pedagogic tool in fields other than mathematics and computer science; STEM fields such as naturals sciences and interdisciplinary engineering are of particular interest.

In a pre-experimental study by Akcaoglu, twenty-one middle schoolers from middle-class families participated in a ten-day long game design summer program offered in Istanbul, Turkey (Akcaoglu, 2014). The program aimed to develop problem solving skills, systems design, and computer programming skills by first teaching students fundamental coding skills and then allowing them to apply these to various problem scenarios and finally design their own games, all of which were mediated by Microsoft Kodu, a game-design software. During game design activities, instructors guided students as they tinkered with their respective games (Akcaoglu, 2014, p. 589). Pre- and post-program tests from the Program for International Student Assessment (PISA) were used to measure students' learning outcomes. The quantitative assessment found that student's systems analysis and design abilities improved. Although limited in scope and prone to self-selection biases, this study provides evidence of how quantitative tools can be used to study short-term learning effects of game design. Longitudinal studies with different assessment tools applied on larger and more diverse student bodies would be welcome to establish quantitative benefits of game design as a pedagogic tool.

As a three-week summer program at the Hexacago Health Academy (HHA), twenty-four youth participated in a game-based program administered by the GCC Design Lab that aimed to educate them on sexual and reproductive health by employing field trips, lectures, meet-ups with industry professionals and game design. For the game design component, participants were divided into teams and each team worked to design a game about a health topic of their choice. They balanced scientific content matter with gameplay and participated in peer review of each others' games, debating and collaborating to solve any issues with the game as it was being created (Macklin et al., 2018, p. 6). The difference between playing educational games and designing games with an educational purpose was not lost to the participants, with one student saying, "I describe [creating and playing games] as different. Kinda difficult, it was just– it had you thinking a lot… I had to go over the game a few times before even playing it, kept on asking questions about the route, and it was a learning experience" (Macklin et al., 2018, p. 12). Based on interviews conducted with students after the program and their qualitative assessment, incorporating game design as a pedagogic tool lead to the development of "critical thinking skills by translating factual content knowledge into a more complex and designed system" (Macklin et al., 2018, p. 9).

In her seminal work, Kafai employs game design as a pedagogic tool to aid the mathematical learning of sixteen fourth-grade students at an inner-city public elementary school in one of Boston's low socio-economic neighborhoods (Kafai, 1995). Over the course of six months, the students designed and produced video games that aimed to teach fractions to younger students. For one hour every day during class, students worked on their games, but could walk around and interact with each other. These sessions were complemented by "focus sessions and classroom meetings" where students discussed their issues with each other, and their difficulties with the concept of fractions and how to best represent them. Framing game design as a "constructionist activity," Kafai's results show that game design can "give children an opportunity to show and develop their abilities in design and learning while creating complex software products designed for use by others" and her case studies are great examples of "how the acquisition of knowledge and creative and critical thinking are integrated in the learning of subject matters involved" (Kafai, 1995, p. 14; Perkins, 1986).

Game Design as a Pedagogic Tool

When Papert first posited game design as a pedagogic tool he asked, "what science should be learned by children who are now preparing themselves for adulthood in the 21st century?" (Papert, 1986). Although it's been four decades since the 1980s, the question is still pertinent. From vaccine misinformation to conspiracy theories, climate change to the flatness of the Earth, there is a huge scientific literacy gap within society that prevents conflict resolution. And this cannot simply be alleviated by increasing or changing the content matter taught in science classes, but by teaching scientific ways of evaluating data at hand, hypothesizing for one's own, designing solutions to global problems and collaborating with people with different perspectives working towards the same goal. A better question now is "how do we teach science" rather than "what science should be taught". Game design stands as a good answer to that question.

The problem space generated by the game design process is interdisciplinary and the solutions generated by students go beyond simple regurgitation of facts. It calls for creative utilization of information, synthesis, and manipulation of content matter, and is thus more representative of the real-world than the more rigidly defined affordances that educational games can offer. Bybee stresses that "intentionally moving curricular presentations into more transdisciplinary applications where a problem or purpose that transcends content is used as an authentic context for learning will bring knowledge and understandings constructed in the classroom more in line with what is actually being required of students and adults in real life" (Bybee, 2013). Game design is that authentic context, which transcends the curriculum it is being used to teach. It allows for a life-like evaluation of problems and gives students a variety of scientific affordances such as testing, collaborating, systems thinking, and interdisciplinary integration.

Game design is a design-based pedagogic tool that can be adapted to fit any curricular context with a process that is uniquely situated between the artistic and scientific processes. Compared to art projects, employed in STEAM initiatives, its quantitatively rigorous and well-defined problem space allows for competencies necessary in STEM fields to be highlighted. Compared to scientific demonstrations or engineering projects, it is less costly to implement and experiment with, while its intrinsic entertainment value helps keep students engaged and sparks interest in underrepresented groups in STEM.

The benefit of a game design project, either as a final project or as a semester-long project, is its ability to function as an extra-curricular activity that increases the time spent by students critically thinking, analyzing, and learning. Instead of assigning problem sets, a traditional academic essay, or a video-blog, why not assign the final project of creating a game? Some humanities and media-arts courses might incorporate some amount of game design, perhaps as a fringe medium, to experiment with and be avantgarde. But game design does not have to be a quirky, one trick pony to demonstrate emergent cultural media. It can be applied as a pedagogic tool for long-standing, traditionally taught courses such as introductory organic chemistry, high-school US History, Latin or Turkish, calculus or partial-differential equations, cell biology or reproductive health, macroeconomics or psychology. The list can go on and on, the point being, game design can be applied to any content matter as a constructionist pedagogy, at the college, high school, or K-12 levels. However, due to the core affordances of game design processes, STEM courses stand to particularly benefit from employing game design.

To employ game design as a pedagogic tool, an instructor or curricular designer can have the learners produce a game, whether analog or digital depending on their technical production skill level. Focusing on the core affordances of the game design process that are relevant for the content matter at hand is helpful. The process of game design, over the product of the game that is produced, should be at the focus. The produced game should not attempt to teach the entire course material or require memorization of facts, but go beyond those to put a twist on the material and present it in a nuanced way. By working in teams, students should communicate with each other about the material and work through any disagreements by digging up the necessary evidence. In order to make something new with the material, they will have to synthesize it and dig deeper into a specific portion of it, making this an amazing reading, research and learning opportunity. The instructor can serve as a guide or mentor, pointing at relevant resources, offering advice when prompted and even participating in the playtesting of the games.

There is need for student-centered, design-based approaches to STEM education to spark student interest in STEM fields and develop core competencies needed to succeed in a technological society. Educational games have been employed for decades, their affordances serving as the primary learning vectors, but their benefits are limited by their constructivist pedagogy. New constructionist approaches to teaching and learning, such as ARGs and game design, have demonstrated an ability to stimulate interest in content matter while maintaining realization of learning outcomes. This is due to the core affordances of game design processes that align with the scientific process: research, synthesis, dialogue, collaboration, interdisciplinary integration, and systems thinking. Game design as a pedagogic tool can answer the needs of contemporary STEM educators and become an essential part of future education initiatives.

References

Akcaoglu, M. (2014). Learning problem-solving through making games at the game design and learning summer program. *Educational Technology Research and Development*, *62*(5), 583–600. https://doi.org/10.1007/s11423-014-9347-4

Barthes, R. (1977). *The Death of the Author*.

Bogost, I. (2010). *Persuasive Games: The Expressive Power of Videogames*. MIT Press.

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. NSTA Press.

Caillois, R. (2001). *Man, Play, and Games*. University of Illinois Press.

France-Presse, A. (2021, November 30). More than a third of world's population have never used internet, says UN. *The Guardian*. https://www.theguardian.com/technology/2021/nov/30/more-than-a-third-of-worlds-population-has-never-used-the-internet-says-un

Fullerton, Tracy. (2014). *Game design workshop: A playcentric approach to creating innovative games* (3rd edition.). CRC Press/Taylor & Francis. http://pi.lib.uchicago.edu/1001/cat/bib/11692868

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment*, *1*(1), 20. https://doi.org/10.1145/950566.950595

Gilliam, M., Bouris, A., Hill, B., & Jagoda, P. (2016). The Source: An Alternate Reality Game to Spark STEM Interest and Learning among Underrepresented Youth. *Journal of STEM Education: Innovations and Research*, *17*(2). https://www.jstem.org/jstem/index.php/JSTEM/article/view/2079

Gilliam, M., Jagoda, P., Heathcock, S., Orzalli, S., Saper, C., Dudley, J., & Wilson, C. (2016). LifeChanger: A Pilot Study of a Game-Based Curriculum for Sexuality Education. *Journal of Pediatric and Adolescent Gynecology*, *29*(2), 148–153. https://doi.org/10.1016/j.jpag.2015.09.008

Hunicke, R., LeBlanc, M., & Zubek, R. (2004). *MDA: A Formal Approach to Game Design and Game Research*. 5.

Jagoda, P. (2020). *Experimental Games: Critique, Play, and Design in the Age of Gamification*. University of Chicago Press.

Jones, I. B. (2018, August 23). *Special Effectivities*. https://vimeo.com/286446396

Kafai, Y. B., & Burke, Q. (2015). Constructionist Gaming: Understanding the Benefits of Making Games for Learning. *Educational Psychologist*, *50*(4), 313–334. https://doi.org/10.1080/00461520.2015.1124022

Kafai, Y. Bettina. (1995). *Minds in play: Computer game design as a context for children's learning*. Lawrence Erlbaum Associates.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Klopfer, E., Osterweil, S., & Salen, K. (2009). *Moving learning games forward*. https://hal.archives-ouvertes.fr/hal-00593085

Krapp, A., & Prenzel, M. (2011). Research on Interest in Science: Theories, methods, and findings. *International Journal of Science Education*, *33*(1), 27–50. https://doi.org/10.1080/09500693.2010.518645

Lee, A. M. I. (2019, August 5). *What is the Every Student Succeeds Act (ESSA)?* https://www.understood.org/articles/en/every-student-succeeds-act-essa-what-you-need-to-know

Macklin, M., Jagoda, P., Jones, I. B., & Gilliam, M. (2018). Game-Based Health Education: The Case of Hexacago Health Academy. *Journal of STEM Outreach*, *1*(1), 10.15695/jstem/v1i1.11. https://doi.org/10.15695/jstem/v1i1.11

McDonald, C. V. (2016). STEM Education: A Review of the Contribution of the Disciplines of Science, Technology, Engineering and Mathematics. *Science Education International*, *27*(4), 530–569.

McGonigal, J. (2011). *Reality Is Broken: Why Games Make Us Better and How They Can Change the World*. Penguin.

McLeod, S. (2019). *[Constructivism as a Theory for Teaching and Learning]*. https://www.simplypsychology.org/constructivism.html

Myers, D. (2008). The Video Game Aesthetic: Play as Form. In *The Video Game Theory Reader 2*. Routledge.

NW, 1615 L. St, Washington, S. 800, & Inquiries, D. 20036 U.-419-4300 | M.-857-8562 | F.-419-4372 | M. (2008, September 16). Teens, Video Games and Civics. *Pew Research Center: Internet, Science & Tech*. https://www.pewresearch.org/internet/2008/09/16/teens-video-games-and-civics/

Papert, S. (1986, November). *NSF Award Search: Award # 8751190—Constructionism: A New Opportunity for Elementary Science Education*. https://nsf.gov/awardsearch/showAward?AWD_ID=8751190

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*, 31–43. https://doi.org/10.1016/j.tsc.2018.10.002

Perkins, D. N. (1986). Thinking Frames. *Educational Leadership*, *43*(8), 4–10.

Psych, C., & Egenfeldt-Nielsen, P. S. S. (2007). Making sweet music: The Educational use of computer games. *Originaltitel:„Att Skapa Ljuv Musik: Det Pedagogiska Anvandandet Av Datorspel", Datorspelandets Dynamik*.

Rogers, S. (2014). *Level Up! The Guide to Great Video Game Design*. John Wiley & Sons.

Schrier, K. (2016). *Knowledge Games: How Playing Games Can Solve Problems, Create Insight, and Make Change*. JHU Press.

Squire, K. (2003). Video games in education. *International Journal of Intelligent Games & Simulation*, 49–62.

STAGE. (2022). *Projects | Scientists, Technologists and Artists Generating Exploration (STAGE)*. https://stage.pme.uchicago.edu/projects-8

Tekinbas, K. S., & Zimmerman, E. (2003). *Rules of Play: Game Design Fundamentals*. MIT Press.

Yanev, V. (2022, February). *Video Game Demographics—Who Plays Games in 2022*. Techjury. https://techjury.net/blog/video-game-demographics/