Casual Games and Casual Learning About Human Biological Systems

Article *in* Journal of Science Education and Technology · September 2015

DOI: 10.1007/s10956-015-9580-6

Claire Christensen
SRI International

Elham Beheshti
Northwestern University

J Sci Educ Technol
DOI 10.1007/s10956-015-9580-6

Casual Games and Casual Learning About Human Biological Systems

C. Aaron Price[1] · Katherine Gean[1] · Claire G. Christensen[2] · Elham Beheshti[3] · Bryn Pernot[1] · Gloria Segovia[1] · Halcyon Person[1] · Steven Beasley[1] · Patricia Ward[1]

Abstract Casual games are everywhere. People play them throughout life to pass the time, to engage in social interactions, and to learn. However, their simplicity and use in distraction-heavy environments can attenuate their potential for learning. This experimental study explored the effects playing an online, casual game has on awareness of human biological systems. Two hundred and forty-two children were given pretests at a Museum and posttests at home after playing either a treatment or control game. Also, 41 children were interviewed to explore deeper meanings behind the test results. Results show modest improvement in scientific attitudes, ability to identify human biological systems and in the children's ability to describe how those systems work together in real-world scenarios. Interviews reveal that children drew upon their prior school learning as they played the game. Also, on the surface they perceived the game as mainly entertainment but were easily able to discern learning outcomes when prompted. Implications for the design of casual games and how they can be used to enhance transfer of knowledge from the classroom to everyday life are discussed.

Electronic supplementary material The online version of this article (doi:10.1007/s10956-015-9580-6) contains supplementary material, which is available to authorized users.

✉ C. Aaron Price
aaron.price@alumni.tufts.edu; Aaron.price@msichicago.org

[1] Museum of Science and Industry, Chicago, 57th Street and Lake Shore Drive, Chicago, IL 60637-2093, USA

[2] Department of Psychology, University of Illinois at Chicago, 1007 W. Harrison St. (M/C 285), Chicago, IL 60607, USA

[3] Northwestern University, c/o TIDAL Lab, 2120 Campus Drive, Annenberg Hall (room 222), Evanston, IL 60208, USA

Keywords Serious games · Casual games · Biology education · Informal education · Museums

Introduction

For decades, educational (aka serious) games have promised to make learning fun. When they succeed, learners will play the games on their own free time. That is, games can be a tool to take learning out of the classroom and into everyday life.

Casual games are particularly well positioned to make that leap. Many educational, serious games turn off some learners because they are too complex and not entertaining enough (Leemkuil et al. 2000; Paul 2014). Casual games are simple enough to be played for a few minutes at a time, available on almost any digital media device, and have low barriers to entry. And they have been spectacularly successful in the marketplace. Transfer of learning from classrooms to everyday life is difficult (Georghiades 2000), partially because students often link what they learn with where (and with whom) they learn—making recall in other settings difficult (Godden and Baddeley 1975). By embedding learning in everyday activities, effective casual games may make learning more accessible outside of formal learning environments. Museums and other science centers that work mostly in the informal space have turned to casual games as a way to extend learning beyond the museum walls (Edwards and Schaller 2007).

The educational game industry sees casual gaming as the next horizon, with STEM content being particularly in demand (Portnow 2014). To date, there has been little research about the use of casual games in education (Litchfield et al. 2007). Math- and science-themed games, in particular, have been identified as specific areas where more research is needed (Young et al. 2012).

The focus of our study is an online, casual game developed to teach about the interconnectedness of human biological systems. We conducted an experimental study of 242 children who were randomly assigned to play either the studied game or a similar game with a different learning goal. Using pretest and posttest, we looked for differences in learning about biological systems and attitudes toward learning about human biology. We conducted follow-up interviews with 41 children to look for more in-depth understanding behind the test results. The research question was: "How does children's understanding of the body as a collection of interconnected systems change by playing a casual, online game about human biological systems?" Our results were analyzed with the knowledge integration framework (Linn 1995) and interpreted through the lens of situated cognition (Brown et al. 1989) and situated learning (Lave and Wenger 1991).

We begin with a literature review about educational and casual games, knowledge integration, situated cognition and transfer, and learning of human biological systems. We then discuss our methods, analysis, and results, using the interviews to extend the quantitative findings. Implications are drawn for educational game developers, science education researchers, and informal science education practitioners.

Literature Review

Educational and Casual Games

The educational potential of games in general has been studied for over half a century (Randel et al. 1992; Mitchell and Savill-Smith 2004; Buckingham 2013). In the last two decades, that focus has moved toward computer games as a powerful new resource to support children's learning (Gee 2005; Habgood and Ainsworth 2011; Linehan et al. 2011). In particular, digital game-based learning (Li and Tsai 2013), online game-based learning (Aldrich 2009), and science-based learning through digital games (Steinkuehler and Chmiel 2006) are all active research fields. Researchers argue that computer games can be effective educational tools by motivating children to learn and by supporting them through direct, structured experience with the lesson. However, despite these promises and the recent effort in developing game-based learning, there has been little success in determining generalizable design principles for effective educational games (Habgood and Ainsworth 2011; Linehan et al. 2011). One challenge is complexity—many factors determine the effectiveness of an educational game. For example, Gee (2005) argues that good games introduce well-ordered problems, are challenging, yet doable, and provide links between skills and strategies for playing the game. Other researchers have argued that to achieve both motivation and learning outcomes, good educational games should intrinsically integrate target learning objectives with the mechanics of game play (Habgood and Ainsworth 2011). In other words, the most engaging parts of the game should be where the learning happens. While most casual games are designed for fun, many of the most popular games have been designed and marketed to enhance learning and cognitive skills of the players (Ijsselsteijn et al. 2007; Kesler et al. 2011; Shute et al. 2015).

While games are valued by educators as ways to motivate learners (Pasnik and Llorente 2012), theory and research frameworks have just begun to examine and test the benefits and opportunities for learning through different *types* of digital games (Gee 2003). Studies of digital games are starting to differentiate between different game types such as massive multiplayer online games (Voulgari et al. 2014), simulations (Kapp 2012), and, more recently, educational "serious" games (Connolly et al. 2012). Differences in benefits between these games are often spoken of in terms of skill-based, social, and affective learning impacts (Squire 2007; Brown 2000). However, there is little research on how learning of scientific content differs between these game types (Mayo 2007; Pivec 2007; Squire et al. 2004).

One game category that has exploded in popularity in the last decade is casual games. Pac-Man, released in Japan in 1980, is often referenced as the first example of this category (Kohler 2010). Casual games differ from other types of studied games primarily because they usually consist of very short experience intervals and can be played in a wide variety of locations. Casual games are played for many reasons, most commonly as a form of entertainment and as a means to pass the time (Hjorth and Richardson 2009). Game sessions last, on average, less than half the time of non-casual games (Nielsen Company 2009). In 2009, over 200 million people played casual games and they made up about 17 % of the entire gaming marketplace (CGA 2013).

Casual Games and Informal Education Environments

Science museums, planetariums, and other science centers in the world annually engage over 90 million guests annually (Association of Science-Technology Centers 2013). Informal learning opportunities such as these account for almost half of the Americans self-reported understanding of science (Falk et al. 2007). Casual games are often used by science centers and museums to increase exhibit interactivity (Klopfer et al. 2005), help design new exhibits (Templeton 2013), and reach audiences beyond the museum's walls (Edwards and Schaller 2007; Birchall et al. 2012). They also act as instances of "play as practice" (Edwards 2013), making learning fun, even when associated with repetition and failure. Museum-based games can be categorized into two groups: *extrinsic* games that adopt popular game designs and apply museum content to them and *intrinsic* games consisting of unique game play tightly linked to the unique nature of the content (Schaller 2014). One of the first museum-created games was "Build a Fish" produced by the Shedd Aquarium in 2003 (Schaller and Principal 2005; Edwards 2013). As of November 2014, we identified about 76 currently available casual games produced by 18 museums or museum collaborations (Beheshti 2014).

Situated Learning and Transfer in Games

Learners strongly associate what they learn with the complex environment of where and with whom they learned it (Brown et al. 1989). Students have trouble remembered information acquired out of an authentic context (Gee 2003). Informal learning environments are more similar (in terms of structure and complexity) to settings learners encounter more often in life, potentially better preparing individuals to apply what they learn in future situations (Feder et al. 2009). As a result, educational games are often designed to create realistic learning environments (Kirk and MacPhail 2002). Van Eck (2006) said: "What you must learn [in an educational game] is directly related to the environment in which you learn and demonstrate it" (p. 4) and added that the important aspect of successful educational games is the specific elements of authenticity they try to embody. Despite this, in a review of the literature, Young et al. (2012) found no studies that included context as an element in the analysis of game impact. They said, "…the missing element [from existing research] may be a more sophisticated approach to understanding learning and game play in the rich contexts of home and school learning" (p. 84). Some games may be more effective in certain environments than others due to different dynamics and social rules in which the games are experienced (Ma et al. 2007). Leemkuil et al. (2000) identified complexity, surprise, role play, and representation as four important elements of game play strongly related to the situational nature of games. But in addition to the curriculum and game play aspects related to situated learning, game developers also need to consider the community and social structures involved in the game experience (Steinkuehler 2004).

Knowledge transfer is one of the most complex yet important issues for education, with no single approach or model emerging despite nearly a half century of research (Day and Goldstone 2012). Many different systems of transfer have been described for many different scenarios and situations (Schwartz et al. 2012). In many circumstances, transfer between everyday life experiences proceeds more efficiently than transfer in formal learning environments (Perkins and Salomon 2012). Authenticity in both game design and in the physical environment in which they are played can support the transfer of knowledge from the game to real life (Herrington et al. 2014). Successful transfer of game experiences to everyday life has been found to be related to the intensity of the game experience (Ortiz de Gortari et al. 2011) and the level of realistic immersion the player feels (Dede 2009). Other ways games affect transfer is through increased motivation (Martens et al. 2004; Perkins and Salomon 2012), interactivity (Herrington and Oliver 1997), and training learners to be flexible in their thought (Goldstone and Day 2012), such as providing players multiple variables to consider and multiple options on which to act. Casual games take all these elements of traditional game experiences and wrap them in a mobile package that can be played almost anywhere, thus adding a situated element to the experience and increasing the opportunity for transfer.

Learning About Human Biological Systems

Systems and system models have been identified as a crosscutting concept in the Next Generation Science Standards (NGSS 2014). Regarding biology, the Middle School Life Science section says students should learn that: "Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems" (p. 61). Young children learn about body systems mostly through direct experience, such as breathing, eating, and illness, rather than through formal education (Gellert 1962; Hatano and Inagaki 1997). By the time children are 8, they generally have a broad knowledge of internal organs but little knowledge about organ processes (Reiss and Tunnicliffe 2001). They begin to understand individual organs and systems by age 10 (Carey 1985; Mathai and Ramadas 2009; Garcia-Barros et al. 2011). College students generally had good knowledge of where organs were physically located within the body, but poor knowledge of their function and how they work together (Prokop and Fancovicová 2006). Understanding the behaviors and functions of a system requires an elaborate network of concepts and principles representing key phenomena and their interrelationships (Hmelo-Silver and Pfeffer 2004). In particular, causal relationships between structures are the most important, yet least accessible, part of complex systems (Hmelo-Silver et al. 2007). It is the interconnected link between complex systems that make them useful as crosscutting concepts, allowing educators to link biology to many other disciplines and vice versa.

Knowledge Integration

Knowledge integration is a perspective on knowing, learning, and assessment that focuses on helping students integrate understanding of a complex domain into broader, existing frameworks (Linn 1995; Linn and Hsi 2000). It is a constructive process, focusing on conceptual similarities rather than differences (Clark and Linn 2013). At its heart, it describes how students attempt to make sense of the world by fitting together all their knowledge and experiences—including educational, cultural, and observational. It has implications for epistemology through exploring how competing and incomplete concepts are reconciled and for ontology through this process ultimate effect on belief systems. Knowledge integration is well suited for the assessment of lifelong learning, like that associated with informal education environments, because it helps students become aware of their own learning process (Linn and Chiu 2011) which they can then modify throughout life. For assessment, it has been used as a flexible framework for analysis of concept maps (Liu and Wang 2010), drawings (Zhang and Linn 2011), interviews (Davis 2004), item selection tasks (Zhang and Linn 2013), and online discourse (Hoadley 2000). When used as a rubric to evaluate explanation answers following a multiple choice question, it has been found to be more sensitive to a wide range of responses than evaluating the multiple choice responses alone (Lee et al. 2011). The framework's flexible applications make it especially suitable for mixed-method studies in informal settings.

Methodology

Research Context

Code Fred: Survival Mode (hereafter Code Fred) is an online, casual educational game released in 2013 (Fig. 1). In the game, the player controls a character trying to survive in the woods while being pursued by a wolf. It consists of a series of 12 mini game-based around multiple crises that develop during the chase. The topics of the 12 mini games are distributed among four overarching scenarios: *strenuous exercise*, *severe trauma*, *infection*, and *starvation and digestion* (Table 1). The overall learning goal of the game is to represent individual body systems and processes, show how they are interconnected and interdependent, and help the player relate that information to their own body. As of December 31, 2014, it had been played approximately 1.26 million times. It won the 2013 American Alliance of Museum's MUSE Gold award for Games and Augmented Reality (MUSE 2013) and is categorized as an educational game on game aggregation Web sites such as Kongregate, Games for Change, and the Science Game Center. A similar game, Simple Machines, was chosen as the control. Simple Machines is also an online, casual educational game developed by the same museum and released in 2009. It has a similar scope and model to Code Fred in that the player must solve a series of mini games, based on Newtonian physics, following an overarching narrative (assembling pieces to help an engineer build a robot). Both games take about 10–15 min to complete. According to Schaller (2014)'s model of museum games, Code Fred qualifies as an extrinsic game because it uses a model popular in game design (a collection of puzzle-based mini games following a single narrative).

Procedures

The study consisted of pretest, posttest, and follow-up interviews. Two cohorts of children were recruited: one for the tests and one for the interviews. Recruitment for the study took place at a large, urban science museum on the south side of Chicago. The testing cohort was recruited from the Museum's public spaces via convenience sampling of children aged 7–12. They took a four-page pretest, while the parents filled out a demographic questionnaire. The children were compensated with a small science-themed toy for taking the pretest. The families were then given a handout with a URL to visit when they returned home. The URL pointed them to one of the two games:

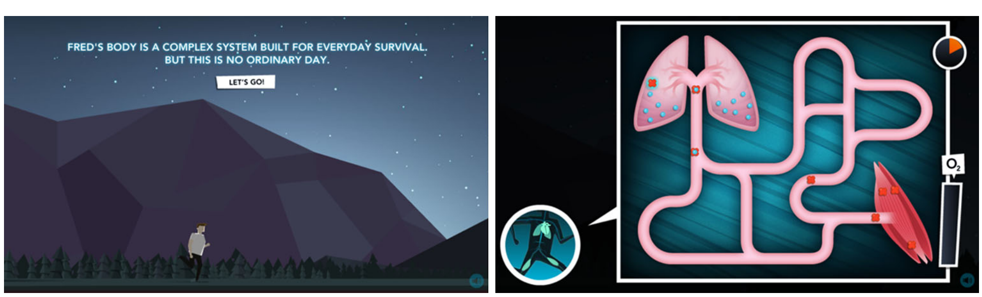

Fig. 1 Code Fred title page and example of a mini game layout

Table 1 List of mini games in Code Fred

Mini game	Scenario	Learning goal
Fight or flight response	Strenuous exercise	Hormones are tiny but very powerful. They are produced in one place and act at a distance on other organs or systems
Hemoglobin delivery	Strenuous exercise	Hemoglobin binds to oxygen in the blood and delivers it to muscles
Pump it up: heart and lung	Strenuous exercise	Heart rate is directly tied to how much oxygen is available to muscles, because O_2 is delivered in the blood that circulates faster or slower depending on the heart rate
Vasculature, losing blood	Severe trauma	After trauma, the nervous system triggers blood vessels to constrict to slow the blood loss
Clotting cascade	Severe trauma	Many body systems are involved in forming a blood clot
Nerve regeneration	Severe trauma	Severed nerves regenerate toward their matching ends to heal
Mechanical barriers/ Cilia	Infection	The body has mechanisms to get bacteria and foreign bodies out before they cause an infection
Phagocytosis	Infection	Phagocytes "eat" bacteria and foreign bodies and alert the immune system to fight an infection
Lymphocytes	Infection	The immune system uses specialized defenses to attack infections
Balance protein breakdown	Starvation and digestion	Protein breakdown is the last source of metabolism when all energy stores have been exhausted. The brain and heart are the most energy "hungry" organs
Digestion process	Starvation and digestion	Understand that nutrients are absorbed in the digestive tract
Balancing the digestion process	Starvation and digestion	The pancreas and the liver work to keep the blood sugar level balanced

Code Fred or Simple Machines. Game assignment was randomly determined but was weighted 2:1 in favor of Code Fred. When they visited the URL, it directed them to play the game after which it forwarded them to a subsequent URL with the posttest. After filling out the posttest, they were rewarded with a $10 Amazon gift card that was e-mailed to them.

In total, 242 children took the pretest and 127 took the posttest (81 of whom played Code Fred and 46 played Simple Machines). According to parental reporting, 62 % were male and 37 % female, with 1 % unreported. The average age of study participants was 11.8 years old (SD = 1.5). There was no significant difference between the ages of the male and female children. Parents reported that their children played an average of 2.3 h of video games per weekday during the summer. Of them, the male children spent an average of 2.8 h per summer weekday playing video games, while female children spent 1.5 h, a difference that was statistically significant according to a *t* test, $t(264) = 6.93$, $p \leq .001$. About 82 % of parents identified their children as white (not Hispanic), 6 % as African-American, 4 % as Hispanic (includes Mexican and Puerto Rican), and 8 % as other ethnicities.

Forty-one interviews were conducted at a table in a public space. According to the parent demographic surveys, 56 % of these participants were male and 44 % were female. The average age was approximately 11.7 years old (SD = 1.4). Approximately 80 % of parents identified their children as white (non-Hispanic), 10 % Hispanic (includes Puerto Rican, Mexican, and "other" self-identified as Latino), 5 % African-American, 2 % Korean, and 2 % checked multiple answers.

The interview cohort was similarly recruited from the Museum's public spaces. However, instead of taking tests they were allowed to play Code Fred until either they completed it or 15 min had passed. Then, they participated in a semistructured interview. Children in the interview cohort were compensated with a Museum gift card for participation.

Instruments

The pretest consisted of nine items. The first four were Likert-scale items about attitudes toward knowledge of the human body (Table 2). These items used a five-point scale ranging from "Strongly Disagree" to "Strongly Agree" or "Very Tough" to "Very Fragile." The next question asked them to "…give an example of a 'system'" (hereafter "System Definition"). The next four items were open-ended questions based on scenarios of the game (Table 3—hereafter "Scenario Items"). The structure of each of these items was the same. The player was presented with five icons of bodily systems, chosen from images used in the game. The player was then given a real-world scenario similar to one from the game and, as a scaffold, was asked to circle any number of icons representing bodily systems

Table 2 Descriptive statistics for the attitude items

Item	Scale	Pretest				Posttest			
		Code Fred		Simple Machines		Code Fred		Simple Machines	
		N	Median	*N*	Median	*N*	Median	*N*	Median
"I know about what is happening inside my body"	SA[a]	15	4	5	3.5	16	4	3	4
	A	28		18		38		24	
	N	23		15		23		10	
	D	13		5		3		5	
	SD	1		2		1		4	
"I want to learn more about what is happening inside my body"	SA	15	3	7	3	15	4	12	4
	A	24		12		39		15	
	N	20		13		23		13	
	D	17		8		2		0	
	SD	5		6		2		6	
"It is important to know what is happening inside my body"	SA	45	5	28	5	37	4	17	4
	A	22		12		38		24	
	N	9		3		5		4	
	D	2		3		0		0	
	SD	1		0		1		1	
"My body is…"	VT[b]	11	4	7	3	8	4	6	3.5
	T	34		12		34		17	
	N	28		23		27		19	
	F	7		3		11		1	
	VF	1		1		1		3	

[a] Strongly agree, agree, neutral, disagree, strongly disagree

[b] Very tough, tough, neutral, fragile, very fragile

Table 3 Scenario items and inter-rater reliability

Scenario	Item description	IRR (*K*)
Strenuous exercise	Someone is running in a race	.68
Severe trauma	Someone fell off a bike and received a large cut	.69
Infection	A person sits next to a stranger at a movie theater. The stranger is sick and coughs during the movie	.73
Starvation and digestion	Someone is really hungry so takes a break to eat a snack	.66

related to the scenario. Finally, they were asked to explain how the circled items would work together in that scenario. The posttest was identical to the pretest except that it was given online instead of via paper. The same item wording, order, and imagery were used in both tests. The parental demographic survey asked about age, gender, race, and video game-playing habits (for example, "On a day like today, how many hours would your child normally spend playing video games?") of their children.

The interview guide (available as Online Supplemental Material) included cognitive interview, or "concurrent think-aloud" questions (Groves et al. 2004) and photo-elicitation methods (Harper 2002). To better understand the unique results found on the quantitative study, the children were asked to explain their thought processes when answering questions taken directly from the scenario items on the test. The icons used in the scenario items were used as prompts to uncover the children's knowledge levels of the different parts of the body. Following the cognitive interview questions, the children were shown screen shots from different mini games. They were asked whether they recalled the game and, if so, to describe what was happening in that specific mini game. Two image decks were created containing five different mini game screen shots per deck, and the children were randomly shown one of the decks. Interviewers asked similar follow-up questions for each item on the interview. The probe questions primarily focused on recall, content knowledge, learning, and sources of preexisting, game-related knowledge. Interviews lasted from 10 to 12 min.

Analysis

Comparison of pretest and posttest results is limited to only the subjects who took both tests. Of those, 81 children played Code Fred and 45 played Simple Machines. The first stage of the analysis was to compare age, gender, and racial distributions of the control and treatment groups to ensure compatibility. Age and gender were compared with t tests, while racial distribution was compared with a Chi-square test. Significance was set prior to analysis at the $p = .05$ level. The next stage of our analysis compared the responses on the four attitude items. Because the Likert scale is not interval based and distributions were not normally distributed, we used the nonparametric Wilcoxon signed-rank test.

The System Definition responses were coded by placing the response into one of four categories: (1) a commonly accepted named human biological system (cardiovascular, digestive, endocrine, immune/lymphatic, integumentary, muscular, nervous, reproductive, respiratory, skeletal, urinary), (2) a non-human biological system (e.g., solar system), (3) those who provided a type of definition of the word “system” (e.g., “A group of parts that work together to perform a task”), and (4) all other responses. Comparisons were independently tested between the pretest and posttest groups of the Code Fred and Simple Machines cohorts using descriptive and Chi-square statistics.

For the scenario items, we only looked at the explanations and did not analyze the circled icons. The explanations were coded by two separate researchers using a rubric based on the knowledge integration framework (Linn et al. 2006) (Table 4), which posits that learning in a written explanation is best reflected by connections between thoughts. The knowledge integration framework and Code Fred are synergistic because they both involve teaching and learning about and through interconnected systems. We felt this was especially aligned with the game’s learning goals which were about understanding how the human body’s systems work together. In general, the researchers looked for how well the player connected the various bodily systems. Inter-rater reliability was measured with Cohen’s kappa statistic, which is considered a conservative measure because it accounts for the fact that the two coders may occasionally agree due to chance. Since we had a small number of categories, we felt it was important to apply a conservative metric. In general practice, 0.75 or higher is often considered *excellent agreement* and 0.40 or lower is often considered *poor agreement* (Banerjee et al. 1999). Our lowest IRR was $K = .66$ (Table 3). Finally, a composite score for the scenario items was created by averaging the scores on the four items.

Differences between groups on the scenario items were tested using repeated-measures ANOVAs. The scores on each scenario item were used as the dependent variable and the game played (Code Fred was assigned a code of 1 and Simple Machines assigned a code of 2) as between-group measure. To test for effects of age, gender, and game-playing habits, we first created dichotomous variables using the split mean method (0 assigned to the bottom half and 1 assigned to the top half) for the age and game-playing habits variables. We then ran a repeated-measures ANCOVA using the same procedure as before except with gender, age dichotomous and game-playing habits dichotomous variables entered as covariates. All statistics were run with SPSS 19.

Interview transcripts were visually inspected and loaded into the Atlas.ti software for analysis. A code structure was created to look for specific categories of responses that may shed light on some of the test results. Specifically, we looked for sources of prior knowledge, deeper understanding behind results of the strenuous exercise scenario item, and whether the children considered the game as mostly educational or entertainment. Each of the coding categories was coded by one member of the research team.

Interviews were also analyzed to look at how children perceived the narrative and educational content of the game. To explore this, we analyzed participants’ descriptions of Code Fred content as a lens into how they perceived the game as a whole. We looked at their responses to the questions of “What is this game (or mini game) about?” “What is this game (or mini game) trying to teach you?” and “What did you learn from this game (or mini game)?” We assumed that children who were able to describe a clear, complete lesson associated with Code Fred were better able to process Code Fred’s educational content than those who could not describe a clear lesson. We conducted a binomial logistic regression analysis to explore age and gender as potential predictors of their ability to describe a lesson. We also included two control variables in the regression: mini game scenarios described and number of mini games covered in the interview. While each interview guide included five mini games, some interviews covered fewer mini games, typically due to time restrictions. We developed five codes to describe participants’ statements about lessons in Code Fred (Table 5). Each interview question was asked repeatedly during the interview, in reference to both Code Fred as a whole and to

Table 4 Coding rubric for open-ended responses to the scenario items

Knowledge integration level (Code)	Description	Example
Full (4) Children understand how two scientific concepts interact in a given context	Elaborate a scientifically valid link between two ideas relevant to a given context	"The lungs bring oxygen to the blood and the heart moves the oxygenated blood to the muscles"
Partial (3) Children recognize potential connections between concepts but cannot elaborate the nature of the connection specific to a given context	Have relevant ideas but only mention a link without elaborating on it	"Lungs and heart work together to get blood flowing so your body will be active"
	Explicitly mentioning two ideas as linked/working together/etc.	"The respiratory gets air to the circulatory and the circulatory gets blood to the body"
		"They both store nutrients"
Isolated (2) Children have relevant ideas but do not connect them in a given context	Have relevant ideas but fail to recognize links between them	"The heart beats quickly to help you move. Your lungs make you breath"
	Make links between relevant and irrelevant ideas	"Platelets cover the wound. The liver cleans the blood"
Irrelevant (1) Students have irrelevant ideas in a given context.	Have incorrect or irrelevant ideas	"Antibodies stop bleeding"
Unknown (0) Students do not offer a relevant idea, but recognize a lack of ability to respond	Awareness of lack of ideas	"I don't know" "?"
Missing Data (.)	No legible response is provided	Blank response or gibberish

several mini games within Code Fred. Thus, a participant's response of "I don't know," for example, does not necessarily indicate that he or she is uncertain about Code Fred as a whole. Rather, he or she could be responding about one particular mini game. Each participant's interview transcript received multiple codes from a single researcher. We further coded each generalizable lesson using three subcodes to better describe the types of lessons participants reported. About one-third of participants described a lesson unrelated to the educational content in Code Fred—typically a lesson about first aid. Most participants provided at least one unarticulated lesson—a lesson that did not include a complete fact.

Results

The two cohorts were demographically similar. We found no significant differences between the Code Fred and Simple Machines cohorts in terms of gender, $t(124) = 1.09$, $p = .278$, age, $t(124) = -.613$, $p = 541$, game-playing habits, $t(121) = .725$, $p = .470$, or race, $\chi^2 = .653$, $p = .419$.

Attitude

The attitude items were all slightly positively skewed for both groups on both the pretest and the posttest. Two items, "I know what is happening inside my body" and "I want to learn more about what is happening inside my body," showed statistically significant differences between the pretest and posttests, $Z = -2.13$, $p < .05$, and $Z = -4.06$, $p < .001$, respectively. In both cases, the differences were mostly manifested as positive changes in agreement with the middle three categories of the scales, while the extreme categories of the scales showed less change. The items "It is important to know what is happening inside my body" and "My body is… [tough or fragile]" both did not show any difference between tests. Among all groups and all tests, no item scored below a median of 3, and there were no major differences between the Code Fred and Simple Machines groups.

System Definition

The System Definition responses for both cohorts were highest for the human biological systems category for both the pretest and posttest (Fig. 2). There was a significant drop between that category and the second highest response category, Parts of a Human Biological System. There was little difference between the Code Fred and Simple Machines cohorts on the pretest. However, on the posttest the Code Fred cohort was more likely to give a human biological system as their response, while the Simple Machines cohort tended to give the same responses as the pretest. The increase in the human biological system response for the Code Fred group can largely be attributed

Table 5 Codes derived from participants' descriptions of Code Fred content

Code	Definition	Example
Don't know	The participant says he or she does not know	**I:** Okay. Great. What do you think the mini game was trying to teach you? **R6:** I don't know
Didn't learn	A denial of learning from Code Fred	**I:** Okay and did you learn anything new about that process by playing Code Fred? **R30:** No
Game play	A description of the game itself—the storyline or actions required of players	**I:** Okay so what was that mini game about? **R41:** You had to send the adrenaline to the eyes, hearts… heart, and liver to keep him running
Game situations	A lesson specific to the situations depicted in Code Fred	**I:** Oh yes, um what would you tell a friend that this game is about? **R29:** It's about your organs in your body and you're learning how like if you ever get your leg hurt if you're out camping how you would uh like do stuff to help it get better
Generalizable lesson	A lesson that would make sense outside of game-related contexts (e.g., game play, game situations)	**I:** Okay, so yeah! No, what did you think the mini game was trying to teach you? **R1:** That um, that ummm.. I guess the lungs, um.. help deliver the I- yeah the lungs help deliver the oxygen
Generalizable lesson subcodes		
Unrelated lesson	A lesson that could not have been learned from playing Code Fred	**I:** Okay, great. And what do you think it was trying to teach you? **R19:** It was trying to teach you like never to do something bad with your leg on purpose so that you can get like sympathy for it
Unarticulated lesson	A lesson that does not include a complete statement of fact	**I:** Ok. Cool, so do you have an idea of what that mini game might have been trying to teach you? **R9:** Um… maybe like something connecting to another thing so some part of your body works
Clear lesson	A stand-alone message about the human body that could have been learned in Code Fred	**I:** Okay, so what do you think it was trying to teach you? **R20:** That the proteins are fuel for the organs and they need the proteins or they'll stop working

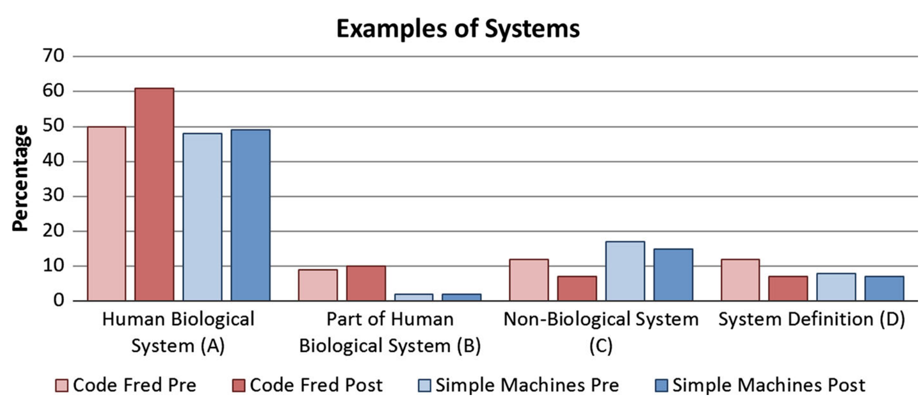

Fig. 2 Categorized counts for examples of systems provided by children

to decreases in the non-biological system and System Definition categories.

Most of the increase in named human biological systems is due to additional listings of the digestive and respiratory systems. The respiratory system is the only system name that is specifically mentioned in the game. The digestive system, while not mentioned, is the topic of the last mini game of Code Fred. When asked why one question was easier to answer, responses suggest that some children found it easier to answer posttest questions about topics they most recently saw in the game, even when the subject matter was more difficult. For example, two children commented on how temporal proximity to the salient feature of the game was related to their ability to answer questions about it:

I Why would you say that question… was harder for you to answer?
C1 Um, I think it was because it was farther along, like at the beginning of the game and so it wasn't as fresh in my memory…
I Can you tell me why it made it easy [to answer]?
C2 Well, because in the game, I just did it. I sort of like a couple levels back and I sort of remembered it.

Scenario Items

The Code Fred group showed increased scoring on the posttest compared to that of the Simple Machines group. First, a comparison of the pretest data between the groups found no differences on any scenario item at the $p = .05$ level, suggesting no differences in the background knowledge between the two groups. Next, our analysis of the pretest and posttest found significant differences on the severe trauma, infection, and starvation and digestion items (Tables 6, 7). All show much more positive increases between the pretest and the posttest for the Code Fred children versus smaller positive increases in the Simple Machines cohort. The slight control group increase could be due to the fact that the posttests were likely taken in an environment where children could better concentrate, or had parental assistance. Yet, the pretest and posttest differences remain statistically significant when the control group differences were included in the analysis. When comparing composite scores, gender and game-playing habits were not significant predictors (Table 8). However, age was significantly related.

One of the scenario items, strenuous exercise, did not show a significant improvement between the tests when accounting for the control group differences. This could be due to the fact that it scored so highly on the pretest, as opposed to the other scenario items. In the interviews, 36 of the 41 children stated that they had previously heard of or knew about the content of the strenuous exercise mini games. Mostly, this was because the organs and systems involved in strenuous exercise were more familiar to the children, mainly the eyes, lungs, and heart. On the other hand, only 25 had referenced prior knowledge related to

Table 7 Repeated-measures analysis of variables of pretest and posttest scenario item scores

	N	MS	*df*	Err	*F*	*p*	η_p^2
Strenuous exercise	76	2.54	1	101	2.36	.128	.02
Severe trauma	71	1.58	1	97	24.85	***	.20
Infection	66	1.32	1	94	11.33	***	.11
Starvation and digestion	63	1.33	1	90	9.22	***	.09

*** $p < .001$

Table 8 Repeated-measures analysis of covariance of pretest and posttest scenario composite scores

	df	MS	*F*	*p*
Within-subjects effects				
Time	1	1.31	3.92	.051
Time × game	1	3.26	9.77	**
Time × age	1	.497	1.49	.226
Time × gender	1	.011	.034	.854
Time × game-playing habits	1	.008	.024	.877
Error	81			
Between-subjects effects				
Intercept	1	23.31	46.55	***
Game	1	11.28	22.52	***
Age	1	11.12	22.2	***
Gender	1	.246	.491	.49
Game-playing habits	1	.423	.846	.36
Error	81			

** $p < .01$

*** $p < .001$

Table 6 Descriptive statistics for codes on the scenario items

	Pre test						Post test					
	Code Fred			Simple Machines			Code Fred			Simple Machines		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
Strenuous exercise	76	2.54	1.08	32	2.38	1.04	76	2.61	.834	33	2.27	1.10
Severe trauma**	71	1.58	1.09	31	1.26	1.03	76	2.72	.776	31	1.52	.962
Infection**	66	1.32	.995	33	1.09	1.01	74	2.38	1.00	31	1.48	.962
Starvation and digestion**	63	1.33	1.00	31	1.10	1.11	75	2.12	.958	31	1.26	1.09

** $p < .01$

the infection scenario, 22 children referenced knowledge related to the severe trauma scenario, and 21 had prior knowledge related to starvation and digestion. We specifically looked for evidence that one reason the strenuous exercise item scored higher on the pretest was because children were likely to have experienced it often during sports and play. However, we found no consistent evidence of this in the interview responses.

In the interviews, children were asked whether they had prior knowledge of the content of the game and, if so, about their recall of the source of that knowledge. Responses were coded into eight categories, and children were allowed to report more than one source of knowledge. By far, the most commonly recalled source of knowledge was school (Table 9). Seventeen children reported background knowledge in all scenario subject areas, and all children had background knowledge in at least one subject area. Thirty-six of the 41 children indicated that they had previously learned about the subject matter in school. Specific examples include:

C4 I had learned about the heart a little bit in school so I knew a little bit about it and how the body needs oxygen and stuff…

The non-school sources of knowledge varied widely with no single dominant source. Example responses include:

C5 It was doing that because um you had to give him eyesight and um the um get his uh heart uh beating faster I think and getting oxygen to the lungs to get in breathing not as heavy.
I Okay and had you learned anything about that topic before playing the game today?
C5 Um just a little bit.
I Okay and where did you learn that?
C5 Um well my my grandparents are actually um they used to be doctors. My grandma was a nurse so sometimes uh they taught me a bit about the body and how stuff like that works.

C6 I have experience from running because, um, I am the fastest in my class. And I could see how these things work together.

Narrative or Educational Experiences

The interviews were also used to investigate how children perceived the game—as either educational or entertainment. All participants were able to describe a generalizable lesson associated with Code Fred, and for most participants that lesson was a clear statement of a complete fact. Twenty-nine participants described at least one clear lesson associated with Code Fred content; the remaining 12 all provided unarticulated lessons. Neither age nor gender predicted the likelihood that a participant would describe a clear lesson from Code Fred (Table 10). One of our control variables, number of mini games covered in the interview, was a significant predictor; for every one additional mini game covered in his or her interview, a participant was nearly four times more likely to describe a clear lesson.

Discussion

Casual games, by their definition, tend to be shorter and less experiential than more serious games. With such limited dosage and so many distractions while playing them, is it realistic to expect a casual game to have an impact on learning? Van Eck (2006) said: “Not all games will be equally effective at all levels of learning.” In this case, children who played Code Fred learned more about how human biological systems relate to each other while also showing slightly improved attitudes and interests in learning more about human biology. Interviews suggest the learning is based on children’s increased ability to recall prior knowledge. While some studies have shown a positive relationship between game intensity and transfer (Ortiz de Gortari et al. 2011), our study shows that even less

Table 9 Sources of prior knowledge reported by children

Source of knowledge ($N = 41$)	Strenuous exercise (%)	Infection (%)	Severe trauma (%)	Starvation and digestion (%)
School/formal education	71	49	20	32
Books	7	2	0	0
Common knowledge	7	2	0	0
Family member	10	2	7	2
Television show	2	0	2	2
Out of school organization	2	2	5	2
Personal experience	10	2	5	5
A doctor	0	2	0	0

Percentages do not equal 100 % because respondents indicated more than one source for some subject areas

Table 10 Logistic binomial regression predicting the likelihood that participants will describe a clear lesson from Code Fred

Predictor	Odds ratio	Lower CI	Upper CI
Age	0.965	0.520	1.79
Gender	0.363	0.07	1.82
Screen shot set	0.545	0.08	3.85
Mini games covered	3.855*	1.39	10.692

All estimates are adjusted for all other listed variables

* $p < .05$

intense game experiences can also support transfer of knowledge from the classroom.

Learning About Human Biological Systems

The change in the attitude items can be seen as reflecting increased motivation. The magnitude of the change was limited due to a ceiling effect in the data, likely caused by predispositions of the children to already be motivated by science. Yet we still saw an increase in interest to learn more about the human body along with an increase in confidence of their current knowledge.

When asked to list examples of systems, children were more likely to list commonly accepted names of human biological systems after playing Code Fred. This was surprising since the game only specifically mentions one human biological system ("respiratory"). So it is likely the game is cueing the child to be thinking about the topic of human biology in general. But where did the specific listed names come from? Interviews show that school was the most commonly referenced source of prior knowledge. For most children, the game stimulated recall and application of something learned in the classroom. Given the complexities in the issue of transfer in education (Day and Goldstone 2012), this is a positive example of how learning can span the formal and informal divide using a simple application. The other referenced sources of prior knowledge are widely distributed, suggesting no other dominant source of prior knowledge. However, recall of the source of prior knowledge is often biased toward the first place that person had been introduced to the subject, and does not rule out additional learning that takes place after the initial exposure (Falk and Needham 2011).

The scenario items allowed the children to demonstrate a more in-depth understanding of how human biological systems work together. The relationships *between* biological systems are the most important, and difficult, to teach (Hmelo-Silver et al. 2007) with even college students showing difficulty in understanding them (Kurt et al. 2013; Prokop and Fancovicová 2006). The fact that strenuous exercise was the highest scoring item on the pretest is likely due to respiration being the biological system most accessible to children (Bartoszeck et al. 2011). The increases in the children's ability to connect systems were limited. Mostly, our studied children went from not being able to connect systems at all to being able to make partial connections between systems. Very few children were able to make complex connections. This could reflect the limits of the educational impact of the short duration and simple design of casual games such as Code Fred. Casual games may introduce new concepts and stimulate recall, but are generally not likely to foster complex learning when used alone in complex environments. Serious games of any type are most often seen as stand-alone learning tools and studied accordingly, while they should be studied in the context of school and social environment in which they are being used (Young et al. 2012). Our results shed light on how children make those connections on their own when playing in an informal learning environment, such as home. Some of the advantages of casual games may also apply to games played as part of online courses (Downes 2010) or games played as homework, since they are physically played outside of the classroom. However, other characteristics of those games often reflect more sophisticated design and learning goals. An interesting follow-up study may want to explore the importance of the game's context versus physical environment where it is played.

Bridging the Informal and Formal Learning Gap

What was it about Code Fred that cued children to recall school-based knowledge? Since learning is situated in the environment, one possibility is that the educational content of the game put the child in an educational state of mind. That, in turn, allowed them easier mental access to what they learned in the classroom. "Games require transfer of learning from other venues—life, school, and other games. Being able to see the connection and transfer existing learning to a unique situation is part of game play" (p. 2) (Oblinger 2006). Research into game design has begun to identify characteristics that have been related to successful computer-based learning environments (Herrington and Oliver 1995; Linn et al. 2004). Many of these design elements exist in Code Fred. Among the principles are the use of authentic activities (in Code Fred, the mini game scenarios reflect real-life situations most game players have experienced—such as sneezing or experiencing a skin abrasion), authentic context (the game's narrative involves being chased by an animal—something that has occurred to most people at least once in their lives), and tight integration of the narrative with learning content. Together they affect motivation (Martens et al. 2004), which also increases the likelihood of transfer (Perkins and Salomon 2012). Another game design characteristic supportive of learning is the opportunity for reflection (Herrington and Oliver 1997), an operational form of metacognition, which has also been shown to support successful transfer (Georghiades 2004). Casual games do not usually offer the opportunity to thoughtfully reflect on your experience within the game itself. However, they do often require large amounts of repetition as stages get replayed until they are passed. This repetition is a type of reflection because the player must take what they did in the prior experience and built upon/improve it through conscious experimentation. Together, increased motivation and reflection present in casual gaming may provide the child with enough support to dig deeper into their mind and connect the game play with prior learning.

Education Through Entertainment

Learning is inherently tied to goals and purpose (Morris et al. 1977, cited by Lobato 2012). For serious games, goals and purpose can sometimes be divergent (Mitchell and Savill-Smith 2004). The purpose is often to educate, while the goal is to win the game (or have fun). This dilemma challenges all designers of serious games. In Code Fred, the narrative and educational content are closely linked. That is, the mini games stem directly from and advance the storyline about Fred's survival. Fisch (2000) posits that when educational and narrative content is closely related, mental effort to comprehend the narrative can also facilitate comprehension of the lesson. In those cases, the effort is not split between the narrative and the lesson, but rather is working toward a singular goal. Code Fred is not described as an educational game anywhere in the game itself or in any of the marketing materials associated with it. About a fifth of the children interviewed initially claimed to have learned nothing playing Code Fred, yet all of the children were able to describe a generalizable lesson when prompted. This suggests that there was not a wide divide between the goals (narrative) and purpose (learning outcomes). Investigation of the social aspects of casual gaming (both in terms of effect on design and also on the game play experience itself) would likely shed significant light on how these games are perceived by the children. While playing a casual game is usually a solitary experience, isolated learning can still be social due to all the abstract layers of social decision making that informed the experience (Oblinger 2006).

Limitations and Future Work

This study has a number of limitations, many of which could be addressed in future work. First, a subsequent study of casual educational games outside of a public science center will help generalizability. Also, more difficult to endorse items would have supported a more sensitive analysis. We attempted some forms of in-game assessment, such as using play-aloud techniques, but found they interfered with game play—mainly because most puzzles are time based. In the future, use of embedded "stealth" assessment in games would provide higher-resolution data to support more complex analysis (Shute and Ke 2012). Also, the posttest was taken at home. While that adds to the study's validity, it is possible children enlisted parental or other help to answer questions. Our control group should account for these effects, but it is still possible that effects unique to one of the two games could have survived the analysis. Future studies could look at delayed impacts as better measures of reliable transfer (Georghiades 2000). Finally, few people play a casual game only once. Further studies on the effect of repetition on learning may help identify ways that casual games can have more sophisticated impacts on learning than what was found in this study.

Conclusion

This study shows how a casual game helped children draw upon prior knowledge they learned in the classroom and apply it to a real-world problem in a non-school setting. The NRC recommends an ecological approach to informal learning in order to frame a continual learning environment (Feder et al. 2009). Casual games can do just that since they are, by their nature, embedded into place and culture and acting as a bridge between informal and formal learning. In informal education, there is room for short duration, simple concept experiences, such as those provided by casual educational games, as a part of a "…balanced media diet… to develop a complete profile of cognitive skills" (p. 69) (Greenfield 2009). As with most forms of educational technology, learning games should be made as simple as possible for the task at hand. Game designers can default to the more parsimonious side of game design and yet still expect serious learning from a not so serious game. Researchers may want to look more deeply into what types of cues are most useful to promote recall of prior knowledge when playing games. Also, in situ and embedded assessment would provide a more closer look at the relationship between game play and the social and environment setting the player resides in. Finally, educators may want to look at serious games as a way to build bridges between formal and informal experiences.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

References

Aldrich C (2009) Learning online with games, simulations, and virtual worlds: strategies for online instruction, vol 23. Wiley, San Francisco

Association of Science Technology Centers (2008) Features included in combination ticket. *2008 ASTC sourcebook of statistics and analysis*. Association of Science-Technology Centers, Washington, DC

Banerjee M, Capozzoli M, McSweeney L, Sinha D (1999) Beyond kappa: a review of interrater agreement measures. Can J Stat 27(1):3–23

Bartoszeck AB, Machado DZ, Amann-Gainotti M (2011) Graphic representation of organs and organ systems: psychological view and developmental patterns. Eurasia J Math Sci Technol Educ 7(1):41–51

Beheshti E (2014) Museum casual games. Retrieved from https://docs.google.com/a/u.northwestern.edu/spreadsheets/d/17vbvTy2dD4gQhAdUFyYRDJXs0VHr4yVd3IBu4MMRde4/edit?usp=sharing

Birchall D, Goldman KH, Evans D, Henson M (2012) Leveling up: towards best practice in evaluating museum games. In: Paper presented at the 16th annual museums and the web conference, San Diego, CA. Retrieved from http://www.museumsandtheweb.com/mw2012/papers/levelling_up_towards_best_practice_in_evaluati.html

Brown JS (2000) Growing up: digital: how the web changes work, education, and the ways people learn. Change Mag High Learn 32(2):11–20

Brown JS, Collins A, Duguid P (1989) Situated cognition and the culture of learning. Educ Res 18(1):32–42

Buckingham D (2013) Beyond technology: children's learning in the age of digital culture. Wiley, New York

Carey S (1985) The human body. In: Conceptual change in childhood. Bradford Books, MIT Press, Cambridge, MA

Casual Games Association (CGA) (2013) Smartphone and Tablet Gaming 2013 Games Market Sector Report. Retrieved August 24, 2015 from http://www.newzoo.com/trend-reports/free-casual-games-association-sector-report-smartphone-tablet-gaming-2013/

Clark DB, Linn MC (2013) The knowledge integration perspective: connections across research and education. In: International handbook of research on conceptual change, pp 520–538

Connolly TM, Boyle EA, MacArthur E, Hainey T, Boyle JM (2012) A systematic literature review of empirical evidence on computer games and serious games. Comput Educ 59(2):661–686

Davis EA (2004) Knowledge integration in science teaching: analysing teachers' knowledge development. Res Sci Educ 34(1):21–53

Day SB, Goldstone RL (2012) The import of knowledge export: connecting findings and theories of transfer of learning. Educ Psychol 47(3):153–176

Dede C (2009) Immersive interfaces for engagement and learning. Science 323(5910):66–69

Downes S (2010) New technology supporting informal learning. J Emerg Technol Web Intell 2(1):27–33

Edwards SE (2013) What museums learn by building games—serious play conference 2013 in Redmond, WA [Online presentation document]. Retrieved from http://www.slideshare.net/jolifanta/what-museums-learn-by-making-games-serious-play-conference-2013

Edwards SE, Schaller DT (2007) The name of the game: museums and digital learning games. In: Din H, Hecht P (eds) The digital museum: a think guide. American Association of Museums, Washington, DC, pp 97–108

Falk JH, Needham MD (2011) Measuring the impact of a science center on its community. J Res Sci Teach 48(1):1–12

Falk JH, Storksdieck M, Dierking LD (2007) Investigating public science interest and understanding: evidence for the importance of free-choice learning. Public Underst Sci 16(4):455–469

Feder MA, Shouse AW, Lewenstein B, Bell P (eds) (2009) Learning science in informal environments: people, places, and pursuits. National Academies Press, Washington, DC

Fisch SM (2000) A capacity model of children's comprehension of educational content on television. Media Psychol 2(1):63–91

Garcia-Barros S, Martínez-Losada C, Garrido M (2011) What do children aged four to seven know about the digestive system and the respiratory system of the human being and of other animals? Int J Sci Educ 33(15):2095–2122

Gee JP (2003) What video games have to teach us about learning and literacy. Comput Entertain CIE 1(1):1–4

Gee JP (2005) Learning by design: good video games as learning machines. E-learning 2(1):5–16

Gellert E (1962) Children's conceptions of the content and functions of the human body. Genet Psychol Monogr 65:93–405

Georghiades P (2000) Beyond conceptual change learning in science education: focusing on transfer, durability and metacognition. Educ Res 42(2):119–139

Georghiades P (2004) Making pupils' conceptions of electricity more durable by means of situated metacognition. Int J Sci Educ 26(1):85–99

Godden DR, Baddeley AD (1975) Context-dependent memory in two natural environments: on land and underwater. Brit J Psychol 66(3):325–331

Goldstone RL, Day SB (2012) Introduction to "new conceptualizations of transfer of learning". Educ Psychol 47(3):149–152

Greenfield PM (2009) Technology and informal education: what is taught, what is learned. Science 323(5910):69–71

Groves RM, Fowler FJ Jr, Couper MP, Lepkowski JM, Singer E, Tourangeau R (2004) Survey methodology. Wiley, Hoboken

Habgood MPJ, Ainsworth SE (2011) Motivating children to learn effectively: exploring the value of intrinsic integration in educational games. J Learn Sci 20(2):169–206

Harper D (2002) Talking about pictures: a case for photo elicitation. Visual Stud 17(1):13–26

Hatano G, Inagaki K (1997) Qualitative changes in intuitive biology. Eur J Psychol Educ 12(2):111–130

Herrington J, Oliver R (1995) Critical characteristics of situated learning: Implications for the instructional design of multimedia. In: Paper presented at ASCILITE 1995 conference, Melbourne, Australia. Retrieved from http://researchrepository.murdoch.edu.au/7189

Herrington J, Oliver R (1997) Multimedia, magic and the way students respond to a situated learning environment. Aust J Educ Technol 13(2):127–143

Herrington J, Reeves TC, Oliver R (2014) Authentic learning environments. Springer, New York, pp 401–412

Hjorth L, Richardson I (2009) Playing the waiting game: complicating notions of (tele) presence and gendered distraction in casual mobile gaming. In: Paper presented at the COST 298 conference, Copenhagen, Denmark. Retrieved from http://researchrepository.murdoch.edu.au/11796/

Hmelo-Silver CE, Pfeffer MG (2004) Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. Cognitive Sci 28(1): 127–138

Hmelo-Silver CE, Marathe S, Liu L (2007) Fish swim, rocks sit, and lungs breathe: expert-novice understanding of complex systems. J Learn Sci 16(3):307–331

Hoadley CM (2000) Teaching science through online, peer discussions: SpeakEasy in the knowledge integration environment. Int J Sci Educ 22(8):839–857

Ijsselsteijn W, Nap HH, de Kort Y, Poels K (2007) Digital game design for elderly users. In: Proceedings of the 2007 conference on future play. ACM, pp 17–22

Kapp KM (2012) The gamification of learning and instruction: game-based methods and strategies for training and education. Wiley, San Francisco

Kesler SR, Lacayo NJ, Jo B (2011) A pilot study of an online cognitive rehabilitation program for executive function skills in children with cancer-related brain injury. Brain Inj 25(1):101–112

Kirk D, MacPhail A (2002) Teaching games for understanding and situated learning: rethinking the Bunker-Thorpe model. J Teach Phys Educ 21(2):177–192

Klopfer E, Perry J, Squire K, Jan MF, Steinkuehler C (2005) Mystery at the museum: a collaborative game for museum education. In: Proceedings of the 2005 conference on computer support for collaborative learning (CSCL), pp 316–320

Kohler C (2010) Q&A: Pac-Man Creator Reflects on 30 Years of Dot-Eating. Wired. Retrieved August 24, 2015 from http://www.wired.com/2010/05/pac-man-30-years/

Kurt H, Ekici G, Aktaş M, Aksu Ö (2013) On the concept of "Respiration": biology student teachers' cognitive structures and alternative conceptions. Educ Res Rev 8(21):2101–2121

Lave J, Wenger E (1991) Situated learning: legitimate peripheral participation. Cambridge University Press

Lee HS, Liu OL, Linn MC (2011) Validating measurement of knowledge integration in science using multiple-choice and explanation items. Appl Meas Educ 24(2):115–136

Leemkuil H, Jong T, Ootes S (2000) Review of educational use of games and simulations. KITS consortium. Retrieved 9 Aug 2015 from doc.utwente.nl/28235/1/review_of_educational.pdf

Li MC, Tsai CC (2013) Game-based learning in science education: a review of relevant research. J Sci Educ Technol 22(6):877–898

Linehan C, Kirman B, Lawson S, Chan G (2011) Practical, appropriate, empirically-validated guidelines for designing educational games. In: Proceedings of the SIGCHI conference on human factors in computing systems, pp 1979–1988

Linn MC (1995) Designing computer learning environments for engineering and computer science: the scaffolded knowledge integration framework. J Sci Educ Technol 4(2):103–126

Linn MC, Hsi S (2000) Computers, teachers, peers: science learning partners. Routledge

Linn MC, Chiu J (2011) Combining learning and assessment to improve science education. Res Prac Assess 5:4–13

Linn MC, Davis EA, Bell P (eds) (2004) Internet environments for science education. Routledge, London

Linn MC, Lee HS, Tinker R, Husic F, Chiu JL (2006) Teaching and assessing knowledge integration in science. Science 313(5790):1049–1050

Litchfield A, Dyson L, Lawrence E, Zmijewska A (2007) Directions for m-learning research to enhance active learning. In: Proceedings of the ASCILITE-ICT: providing choices for learners and learning, Singapore, pp 587–596

Liu MC, Wang JY (2010) Investigating knowledge integration in web-based thematic learning using concept mapping assessment. Educ Technol Soc 13(2):25–39

Lobato J (2012) The actor-oriented transfer perspective and its contributions to educational research and practice. Educ Psychol 47(3):232–247

Ma Y, Williams D, Prejean L, Richard C (2007) A research agenda for developing and implementing educational computer games. Br J Educ Technol 38(3):513–518

Martens R, Gulikers J, Bastiaens T (2004) The impact of intrinsic motivation on e-learning in authentic computer tasks. J Comput Assist Learn 20(5):368–376

Mathai S, Ramadas J (2009) Visuals and visualisation of human body systems. Int J Sci Educ 31(3):439–458

Mayo MJ (2007) Games for science and engineering education. Commun ACM 50(7):30–35

Mitchell A, Savill-Smith C (2004) The use of computer and videogames for learning. Learning and Skills Development Agency, London. http://www.m-learning.org/docs/The%20use%20of%20computer%20and%20video%20games%20for%20learning.pdf

Morris CD, Bransford JD, Franks JJ (1977) Levels of processing versus transfer appropriate processing. J Verbal Learn Verbal Behav 16(5):519–533

Oblinger D (2006) Simulations, games, and learning. Retrieved from EDUCAUSE learning initiative. https://net.educause.edu/ir/library/pdf/ELI3004.pdf

Ortiz de Gortari ABO, Aronsson K, Griffiths M (2011) Game transfer phenomena in video game playing: a qualitative interview study. IGI Glob 1(3):15–33

Pasnik S, Llorente C (2012) PBS KIDS transmedia suites gaming study: a report to the CPB-PBS ready to learn initiative. Retrieved from Center for Children & Technology website: http://cct.edc.org/publications/pbs-kids-transmedia-suites-gaming-study

Paul AM (2014) Can education games ever be truly fun to play? [Blog]. Retrieved from http://anniemurphypaul.com/2014/02/can-educational-games-ever-be-truly-fun-to-play/#

Perkins DN, Salomon G (2012) Knowledge to go: a motivational and dispositional view of transfer. Educ Psychol 47(3):248–258

Pivec M (2007) Editorial: play and learn: potentials of game-based learning. Br J Educ Technol 38(3):387–393

Portnow J (2014) Learning through play: a promise to future generations. Casual Connect Magazine Summer 2014, pp 47–48. Retrieved from http://issuu.com/casualconnect/docs/casualconnectsummer2014

Prokop P, Fancovicová J (2006) Students' ideas about the human body: do they really draw what they know. J Balt Sci Educ 2(10):86–95

Randel JM, Morris BA, Wetzel CD, Whitehill BV (1992) The effectiveness of games for educational purposes: a review of recent research. Simul Gaming 23(3):261–276

Reiss MJ, Tunnicliffe SD (2001) Students' understandings of human organs and organ systems. Res Sci Educ 31(3):383–399

Schaller D (2014) Game mechanics and the museum: designing simple gameplay around complex content. In: Paper presented at the 18th annual museums and the web conference, Baltimore, MD. Retrieved from http://mw2014.museumsandtheweb.com/paper/game-mechanics-and-the-museum-designing-simple-gameplay-around-complex-content/

Schaller D, Principal EWA (2005) What makes a learning game? Eduweb. Retrieved August 24, 2015 from http://eduweb.com/schaller-games.pdf

Schwartz DL, Chase CC, Bransford JD (2012) Resisting overzealous transfer: coordinating previously successful routines with needs for new learning. Educ Psychol 47(3):204–214

Shute VJ, Ke F (2012) Games, learning, and assessment. In: Ifenthaler D, Eseryel D, Ge X (eds) Assessment in game-based learning. Springer, New York, pp 43–58

Shute VJ, Ventura M, Ke F (2015) The power of play: the effects of Portal 2 and Lumosity on cognitive and noncognitive skills. Comput Educ 80:58–67

Squire KD (2007) Games, learning, and society: building a field. Educ Technol 47(5):51–54

Squire KD, Barnett M, Grant JM, Higginbotham T (2004) Electromagnetism supercharged!: learning physics with digital simulation games. In: Proceedings of the 6th international conference on learning sciences (ICLS), pp 513–520

Steinkuehler CA (2004) Learning in massively multiplayer online games. In: Proceedings of the 6th international conference on learning sciences. International Society of the Learning Sciences, pp 521–528

Steinkuehler C, Chmiel M (2006) Fostering scientific habits of mind in the context of online play. In: Proceedings of the 7th international conference on learning sciences. International Society of the Learning Sciences, pp 723–729

Templeton B (2013) Museum games: the kids are all right. Retrieved from http://www.theguardian.com/culture-professionals-network/culture-professionals-blog/2013/feb/08/science-museum-ouch-game-students

The Nielsen Company (2009) Insights on casual games: analysis of casual games for the PC. Retrieved from http://www.nielsen.com/content/dam/corporate/us/en/newswire/uploads/2009/09/GamerReport.pdf

Van Eck R (2006) Digital game-based learning: it's not just the digital natives who are restless. Educa Rev 41(2):16

Voulgari I, Komis V, Sampson DG (2014) Learning outcomes and processes in massively multiplayer online games: exploring the perceptions of players. Educ Tech Res Dev 62(2):245–270

Young MF, Slota S, Cutter AB, Jalette G, Mullin G, Lai B, Simeoni Z, Tran M, Yukhymenko M (2012) Our princess is in another castle a review of trends in serious gaming for education. Rev Educ Res 82(1):61–89

Zhang ZH, Linn MC (2011) Can generating representations enhance learning with dynamic visualizations? J Res Sci Teach 48(10):1177–1198

Zhang ZH, Linn MC (2013) Learning from chemical visualizations: comparing generation and selection. Int J Sci Educ 35(13): 2174–2197