International Journal of Human–Computer Interaction

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/hihc20

Video Game Design for Learning to Learn

Angela Pasqualotto, Jocelyn Parong, C. Shawn Green & Daphné Bavelier

To cite this article: Angela Pasqualotto, Jocelyn Parong, C. Shawn Green & Daphné Bavelier (2023) Video Game Design for Learning to Learn, International Journal of Human–Computer Interaction, 39:11, 2211-2228, DOI: 10.1080/10447318.2022.2110684

To link to this article: https://doi.org/10.1080/10447318.2022.2110684

INTERNATIONAL JOURNAL OF HUMAN-COMPUTER INTERACTION
2023, VOL. 39, NO. 11, 2211–2228
https://doi.org/10.1080/10447318.2022.2110684

Video Game Design for Learning to Learn

Angela Pasqualotto[a,b], Jocelyn Parong[c], C. Shawn Green[c], and Daphné Bavelier[a,b]

[a]Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland; [b]Brain and Learning Lab, Campus Biotech, Geneva, Switzerland; [c]Department of Psychology, University of Wisconsin-Madison, Madison, WI, USA

ABSTRACT

Over the past 20 years, the proposal that immersive media, such as video games, can be leveraged to enhance brain plasticity and learning has been put to the test. This expanding literature highlights the extraordinary power of video games as a potential medium to train brain functions, but also the remaining challenges that must be addressed in developing games that truly deliver in terms of learning objectives. Such challenges include the need to: (1) Maintain high motivation given that learning typically requires long-term training regimens, (2) Ensure that the content or skills to be learned are indeed mastered in the face of many possible distractions, and (3) Produce knowledge transfer beyond the proximal learning objectives. Game design elements that have been proposed to support these learning objectives are reviewed, along with the underlying psychological constructs that these elements rest upon. A discussion of potential pitfalls is also included, as well as possible paths forward to consistently ensure impact.

Over the past four decades, video games have taken their place amongst, or even surpassed, older forms of media such as television and movies, as a medium of choice to deliver immersive and captivating experiences. And as was the case with these previous forms of media, as the commercial entertainment market for video games grew (Mares & Pan, 2013), so too did interest in the potential use of video games as learning tools (Carter et al., 2014; Gee, 2003; Greenfield, 1994).

Indeed, well-designed video games inherently instantiate a host of known principles of effective pedagogy, including encouraging practice that is distributed across time (Gentile & Gentile, 2008), providing experiences that are appropriately structured in difficulty and scaffolded (Bjork & Bjork, 2011; Mayer, 2020), and requiring learning to mastery (Gee, 2005). In turn, this has led to the optimistic view that this immersive media can be purposefully leveraged to promote learning (Connolly et al., 2012; de Freitas, 2018; Gentile & Gentile, 2008; Rebetez & Betrancourt, 2007). To this end, researchers and educators have explored the possibility both of repurposing commercial, off-the-shelf games that were initially intended for entertainment (e.g., Minecraft Education; Kuhn, 2018) and of designing games from scratch specifically for education and training (Adams et al., 2016). The specific learning objectives tackled in this domain have been exceptionally broad. Indeed, considering only work in more applied spaces, these include an incredibly wide range of goals situated in education (e.g., teaching basic facts, or skills such as in mathematics), to athletics, to a host of job- and/or day-to-day skills (e.g., performing endoscopic surgery, flying planes or drones, driving, etc.; Ferraro et al., 2022; Gupta et al., 2021; McKinley et al., 2011). Accordingly, a host of different labels for this overarching practice have flourished – *entertainment education*, *edutainment*, *game-based learning*, *digital game-based learning*, and *cognitive training (*see Breuer & Bente, 2010, for a review). However, they all share, at their core, an interest in using video games for educational or learning purposes (Gee, 2004).

And while the empirical results seen to date provide a great deal of optimism with respect to using games for these ends, one global insight that has been seen repeatedly across this rich literature is that the path to using video games as learning vehicles has perhaps not been as smooth as originally envisioned (Mayer, 2016). For instance, challenges have often been faced when attempting to keep the beneficial characteristics of commercial video games present, while at the same time shifting from content focused purely on entertainment (whether fighting monsters, exploring new worlds, or role-playing as powerful and dynamic characters) to that focused on more real-world learning applications (e.g., learning how to read or how to operate a plane). Furthermore, while commercial video games reliably instantiate many characteristics of effective learning, video games also often contain characteristics that are less virtuous in the face of specific focused learning goals, as design elements commonly used in commercial video games to produce

CONTACT Angela Pasqualotto angela.pasqualotto@unige.ch Faculty of Psychology and Educational Sciences, University of Geneva, 1205 Geneva, Switzerland

engagement and motivation can potentially also distract the learner away from the learning objectives.

This article discusses three main issues in the use of video games as learning tools. The first challenge is the need to design video games to not only promote initial interest in the learning topic, but also to keep the learner motivated long enough to deliver adequate time on task for learning to occur. Ensuring that learners continue to come back and engage attentively with the learning paradigm is central to all real-world learning objectives, from students in a classroom, to young adults training for the workforce, to older adults keen to learn a new skill, or to those recovering from an injury. After all, perhaps the most commonly replicated principle of learning is the "Total Time Hypothesis" originally put forward by Hermann Ebbinghaus (1885), which states quite simply that greater amounts of time spent learning results in greater amounts of learning and retention of material. This still holds true today. Given this first need, a key question is how to develop video games that support time on task and foster motivation to engage with the video game long enough for the planned learning outcomes to be mastered (van Gog, 2013). Just as has been found with older forms of media, how to accomplish this in the context of material that individuals might not have strong internal motivation to consume is no short order (e.g., in the same way that there are almost certainly far more individuals willing to watch The Lord of the Rings trilogy, which lasts over 11 h all told, than there are individuals willing to watch over 11 h of educational videos focused on cell organelles or other academic content). Arguably though, video games have a leg up with respect to producing long-term motivation over older forms of media or of instruction, a point that will be considered in the context of major theories such as Self-Determination Theory (Deci et al., 1999; Rigby & Ryan, 2011; Ryan & Deci, 2000) and Expectancy-Value Theory (Wigfield et al., 2010; Wigfield & Eccles, 2000).

A second challenge concerns the importance of attaining learning objectives by aligning learners' attention with desired learning outcomes (whether those are related to specific knowledge or more general skills). It is here that video games can be a double-edged sword. Commercial video games can be exceedingly immersive and engaging in part because their learning goals are reasonably unconstrained (i.e., the only real "learning goals" are to learn the game, become immersed in the fiction/narrative of the designer, etc.) As a result, they need not worry about whether the tools they use to promote immersion and engagement at the same time direct attention away from some to-be-learned information. This is obviously not true in the case of games for impact, where the learning goals typically come first, with the game then being constructed to hit those goals. Here, unless the immersion and engagement are naturally aligned with the learning objectives, they may hinder, rather than help learning outcomes (Sweller et al., 2019). It will thus be necessary to consider work on multimedia education in order to examine how such alignment can be done effectively, as well as the flip side, of where certain techniques end up being counter-productive with respect to learning.

Finally, the third challenge lies in training for transfer. Although there is certainly a strong degree of truth to the old adage "practice makes perfect" (or "permanent" depending on your disposition), when it comes to real-world utility, that is often insufficient. This is due to what has been dubbed "the curse of specificity" (Bavelier et al., 2012; Deveau et al., 2014). In essence, while individuals nearly always improve on the exact task upon which they are trained, they frequently fail to show generalization of these improvements to even seemingly similar new untrained tasks. The "curse" reflects, here, the fact that in the real-world, knowledge or skills frequently need to be brought to bear in contexts that are different from that of the original learning context. This is true whether in education (e.g., it does children limited good if they can solve mathematics equations of the form $3 + 5 = \_\_\_$, but then cannot solve an equation of the form $\_\_\_ = 3 + 5$; McNeil & Alibali, 2005), perception (e.g., it does an elderly individual limited good if they can detect only one particular peripheral shape on a lab computer and can't detect a car approaching from the left at an intersection; Huxlin et al., 2009), or cognition (e.g., it does an individual with a traumatic brain injury limited good if they increase their ability to remember sequences of letters displayed one after another on a tablet, but can't recall items to get at the grocery store; Kramer et al., 2004). While the past decade has seen an explosion of work focused on methods to produce greater generalization of learning, one promising avenue has involved the use of a particular type of video game (action video games). In a third and last section, the growing literature on action video games is reviewed, focusing on the type of generalization that is observed and the mechanics inherent in those games (but not all games) that may make such generalization possible.

1. Challenge ONE—Delivering time on task

1.1. Why is time on task needed?

To attain levels of meaningful and practical gains, most training regimens call for at least tens of hours of training. In short, a certain time on task is required to induce persistent changes in behavior (Luis-Ruiz et al., 2020; MacLean et al., 2010; Scionti et al., 2020). For example, in cognitive training intervention studies, researchers have frequently assigned their participants to train for several sessions per week, each lasting about 20–60 min (Jaeggi et al., 2008; Loosli et al., 2012), for a total of tens to even hundreds of sessions over weeks to months (Schmiedek et al., 2010). Research in this space has found that extended lengths of time may be necessary to observe the intended long-lasting effects of training. For example, a recent meta-analysis examining research on the use of video games to improve cognitive skills showed a dose-response curve with increased impact as training durations increased from 8 to 20 h of video game play (Bediou et al., 2018).

Moreover, researchers have found that an extended length of time is necessary to observe the intended long-lasting effects of training and reach expert levels of performance

(Ericsson, 2006; Ericsson & Harwell, 2019). No matter what field (e.g., sports or music or math), the amount of time an individual has spent practicing during their lifetime contributes a significant portion (18–25%) of the variance in performance level (Macnamara et al., 2016; Macnamara & Maitra, 2019).

Given the substantial body of evidence indicating that the longer time a learner spends in training, the greater the learning gains, a practical challenge in designing video games for impact is for the video game to induce enough motivation to guarantee time on task for that duration. Simple novelty can be sufficient to promote initial engagement for a few minutes, and possibly a few hours. This is true whether it's a new exercise program, a language learning app, or a video game. However, maintaining this motivation after the novelty period has worn off is sometimes a taller order. Thus, a key design challenge for any learning experience is to ensure that the learner will be motivated to engage in training for a significant amount of time (Mayer, 2016; Takacs & Kassai, 2019; van Gog, 2013).

In the case of video games, here it is important to note some distinctions between commercial video games and games for impact. It is very clear that commercial video games designed for entertainment already provide this motivation, given the astounding number of hours of video games played worldwide. However, this may not be true of games designed for learning. First, commercially available video games are designed with a much higher budget than games for impact, and thus have the means to deliver an enticing experience for hundreds of hours or more. Second, the range of commercially available video games is extremely diverse, allowing each player autonomy of choice in which games to play; in contrast, games for impact are typically assigned to the learner. Third, commercial video games are often designed to evolve over time with changes in rules, graphic style, or narrative from one version to another. Such variability is appealing and motivating to players to engage in game play. Most games for impact lack these key components. Accordingly, some video game training studies report that participants have difficulty in complying with demanding training schedule (even with extrinsically motivating factors, such as monetary compensation), leading to dropout rates as high as 25–30% (Chooi & Thompson, 2012; Jaeggi et al., 2014; Redick et al., 2013).

Another motivating factor to consider is the content delivered within the game or the difficulty at which it is played. High dropout rates can occur if the learning experience the game delivers is not properly matched to the proficiency level of the trainee. For example, Boot and colleagues (2013) showed that a commercially available action video game, which was predicted to have a high cognitive benefit based on previous studies on young adults, induced the lowest levels of improvement and, critically, of compliance among older adults. The chosen game was just too difficult for older adults, in violation of a key notion in the field of learning – that of keeping the trainee in their zone of proximal development (Vygotsky, 1978).

Thus, design efforts should focus on understanding what factors influence trainees' motivation to spend time on task and complete their assigned video game training. Some of these factors may be rather fixed, such as participants' age, personality traits, or familiarity with video games, while others may be more plastic, such as susceptibility to reward or incentivization through personalization (Jaeggi et al., 2014; Katz et al., 2014; for a meta-analysis, see Traut et al., 2021). A key design question then becomes how can video games enhance motivation for the play experience? To this end, the literature on motivation and video games is first briefly reviewed before design components likely to enhance motivation to play are considered.

1.2. Motivation theories and their explanatory power for understanding time on task

There is abundant evidence that motivation can significantly influence in-game experiences (Malone, 1981), and conversely, that in-game experiences can affect motivation to play. In this regard, this chapter will focus only on two major theories of motivation, Self-Determination Theory – SDT (Deci et al., 1999; Rigby & Ryan, 2011; Ryan & Deci, 2000) and Expectancy-Value Theory – EVT (Wigfield et al., 2010; Wigfield & Eccles, 2000). In SDT, motivation arises from three basic psychological needs being fulfilled: competence, autonomy, and relatedness (Vansteenkiste et al., 2020). The sense of *competence* refers to the need to perceive oneself as effective and able within a given context (Van den Broeck et al., 2016). Completing challenging tasks and feeling able to master them are core parts of this need. Competence alone, though, will not increase intrinsic motivation unless it is paired with a sense of autonomy. The need for *autonomy* regards the sense of choice, or the need to have and maintain control over one's life (Yu et al., 2018). To meet this need, it is important that players are able to choose among several courses of action and sense that the choice they make is related to their own goals and attitudes (e.g., task meaningfulness; Ariely, 2016). Thus, positive feedback, if seen as controlling, can adversely impact people's intrinsic motivation for self-direction, calling for a nuanced use of feedback. Finally, *relatedness,* or one's feelings of belonging to a group of significant others, can be fulfilled through interacting or connecting with others (whether real or within a video game). SDT researchers have observed that these three components within a video game can affect the willingness of players to continue playing and the likelihood of returning in the future (Mills et al., 2018; Possler et al., 2020; Ryan et al., 2006), which in turn will impact intrinsically-regulated motivation (Przybylski et al., 2010; Ryan & Deci, 2000).

In EVT, expectations of success and subjective task value are two of the most immediate predictors of achievement behavior such as effort, performance, choice, and persistence. *Expectancy* of success refers to the learners' beliefs of whether they will be capable of succeeding at a task. Note that expectancy for success is closely associated with the concept of self-efficacy, which is defined as one's confidence in being able to complete a task, derived from social cognitive theory (Bandura, 1986), as well as that of competence from SDT cited above. EVT researchers and game designers have successfully applied this theoretical framework to analyze how various cognitive, affective, and social factors during game play influence users' expectations of success, competence, or task values, which, in turn, affect their behaviors and motivations (Chen et al., 2013; Rachmatullah et al., 2021; Turkay et al., 2014).

Consistent with the importance of competence/expectancies of success in theories of motivation, learners show higher motivation to pursue objectives when they expect to quickly develop the competence necessary to succeed at a given task. For example, Cochrane, Anthony, Balweg, Klaas, and Green (submitted) have shown that the perceived rate of change in competence in the context of cognitive training is a stronger predictor of motivated effort than the overall level of competence. In particular, users stayed in a task longer when they were provided feedback that they were rapidly improving than when they were given feedback that they are good, but not getting any better, at the task. Conversely, competence frustration, or the lack of success in developing competence, is often accompanied by negative outcomes such as disengagement from interventions and higher drop-out rates (Earl et al., 2017). Interestingly, earlier frustration can also serve as motivation for future tasks. In Fang et al.'s (2018) study, competence-frustrated trainees exhibited increased intrinsic motivation for a subsequent task that offered them a taste of competence. These results are in line with SDT and previous research that showed participants who reported autonomy frustration and/or relatedness frustration during an initial task put forth more effort and performed better in a subsequent task if that task offered them the chance to restore their undermined autonomy (Radel et al., 2011, 2014) or to feel socially accepted (DeWall et al., 2008), respectively. This may explain the success of video games which alternate between game play periods where difficulty accelerates and other periods which rather allow the player to fulfill their sense of competence. For example, in linear video games, "boss fights" (i.e., where a player must fight a particularly difficult enemy and thus are likely to fail multiple times before succeeding) are often followed by game sections containing mostly easy-to-defeat enemies. Similarly, in more open-world, such boss fights are often followed by new parts of the map being opened up that can be explored.

1.3. Game design components to deliver time on task

As motivation is an important factor for driving time on task in video games for impact, game designers can take advantage of some game components to support motivation. Among these are feedback, clear goals, avatars, perceptual choice points to cite a few. The list presented is not exhaustive and rather the interested reader is directed to the more extensive body of work existing on this topic (Bormann & Greitemeyer, 2015; Groening & Binnewies, 2021; Mekler et al., 2017; Sailer et al., 2017; Xi & Hamari, 2019).

1.3.1. Feedback

Numerous authors have proposed that the sense of competence can be addressed by using informative feedback such as points, badges, or leaderboards (Hense et al., 2014; Rigby & Ryan, 2011; Sailer et al., 2017). With points, players can receive instantaneous feedback at the time of their actions. Badges and leaderboards serve as a means of providing feedback in a more cumulative fashion over time. In addition, performance graphs allow players to visualize their progress throughout each game, thus providing a sense of continuous feedback (note here the deliberate use of "feedback" versus reward; it is unclear whether individuals feel "rewarded" by arbitrary items such as badges, but these should provide a sense of competence). These three different types of feedback differ in terms of the timescale at which they inform the player of their game performance. Whether providing feedback at different timescales heightens intrinsic motivation remains largely unknown. Future research should evaluate the impact of such time-layered feedback on intrinsic motivation.

Among these three types of feedback, the most studied are visual representations of advancement (e.g., progress bars) that allow players to know how close they are to completing the assigned task/quest (Sailer et al., 2013, 2017). The closer a player is to completing a task/quest/level, the faster they work towards reaching it (Madigan, 2015; Yan et al., 2011). Not only do visual representations of advancement provide immediate feedback about the player's competence, but these representations can also influence the probability that the player comes back to play. For instance, artificially advancing players in a game makes them believe they already made progress. As a result, they are more likely to invest the time and effort needed to complete a task, a phenomenon termed "endowed progress effect" by Nunes and Dreze (2006). However, the effect of progress indicators depends on the length of a task; if the task is lengthy, the presence of a progress bar can cause quitting (Yan et al., 2011).

In addition, games that provide social feedback are positively associated with feelings of relatedness (Rogers, 2017). For instance, playing a video game with another person can enhance feelings of relatedness, as Tamborini et al. (2010) and Ryan et al. (Ryan et al., 2006) showed. The same applies to games involving online multiplayer as well as human cooperators.

1.3.2. Clear goals

Boosting competence by inducing a sense of progress in the player can be achieved not only through feedback, but also through clear goal setting. As with feedback, breaking down goals to smaller chunks provides a player feedback on their progress at a higher pace, while regulating their effort toward distant goals (Baumeister & Vohs, 2007). For example, many games, particularly those of the role-playing variety, show players the full "skill tree" from the very beginning of the game (this is where players allocate points that they have gained via their in-game experience in order to increase certain character abilities). Critically, these skill trees always progress in steps. The player must allocate points to the first point in a branch (e.g., "skill 1A"), before they can allocate points to skills further down the branch (e.g., skills 1B, 1C, 1D …). This, thus, very naturally gives the player very manageable proximal goals (i.e., to move up to the next skill level along a branch), as well as long-term goals (gain the maximum level of skill along the branch). Here it is worth noting that because such trees often contain more branches than the player could conceivably traverse in a single game play through, these also should promote feelings of autonomy, as players choose for themselves which skills to attain (i.e., one player may choose to increase their magical abilities, while another may choose to increase their fighting skills).

1.3.3. Align challenge with competence

In addition to goals being clear, a key game design issue is to design goals that are challenging, but yet manageable to induce a sense of competence. Indeed, a main achievement of the video games industry is arguably to deliver experiences that constantly keep the player in their zone of proximal development. While this is known as a critical feature of learning since Vygotsky (1978), the robust implementation of this well-accepted learning concept is frequently unmet, whether in the field of education or that of sports/music training, or that of health rehabilitation. Commercial video games meanwhile are able to reliably provide a method for keeping players in their zone of proximal development. This is done not only by clear scaffolded goals with rich feedback, but increasingly games adapt on the fly to the performance of the player, reducing difficulty when players struggle and increasing difficulty when players appear to be progressing too easily. Accordingly, the provision of positive feedback, together with the opportunity of acquiring new skills through skill-graded goals, produces a sense of self-efficacy and self-validation in the experience (Przybylski et al., 2010). As quests become more challenging, easier quests can also be introduced to release the tension and allow for periods of restoration of the feeling of competence. Together, these aspects create a cycle of progression in which players thrive to improve their abilities and skills in order to complete more challenging quests, while also remaining confident as they complete easier tasks.

1.3.4. Avatars

Avatars have been proposed to fulfill several motivational needs. By letting players view and refer to virtual representations of themselves, avatars may increase the sense of competence in one's skills (i.e., seeing one's avatar become more skillful in turn makes the players themselves feel more skillful; Xi & Hamari, 2019). Avatars are also relevant to the need for *autonomy* as they provide players with perceived freedom of decision (Peng et al., 2012). For example, in EverQuest (Sony Online Entertainment, 1999), players customize a character for their gameplay, providing an opportunity for gamers to autonomously experiment with their own identity in a safe environment. Recently, Livingston et al. (2014) investigated how experienced players value their avatars in World of Warcraft (Blizzard Entertainment, 2004). Players reported that they found value in designing, creating, and purchasing clothing and apparel items for game characters, as well as their representations of relationships, facilitating social and verbal interactions to promote social value. Promoting social relatedness in this way is another path to heightened motivation. This is also what massively multiplayer online games (MMOs) try to achieve through the "multiple-players" component, which allows the concurrent inclusion of large numbers of gamers. As a result, participants will organize in teams, collaborating within teams and competing across teams, creating a sense of belonging (Adams et al., 2019). A specific subgenre of MMOs, massively multiplayer online role-playing games (MMORPG), expand on this format of play with the introduction of role-playing characteristics through the creation of an avatar for each player (Cole & Griffiths, 2007; Raith et al., 2021). In sum, providing opportunities for players to develop and build relationships through their avatars or otherwise appears to increase players' motivation to continue playing.

1.3.5. Perceived choice points

Autonomy can be enhanced not only by giving the possibility to the player of personalizing their avatar, but by letting the player select tasks, movements, and/or rewards as the game play unfolds. Indeed, in terms of autonomy satisfaction, the games that are most effective seem to be the ones that allow players to make their own choices in the way they navigate the game. For example, open-world games such as Red Dead Redemption (Rockstar Games, 2010) boost player's sense of autonomy by providing choices on everything from which side quests to pursue, to how to spend resources, to how to complete various missions (i.e., there isn't a single way to complete a mission, instead players can choose for themselves how to meet the goals). A note of caution when designing choice points may be warranted though; research on decision making suggests that having too many choices may be counterproductive. Players are likely to suffer from biases such as the need to keep possible options always open, which in turn can induce unwanted cognitive and emotional load (for a review of biases to avoid in decision making see Ariely & Jones, 2008).

Another choice point that can be used for motivation is one in which the consequences are largely unknown at the time of the decision (usually under a time frame that feels short). This concept has been called "psychological reactance" (Brehm, 1966) and is defined as "the motivational state that is hypothesized to occur when a freedom is eliminated or threatened with elimination" (Brehm & Brehm, 1981, p. 37). For example, The Walking Dead game (Telltale Games) forces the players to quickly decide whether to help another survivor in the zombie apocalypse. As the player cannot know whether this survivor will become an enemy or not, such a high uncertainty decision induces a motivational state that differs from the typical motivation associated with informed choice. Psychological reactance could also be evoked when deciding which factions to join in games such as Skyrim, Fallout, or Halo Infinite. Of note, decision making under high uncertainty is perceived as stressful and unpleasant, a phenomenon exacerbated in general anxiety disorder (Tanovic et al., 2018). Thus, psychological reactance as a game mechanic should be used with caution. In environments in which most decisions are associated with a sense of control, occasionally forcing a high-uncertainty decision may, through arousal, augment motivation, but this should not be overdone.

1.3.6. Story-telling

Stories that offer a shared, meaningful role to the players can also be used to fulfil the player's need for relatedness (Bormann & Greitemeyer, 2015; Rigby & Ryan, 2011; Sailer et al., 2013). Together with teammates, who can be real co-players or non-player characters, a sense of relatedness can be evoked by emphasizing the importance of the players' actions for the group's performance (Rigby & Ryan, 2011). Indeed, a shared goal, which can be conveyed within a meaningful story, can foster experiences of social relatedness (Sailer et al., 2013). Stories may add to presence by linking the player to other agents, whether a team of players (as in multiplayer games) or fictional ones such as AI designed companions (Baylor, 2009).

Games for impact are arguably challenging to design because they not only need to deliver time on task and thus foster motivation, but also need to remain cognizant of the very learning objectives and how these can be seamlessly integrated in the game play. This second challenge is addressed below.

2. Challenge TWO: Attaining learning objectives while playing a video game

2.1. Mastering content or skills while being immersed in a rich, full of distractions video game world

While designing an experience in such a way as to keep players motivated is a necessary ingredient in producing the necessary time on task for a game for impact, it is not remotely sufficient. Indeed, video games have long been hailed for not only initially capturing, but also maintaining, attention within the game, naturally delivering the kind of engagement that any long-term learning activity calls for (Linnenbrink-Garcia et al., 2016). However, engagement can both help and hinder learning, depending on whether it is directed towards the to-be-learned aspects of the task or to other irrelevant aspects. The "seductive detail effect" refers to when the learner's attention is directed towards interesting, but irrelevant features, in turn detracting the trainee from the learning goals in the game (for a meta-analysis, see Sundararajan & Adesope, 2020). These features may include irrelevant stimuli, such as pictures or a narrative, or even other game features, such as feedback on learning-irrelevant goals (Katz et al., 2014). For instance, if the primary to-be-learned information are mathematical abilities, the presence of "side quests" to collect golden rings may produce engagement (in those players who enjoy collecting rings and seek out the opportunity to do so) while simultaneously impeding learning (in that the side quests are detracting from engagement with the main learning topic; Logan & Woodland, 2015).

Such situations, where game mechanics meant to produce excitement/motivation at the same time direct attention away from to-be-learned material, may partially explain why many games have failed to provide positive results. As noted by O'Neil and Perez (2008): "While the effectiveness of game environments can be documented in terms of intensity and longevity of engagement […] as well as the commercial success of games, there is much less solid empirical information about what outcomes are systematically achieved […] and there is almost no guidance for game designers and developers on how to design games that facilitate learning" (p. ix). It is, thus, critical to align engagement with the skills and/or content to be learned, while limiting the allocation of cognitive or emotional resources to task-irrelevant or distracting information (Blumberg, 2014; Gentile & Gentile, 2008; Rosser et al., 2007).

The next sections consider the current state of knowledge in cognitive and affective science as to how attention, cognition, and emotion affect learning, followed by an analysis of the game components that can be used to align such control mechanisms with learning objectives.

2.2. Impact of attention, cognition and emotion control on learning

Research on human information processing has demonstrated a host of significant bottlenecks. Some of these bottlenecks are simply with respect to our ability to extract information from the environment (e.g., our sensory systems have physical constraints in terms of how much information from the outside world can be transduced into electrical activity over a given period of time. But the more severe forms of bottlenecks are at higher stages of the processing stream (i.e., in terms of how much information we can simultaneously make use of to guide planning or reasoning; Norman & Bobrow, 1975). And indeed, it is these latter types of bottlenecks that likely set upper bounds on learning (e.g., if the information stream of to-be-learned material exceeds attentional or working memory capacity). This in turn highlights the importance of ensuring that instructional experiences to properly consider resource use – e.g., distribution of attention and the level of cognitive or emotional load experienced (Sweller et al., 2019).

2.2.1. Attention

Our understanding of the factors by which the distribution of attention can be manipulated has been traditionally informed by cognitive science and visual science (Goldhaber, 1997). Briefly, cognitive and vision sciences indicate a range of visual features that will tend to automatically capture attention. According to various studies (e.g., Eimer et al., 2009; Folk et al., 1992), attentional capture is dependent on search goals as salient stimuli tend to capture attention involuntarily when they match the searched-for target characteristic. For instance, it is well established that abrupt visual onsets (whether in the form of an item suddenly appearing where none was before or in the form of sudden changes in basic visual feature like color, form, or orientation) are effective in capturing attention, as compared to similarly salient, but static, differences in brightness and color (Cole et al., 2009; Theeuwes, 1991; Turatto & Galfano, 2000; Yantis & Jonides, 1984). Luminance changes in particular show unique attentional prioritization in perceptually complex scenes (Yantis & Jonides, 1984), as do changes in direction of motion (Howard & Holcombe, 2010). Furthermore, non-salient stimuli that have been previously associated with reward also automatically capture attention, an effect that is quite persistent over time (Anderson et al., 2011; Anderson & Kim, 2019; Anderson & Yantis, 2013), calling for caution when using badges or scoreboards. Crucially, these stimuli have the capability to automatically capture attention, even when unrelated to a given task, effectively acting as potent distractors (Jonides & Yantis, 1988; Theeuwes, 1993). Indeed, because learning typically requires that attention be directed to the to-be-learned skills or content, the use of features that direct attention away from those skills/content will largely serve to inhibit learning.

2.2.2. Cognitive load

Not only is the use of features that direct the learner's attention to irrelevant stimuli problematic because it reduces the extent to which attention is paid to relevant stimuli, such features also represent undue cognitive load. In short, cognitive load refers to the amount of cognitive control resources a task calls for. Cognitive load is greater in tasks that require more information to be held in working memory, involve more demanding memory retrieval, or necessitate more complex memory content manipulation. These demands, particularly when accumulated via multiple sources of distraction, can lead to cognitive overload. As demonstrated by Lavie's theory of load, under high cognitive load, distracting items more easily gain access to deeper levels of processing, becoming in effect even more distracting (Lavie, 2010; Watson et al., 2019). The neural bases of such cognitive control have been ascribed to the fronto-parietal control network and in particular to the control exerted by the dorsolateral prefontal cortex on both perceptual information processing and memory retrieval. Accordingly, such frontal control is seen as central during the early stages of learning; whereby, in the later stages of automatization more subcortical structures such as the basal ganglia becomes more prominent, at least during skill learning.

Cognitive theories in instructional design also highlight the importance of cognitive load in learning. Sweller's cognitive load theory (1988) and Mayer's cognitive theory of multimedia learning (Mayer, 2017; Moreno & Mayer, 2007) assume learners can only keep a limited amount of data in working memory at a given time. Cognitive overload occurs when too much information, whether relevant or irrelevant, is simultaneously processed by the learner at once. Sweller et al. (2019) categorized cognitive load into three categories: intrinsic, extraneous, and germane. Intrinsic load is the cognitive demand inherent in the task itself that depends on the level of complexity of the learning materials (Nelson & Erlandson, 2008). Extraneous cognitive load refers to the cognitive demands wasted on processing irrelevant or extraneous information presented alongside the relevant material. Finally, developing mental models to understand information and automate skills constitutes the germane cognitive load, or in other words, the overarching goal of instruction. Germane load can be optimized by matching the material's level of complexity to the learner's zone of proximal development and reducing the extraneous load through optimal design. However, task features are not the only contributing factors to a learner's cognitive load; the learner's prior knowledge and internal states, such as arousal also play a role in a learner's cognitive load. Galy et al. (2012) showed that subject-specific characteristics, such as alertness, lighten cognitive load in addition to task-related features. Similarly, arousal levels diminish the amount of cognitive resources learners need to process items immediately upon recall (Fabbri et al., 2008; Mélan et al., 2007). While these studies suggest that increased cognitive load may lead to detriments in learning, cognitive load that is too low is also not ideal. Jackson et al. (2014) found that low levels of cognitive load and the absence of arousal had a detrimental effect on practice-related improvements in inhibitory control, short-term memory, metacognitive monitoring and decision-making. Thus, like attention, cognitive load must be manipulated in a tightly controlled way so as to sustain optimal levels of learning.

2.2.3. Emotion

Not only can emotional content capture attention such as in the scream illustration, but the affective state of the learner can also alter perceived task load, and thus in turn learning (Chamberland et al., 2015). The affective mediation assumption of Moreno's Cognitive-Affective Theory of Learning with Media (CATLM; Moreno, 2006) posits that emotional factors may mediate the cognitive engagement of the learner, ultimately leading to an increase in learning. Indeed, rich affective-based interactions within video games can enhance players' experience by directing their attention to the to-be-learned materials (Boyle et al., 2012, 2016; Mcquiggan et al., 2010). Through mechanisms such as mood-dependent or mood-congruent processing, emotion can enhance (or diminish) cognitive resources such as working memory (Curci et al., 2013; Levens & Phelps, 2008; Plancher et al., 2019). More generally, several studies suggest that positive emotions (e.g., enjoyment, hope, and satisfaction) can lead to higher levels of behavioral and cognitive engagement enhancing learners' capability for learning and integrating new information (Ben-Eliyahu & Linnenbrink-Garcia, 2013; Nye et al., 2021; Schunk & DiBenedetto, 2020). According to Um et al. (2012), multimedia learning environments can induce positive emotions in learners, which can create positive feelings that facilitate learning on both a comprehension and transfer level. Negative emotions are usually associated with lower academic performance as well as lower behavioral and cognitive engagement. For example, boredom is an important indicator of detachment from the task at hand (Buday et al., 2012; Sharek & Wiebe, 2014). Capitalizing on the attention they summon, there have been attempts to harness negative emotions, like fear, in some serious games to enhance safety training (Mitsuhara et al., 2017; Reiners et al., 2014). While it is well documented that fear automatically attracts attention, it can also act as the focal point of memory, preventing processing or consolidation of other information not related to the fearful experience.

As with other means of capturing attention and engagement, in order to be effective, emotion-inducing events should be coherent with where and when the player's attention should be allocated given the specific learning objectives. Indeed, researchers investigating the impact of seductive details in learning have noted a delicate balance between the emotional benefits and the cognitive disadvantages these may have on learning, calling for caution in emotional design in multimedia learning (Rey, 2014). In sum, while increasing attention and engagement may very well support learning, when directed inappropriately, it is more likely to distract from it. Thus, it is not sufficient for a video game to merely be engaging if its goal is to enhance learning. A main concern should be how to best manipulate attention and cognitive load through game design to facilitate the desired learning outcomes.

2.3. Game design components to align attention and learning objectives

A key question then is how to effectively design video games to align the learner's attention and cognitive load to the stated learning objectives. The following sections discuss game components that can be manipulated to attain learning objectives (Hodent, 2017; Weitze, 2014).

2.3.1. Game components that direct attention to the to-be-learned material

Video games provide a rich experience both in terms of stimulating different sensory modalities, tapping a variety of cognitive processes, and memory storage. A first challenge is for the game play to properly direct attention to combining multiple modalities and sources of information in a transparent fashion, so as to not distract learning.

Visual or auditory cues, if correctly designed, can reduce extraneous processing by drawing learners' attention to key elements and their interconnections (Castro-Alonso et al., 2021; Nelson & Kim, 2020; Van Gog, 2014). For example, Nelson et al. (2014) showed that students who completed an assessment game module with visual cues towards the important information reported less perceived cognitive load and higher assessment efficiency than those who completed it without visual cues. In commercial video games, changes of physical properties (particularly color and luminance) have been effectively used to build a clear hierarchy of the elements that should be attended. In action video games, for instance, attentional priority is often to enemies/sources of danger first, then interactive objects, and finally background elements. Changes in visual features such as color or luminance can give players hints of what they should do: where to go, who to attack, and what to collect (see, for an example, Bullet Echo, ZeptoLab, 2020). In addition, designers should tune the number of details to make sure that the most relevant parts of a game in terms of learning objectives are the easiest to process. For example, Journey (Thatgamecompany, 2012) is an elegant minimalistic game that employs areas of rest and areas of high detail, creating contrast and highlighting the importance of certain elements over others. Thus, whenever possible, designers should bring focus to the more learning-relevant details and eliminate details that distract away from the learning objectives (Castro-Alonso et al., 2021). In this regard, the type of material used appears to be another factor modulating the negative impact of seductive details on learning, with text materials having been documented to be more detrimental compared to images (Rey, 2012).

Furthermore, most of the reviewed studies have focused on the impact of changes in physical properties of *visual* objects as a way to direct players to the to-be-learned material. This "ocularcentrism has […] plagued video game studies" (Collins, 2013, p. 22); however, sounds should also be carefully designed to signal and cue players' attention. A game's sound design – which typically includes soundtracks, ambient sounds, and sounds associated with the player's actions – has the potential to evoke different emotions in learners and thus contribute to learning (Cassidy & MacDonald, 2010; Munday, 2007). Moreover, it is possible to use game aesthetics to capture and reflect the players' emotional state through a combination of music and visuals (Drossos et al., 2012; Liljedahl, 2011). In doing so, game aesthetics and the emotions they trigger should be considered as a strategic element in game narrative that aims "to enhance the richness of the playing experience, and afford sensual, visceral, and/or intellectual stimulation to the player" (Browne et al., 2012, p. 149). As opposed to designs that add seductive details irrelevant to the learning process, emotional design manipulates the affective qualities of components of the environment (e.g., sounds, colors, shapes, etc.) without adding any new content that would be a competition for cognitive resources (Plass & Kalyuga, 2019). In the Legend of Zelda series (Nintendo et al., 1986), for example, rewarding sounds are often associated with an emotional state, character, place, or object. Moreover, music can be used to signal players that they are safe or that they need to pay attention to an impending danger (Hodent, 2017). For example, when the player is in an exploration mode, the music might show a calm and inquisitive tone, whereas a battle mode might feature a frantic and aggressive sound. In sum, emotions can be manipulated to guide the players' engagement.

The study of methods to seamlessly induce emotions that are aligned with learning outcomes is a relatively new field of investigation in the video game literature (Huang et al., 2016; Mayer & Estrella, 2014; Plass et al., 2014; Um et al., 2012). Thus, despite the fact that these design factors are likely to play an important role in game design for impact, in order to provide specific design specifications, it would be crucial to accumulate evidence about the proper use of emotions to summon attention, reduce load and facilitate processing so as to positively impact learning outcomes.

2.3.2. Game play and learning goals alignment

In order for games to be effective learning tools, they should have clearly defined goals, and the cognitive processing involved in the game should closely align with the learning objectives (Mayer, 2016). As may be obvious, game goals and learning goals are not necessarily the same and may diverge significantly (Schrier, 2018). In this regard, Whitton (2009) suggested that "a key challenge when designing a game for learning is ensuring that the goals within the game support the learning objectives and do not detract from them" (p. 90). If a game requires engagement with the intended learning objectives in order to progress, then it has a much greater chance of success as a learning tool (Salen et al., 2011; Weitze, 2014; Whitton, 2009). On the other hand, if for example, the player can finish a level by simply clicking randomly, then the game goals can be easily achieved but little learning will occur.

Thus, designing games for impact means not only setting clear goals but also, at all times, ensuring these goals work in the service of the expected learning outcomes. To demonstrate the importance of game goals on learning outcomes, Arena (2012) examined how playing one of two commercial games may prepare community-college students to learn from a World War II lecture. The games compared were Call of Duty 2 (Infinity Ward, 2005), which mostly directs players' attention to tactics on the battlefield, and Civilization IV (Firaxis Games, 2005), which directs players' attention to strategic choices nations need to make. Note that neither of these games covered World War II and thus their content was irrelevant to the stated learning goals of the lecture on World War II. After their respective game play and the WWII lecture, students were asked to read two different scenarios, one focused on battle tactics and the other one focused on nation strategies. For example, one battle tactics scenario read, "On June 6, 1944, an American Ranger battalion landed on the beach at the foot of the cliffs of Pointe du Hoc, in France. They then climbed those cliffs under fire from the Germans to destroy a set of large artillery guns." One nation strategy scenario meanwhile read: "In 1940, in Mers-el-Kebir, Algeria, commanders of some British ships spoke with commanders of some French ships, and then the British ships fired on the French ships, sinking the ships, killing over 1,200 French sailors." For each scenario, students had to state the questions they would ask to figure out why this happened. Scoring the students' response as a function of the scenario indicated that those students that had played Call of Duty were more likely to ask questions about battle tactics than those who had played Civilization when presented a battle tactics scenario and were less likely to ask questions about nation strategy than those that had played Civilization when presented a nation strategy scenario. Thus, by directing attention to different levels of knowledge during war-based experiences, Call of Duty and Civilization IV induced different learning (and learning-to-learn) outcomes.

Delivering a video game experience where attention, cognitive load, and learning outcomes are properly aligned is bound to result in an impactful game for learning; yet, to this day very few instructional games have achieved such alignment. In many cases, learning goals and game goals are kept separate and a short game (e.g., puzzle) without any connection to the learning objectives (e.g., solve a math problem) may be given as a reward to the learner/player. Among the notable exceptions is "Re-Mission" and "Re-Mission 2" (2006, 2012) from HopeLab. The learning goal in this video game is to encourage young people with cancer to stick to their treatments and to change their attitudes towards chemotherapy, two important predictors of treatment success. The game features a powerful microscopic robot that blasts away enemies (i.e., cancer cells) in order to prevent them from completing the tumor before it enters the bloodstream. Through playing the game, the young player learns what happens in their body when cancer cells attack and which actions they can take to reduce the counts of harmful cells, while engaging the player with their learning goals. Research has shown that playing Re-Mission improved clinical outcomes associated with success in cancer treatment at the behavioral and psychological level (Kato et al., 2008). Additionally, young people's attitudes and behaviors also improved, with greater adherence to antibiotic and chemotherapy treatments (Cole et al., 2012).

When aligning learning goals with game goals, careful consideration should be given not only to game challenges and rules, but also feedback (Salen et al., 2011; Weitze, 2014). Despite the importance of feedback in game-based environments, relatively little research has systematically evaluated the effect of feedback characteristics on learning outcomes. In particular, when exactly the game should deliver feedback has mixed recommendations. Learners seem to benefit most from detailed process feedback (Erhel & Jamet, 2013; Law & Chen, 2016; Serge et al., 2013) as is provided in Re-mission; players received immediate feedback in order to understand which are the most efficient weapons they have available to defeat the cancerous cells (e.g., radiation, antibiotics, chemotherapy). However, there are a number of moderating factors that may influence whether feedback should be delayed versus provided immediately, such as the type of task or the intended learning objectives (e.g., promoting retention versus transfer; Lester et al., 2020). Additional research needs to be conducted in order to answer the question of when and how to provide feedback in video games, as well as in other forms of game-based learning environments (Lester et al., 2020; Yan et al., 2011).

2.3.3. Scaffolding

Playing a video game can often cause players to experience some level of cognitive load (Nelson & Erlandson, 2008). Scaffolding, or the layering of increasingly complex levels or learning objectives, has been shown to facilitate learning (Mayer, 2020). Video games are seen to excel in scaffolding as they naturally deliver real time, personalized progression in the game play (Madigan, 2015). In this regard, Gee (2005) describes scaffolding as fish tanks: "little simplified ecosystem that clearly displays some critical variables and their interactions that are otherwise obscured in the highly complex ecosystem in the real world" (Gee, 2005, p. 12). Designers should begin by creating simplified models of a complex ecosystem or "fish tank," so learners can familiarize themselves with it gradually. The game should then become more and more complex along the way, until the learner fully comprehends how the whole game system works.

A good example of scaffolding for game play is represented by the video game Horizon: Zero Dawn (Sony Interactive Entertainment, 2017). As the player moves through a complex, post-apocalyptic open world, they are often faced with many options and strategies to choose from. A strong point of the game is that despite its complexity, it makes things simple enough for the player to learn though several mechanics (Madigan, 2015). The "hunting grounds" is a good example of this. Players can place themselves in increasingly difficult situations and learn new strategies which will carry over into other parts of the game.

A main challenge when scaffolding in games for impact is to deliver a game play that allows for the development of a coherent mental model for the to-be-learned skills or content. Video games can be designed to integrate scaffolding to facilitate the mental organization of selected information into a coherent mental model. A game-based environment that incorporates notebooks, and checklists allows players to record key pieces of information and reflect on what they already know about the problem they are tackling (Shores et al., 2011). For instance, in Crystal Island (Lester et al., 2020), a virtual diagnosis worksheet (a note-taking tool) was integrated into the narrative-centered learning environment. As they attempted to figure out what caused an illness outbreak on a fictional island, players could make notes, select likely causes, and provide a final diagnosis. A study by Nietfeld et al. (2014) found that students who used the virtual worksheet showed greater learning gains and reported higher learning levels, in addition to being more engaged. Another set of instructional scaffolds commonly found in game-based learning environments is graphic organizers and concept matrices. The use of these can assist players in self-assessing and self-reflecting on their capabilities or their current level of knowledge (Rowe et al., 2013). In Crystal Island, users can use concept matrices to reinforce their understanding of microbiology principles and this has been linked to higher learning outcomes (Rowe et al., 2013). Researchers have also found that embedding sub-challenges within a video game can support more efficient learning than asking learners to complete more complex activities (Shores et al., 2012). One illustration of how video games exploit this type of scaffolding comes from the tutorial scenarios in Portal 2 (Valve Corporation, 2011): through this intelligent tutoring environment players are enabled to play scaled-down versions that emphasize key game elements and relationships.

To sum up, a game for learning should provide proper scaffolding not only of the game play but also of the learning objectives. Game goals should therefore be constrained both by playability and learning goals so that the design allows players to gradually acquire through the very game play all of the learning outcomes (Madigan, 2020; Weitze, 2014).

3. Challenge THREE: Designing for transfer

The preceding sections emphasize the importance of designing games that direct attentional and cognitive resources on the to-be-learnt material, as well as use proper motivational systems to deliver the needed time on task. Another challenge, though, in the learning sciences concerns the issue of transfer or overcoming what is also called the "curse of learning specificity" (Bavelier et al., 2012; Deveau et al., 2014).

3.1. Why is transfer of learning desirable?

As noted in the introduction, training nearly always improves performance on the practiced task (i.e., even if there are mismatches of the type discussed in the previous section, this shouldn't completely block learning, it should just make it considerably slower). Yet, more often than not, learning on the task itself does not result in improved performance on other tasks. For instance, in the field of perceptual learning, participants trained to detect the presence of dots moving up and to the left might become exquisitely attuned to such displays (such that they can perform incredibly well at such detections, even in the presence of significant noise or with very short presentation times). However, at the end of training, they frequently show no increased aptitude at detecting dots moving, for instance, down and to the right (Sagi & Tanne, 1994). Similarly, individuals repeatedly trained on one psychological task designed to measure executive functions will frequently become much better at that one task, but then show no improvements on any other similar measures of executive function (Lee et al., 2012; Stojanoski et al., 2021). And finally, this is a persistent issue in education, where students may, for instance, show great improvements on solving problems when presented as equations, but then show limited ability to solve the same problems when presented as word problems (Schanzer et al., 2015). Obviously then, this is a significant real-world obstacle since being perfect on just the exact training task is rarely the purpose of instruction or training. Instead, in order to have any real-world utility, the benefits of training must extend beyond the context of the training itself, and thus in the discussed case, the context of the video game play.

Thus, after considering game mechanics that can impact time on task and can be used to align learners' attention with the to-be-learned skills and content, the third challenge of delivering transfer beyond the trained tasks will be now addressed by reviewed first the existing theoretical framework on transfer and then the game design components to enhance transfer.

3.2. Existing framework: How to facilitate learning transfer

While for much of the history of various learning fields (e.g., perceptual learning, cognitive learning), specificity of learning was the expected outcome, over the past several decades a variety of approaches and paradigms have been examined that appear capable of overcoming the "curse of specificity" (Bavelier et al., 2012; Deveau et al., 2014; Green & Bavelier, 2003) and instead of producing more general learning outcomes. One such approach is leveraging action video game play. While action video games contain the same basic characteristics known to produce sustained motivated effort discussed in the previous section, unlike many other types of video games, they also contain a number of other characteristics that seem to allow for surprisingly broad learning outcomes. Action video games refer here to fast paced, perceptually rich video games that require players to move around in the game environment, to effectively monitor their surroundings, while making frequent, quick, and accurate motor responses to new stimuli. Generally speaking, scientific research has tended to use action video games to refer to two sub-genres of video games – first- and third-person shooter games (with the primary difference being the character viewpoint, Dale & Green, 2017). A recent meta-analysis (Bediou et al., 2018) has shown that individuals trained on action video games improve not only on the games themselves, but on a wide range of tasks that are meant to tap a host of basic cognitive skills including top-down attention, multi-tasking, and perception (noting that these tasks look nothing like action video games and instead look like typical sterile psychology tasks)

Importantly though, while the range of cognitive skills improved by action video games is notable given the typical curse of learning specificity, this is not to say that all cognitive skills are equally enhanced as a result of action video game experience. Some skills appear to benefit to a great degree, including for instance, attentional control, which refers to the ability to focus on the task at hand and to ignore sources of noise or distraction, while simultaneously remaining highly flexible in directing attention over space and time as a function of task demands. Other skills seem to benefit less or not at all, for instance, language skills or facial emotion recognition (not surprisingly given that these are not strongly tapped by action video games).

Recent work has significantly extended the basic finding that action video game play results in an increased ability to process task-diagnostic information and suppress noisy or irrelevant information (Green et al., 2010). This work has argued that increases in this type of attentional control will, in turn, result in enhancements in the ability to learn novel tasks (Bejjanki et al., 2014; Berard et al., 2015; Gozli et al., 2014). As such, this form of generalization is referred to as "learning to learn". In a recent intervention study, participants trained on commercial action video games were contrasted to those trained on control, commercially-available strategy games on two different learning tasks. This work found a faster learning rate in a perceptual learning task and a cognitive learning task among action-trainees than in control-trainees upon completing their respective 45 h of training (Zhang et al., 2021). This intervention study demonstrates a causal role of action video games to enhance learning speed while controlling for possible enjoyment, motivational, social or expectation effects via an active control group also training on popular, commercial video games.

Finally, while the majority of the literature in this space has contrasted action video games (again, primarily first- and third-person shooters) with non-action games (primarily life simulation type games, such as The Sims or Zoo Tycoon), the emergence of new video game genres over the past decade has spurred a great deal of work seeking to characterize their impact. In particular, many new genres are what might be called "hybrid" genres – combining components of classic action-shooter games with other genres. For instance, many of the most highly successful games of the past decade have been "action-RPG", "action-adventure," or "action-RTS" hybrids, which combine many aspects of action-games (e.g., first-person or third-person shooter mechanics) with classic role-playing game (RPG) (e.g., character progression trees that allow various skills to be leveled up; dialog options; etc.), classic adventure (e.g., exploration of reasonably open-worlds), or classic real-time strategy (RTS) (e.g., control of multiple units) characteristics. Because these games contain significant "action" components, the strong prediction has been that they would produce similar benefits as seen with more classically defined action video games. This has largely been borne out in the data, where, for instance, in cross-sectional work players of the "action-like" genres tend to show similar advantages as do players of the more classically defined action genre (first- and third-person shooters) (Dale et al., 2020; Dale & Green, 2017; Large et al., 2019). This, thus, strengthens the argument that what is important for producing generalizable increases in perceptual and cognitive function is not genre per se, but is instead certain processing demands.

3.3. Game design components to enhance transfer

The surprisingly wide benefit of action video game play on cognition raises the question of which game components contribute to its impact. Here researchers have examined which components are shared across game genres that do (e.g., action video games; action-RTS; action-RPG; action-adventure) and do not (e.g., life simulation, turn-based strategy) enhance cognition. In this comparison, it is first notable that many characteristics strongly overlap between the former and latter type of games. Essentially all games, action and non-action alike, deliver a highly fun and rewarding experience; they make use of astutely designed entry levels and difficulty increases for scaffolding; they exploit rich reward structures at different time scales, as well as the use of avatars, story-telling, and the like. As such, these characteristics may be necessary for producing the enhancements that are observed (e.g., as per the previous section, in driving long-term motivated effort), but they are clearly not sufficient.

Cardoso-Leite et al. (2020) proposed five key game features that underlie the enhanced cognitive abilities that result from playing action video games. These include (i) pacing or the need for making decisions under time pressure, (ii) dividing or sustaining attention over a large part of one's environment, (iii) the need for high precision or focused attention, (iv) the need to switch between the former divided attention state and the latter focused attentional state (as required by precise aiming in shooter games for example) as a function of the ever-changing game contingencies; (iv) the need for prediction (the activities need to be structured enough that one can learn through trial and errors), and (v) the need for variability (the activities need to be diverse enough to avoid automatization of the trained brain functions; indeed full automatization limits generalization and the benefits of learning-to-learn). It is hypothesized that the combination of these five different game aspects is central in enhancing attentional control and learning-to-learn (Bavelier & Green, 2019). Yet, very few games play mechanics naturally align all of these 5 components. Unfortunately, each in isolation appears to fail to achieve the level of attentional training enhancement and transfer seen when these are properly aligned within the game play (for further discussion, see Cardoso-Leite et al., 2020).

4. Conclusions

Video games hold potential for providing an engaging, entertaining, and effective learning experience. Video games deliver active, adaptive, and immersive experiences, an ideal combination of strength to maximize learning. Yet, video games for impact must simultaneously deliver the motivation to keep engaging with the learning experience, the attention to the skills or content to be learned and the possibility of transferring what has been learned outside of the gaming context. These joint demands call for exquisite care during game design. Indeed, most if not all game design elements, from the visual and auditory stimuli used, to the cues used to draw attention to specific aspects, to the feedback given to the user, as well as the emotions any of these features evoke, must be properly aligned with the underlying cognitive processes that the learning goals call for. As discussed above, a rich, engrossing game experience that captivates the player's attention and places proper load on their cognitive or emotional resources may be utterly futile if it does not align resource allocations with learning goals. Yet, when these game design principles are met, the learner can experience the appropriate cognitive load on relevant learning materials that are conducive to enhanced learning outcomes. Future research, among cognitive and educational researchers, as well as game designers, should focus on how to achieve alignment between game playability and learning outcome without detracting from the entertainment value of video games.

Disclosure statement

Bavelier declares she is founding member and on the scientific board of Akili Interactive, Boston.

Funding

This work has been funded by the Office of Naval Research grant [N00014-17-1-2049 to C.S.G.], and the NCCR Evolving Language as well as the Office of Naval Research [N00014-20-1-2074 to D.B.].

ORCID

Angela Pasqualotto http://orcid.org/0000-0003-2172-5492
Jocelyn Parong http://orcid.org/0000-0001-7076-2535
C. Shawn Green http://orcid.org/0000-0002-9290-0262
Daphné Bavelier http://orcid.org/0000-0002-5904-1240

References

Adams, B. L. M., Stavropoulos, V., Burleigh, T. L., Liew, L. W. L., Beard, C. L., & Griffiths, M. D. (2019). Internet Gaming Disorder behaviors in emergent adulthood: A pilot study examining the interplay between anxiety and family cohesion. *International Journal of Mental Health and Addiction*, *17*(4), 828–844. https://doi.org/10.1007/s11469-018-9873-0

Adams, D. M., Pilegard, C., & Mayer, R. E. (2016). Evaluating the cognitive consequences of playing portal for a short duration. *Journal of Educational Computing Research*, *54*(2), 173–195. https://doi.org/10.1177/0735633115620431

Anderson, B. A., & Kim, H. (2019). On the relationship between value-driven and stimulus-driven attentional capture. *Attention, Perception & Psychophysics*, *81*(3), 607–613. https://doi.org/10.3758/s13414-019-01670-2

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(25), 10367–10371. https://doi.org/10.1073/pnas.1104047108

Anderson, B. A., & Yantis, S. (2013). Persistence of value-driven attentional capture. *Journal of Experimental Psychology. Human Perception and Performance*, *39*(1), 6–9. https://doi.org/10.1037/a0030860

Arena, D. A. (2012). *Commercial video games as preparation for future learning*. Stanford University.

Ariely, D. (2016). *Payoff: The hidden logic that shapes our motivations*. Simon and Schuster.

Ariely, D., & Jones, S. (2008). *Predictably irrational*. Harper Audio.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory* (pp. xiii–617). Prentice-Hall, Inc.

Baumeister, R. F., & Vohs, K. D. (2007). Self-Regulation, Ego Depletion, and Motivation. *Social and Personality Psychology Compass*, *1*(1), 115–128. https://doi.org/10.1111/j.1751-9004.2007.00001.x

Bavelier, D., & Green, C. S. (2019). Enhancing attentional control: lessons from action video games. *Neuron, 104*(1), 147–163. https://doi.org/10.1016/j.neuron.2019.09.031

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience*, *35*(1), 391–416. https://doi.org/10.1146/annurev-neuro-060909

Baylor, A. L. (2009). Promoting motivation with virtual agents and avatars: Role of visual presence and appearance. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1535), 3559–3565. https://doi.org/10.1098/rstb.2009.0148

Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2018). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. *Psychological Bulletin, November*, *144*(1), 77–110. https://doi.org/10.1037/bul0000130

Bejjanki, V. R., Zhang, R., Li, R., Pouget, A., Green, C. S., Lu, Z.-L., & Bavelier, D. (2014). Action video game play facilitates the development of better perceptual templates. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(47), 16961–16966. https://doi.org/10.1073/pnas.1417056111

Ben-Eliyahu, A., & Linnenbrink-Garcia, L. (2013). Extending self-regulated learning to include self-regulated emotion strategies. *Motivation and Emotion*, *37*(3), 558–573. https://doi.org/10.1007/s11031-012-9332-3

Berard, A. V., Cain, M. S., Watanabe, T., & Sasaki, Y. (2015). Frequent video game players resist perceptual interference. *PLoS One*, *10*(3), e0120011. https://doi.org/10.1371/journal.pone.0120011

Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself. But in a good way: Creating desirable difficulties to enhance learning. In *Psychology and the real world: Essays illustrating fundamental contributions to society* (Vol. 2, pp. 59–68). Worth Publishers.

Blizzard Entertainment. (2004). *World of warcraft*. Blizzard Entertainment.

Blumberg, F. C. (2014). *Learning by playing: Video gaming in education*. Oxford University Press. https://doi.org/10.1093/acprof:osobl/9780199896646.001.0001

Bormann, D., & Greitemeyer, T. (2015). Immersed in virtual worlds and minds: Effects of in-game storytelling on immersion, need satisfaction, and affective theory of mind. *Social Psychological and Personality Science*, *6*(6), 646–652. https://doi.org/10.1177/1948550615578177

Boyle, E. A., Connolly, T. M., Hainey, T., & Boyle, J. M. (2012). Engagement in digital entertainment games: A systematic review. *Computers in Human Behavior*, *28*(3), 771–780. https://doi.org/10.1016/j.chb.2011.11.020

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Ribeiro, C., & Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, *94*, 178–192. https://doi.org/10.1016/j.compedu.2015.11.003

Brehm, J. W. (1966). *A theory of psychological reactance*. Academic Press.

Brehm, S. S., & Brehm, J. W. (1981). *Psychological reactance: A theory of freedom and control*. Academic Press.

Breuer, J. S., & Bente, G. (2010). Why so serious? On the relation of serious games and learning. *Journal for Computer Game Culture*, *4*(1), 7–24. https://doi.org/10.7557/23.6111

Browne, C., Yannakakis, G., & Colton, S. (2012). Guest editorial: Special issue on computational aesthetics in games. *IEEE Transactions on Computational Intelligence and AI in Games*, *4*(3), 149–151. https://doi.org/10.1109/TCIAIG.2012.2212900

Buday, R., Baranowski, T., & Thompson, D. (2012). Fun and games and boredom. *GAMES FOR HEALTH: Research. Development, and Clinical Applications*, *1*(4), 257–261. https://doi.org/10.1089/g4h.2012.0026

Cardoso-Leite, P., Joessel, A., & Bavelier, D. (2020). Games for enhancing cognitive abilities. In J. Plass, R. Mayer, & B. Homer (Eds.), *Handbook of game-based learning*. MIT Press. https://mitpress.mit.edu/books/handbook-game-based-learning

Carter, M., Downs, J., Nansen, B., Harrop, M., & Gibbs, M. (2014). Paradigms of games research in HCI: a review of 10 years of research at CHI. In *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play* (pp. 27–36). ACM.

Cassidy, G. G., & MacDonald, R. A. R. (2010). The effects of music on time perception and performance of a driving game. *Scandinavian Journal of Psychology*, *51*(6), 455–464. https://doi.org/10.1111/j.1467-9450.2010.00830.x

Castro-Alonso, J. C., de Koning, B. B., Fiorella, L., & Paas, F. (2021). Five strategies for optimizing instructional materials: Instructor-and learner-managed cognitive load. *Educational Psychology Review*, *33*(4), 1379–1407. https://doi.org/10.1007/s10648-021-09606-9

Chamberland, C., Grégoire, M., Michon, P.-E., Gagnon, J.-C., Jackson, P. L., & Tremblay, S. (2015). A cognitive and affective neuroergonomics approach to game design. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *59*(1), 1075–1079. https://doi.org/10.1177/1541931215591301

Chen, J. A., Zap, N., & Dede, C. (2013). Using virtual environments to motivate students to pursue STEM careers: An expectancy-value model. In *Immersive environments, augmented realities, and virtual worlds: Assessing future trends in education* (pp. 42–56). IGI Global.

Chooi, W.-T., & Thompson, L. A. (2012). Working memory training does not improve intelligence in healthy young adults. *Intelligence*, *40*(6), 531–542. https://doi.org/10.1016/j.intell.2012.07.004

Cole, G. G., Kuhn, G., Heywood, C. A., & Kentridge, R. W. (2009). The prioritization of feature singletons in the change detection paradigm. *Experimental Psychology*, *56*(2), 134–146. https://doi.org/10.1027/1618-3169.56.2.134

Cole, H., & Griffiths, M. D. (2007). Social interactions in massively multiplayer online role-playing gamers. *Cyberpsychology & Behavior*, *10*(4), 575–583. https://doi.org/10.1089/cpb.2007.9988

Cole, S. W., Yoo, D. J., & Knutson, B. (2012). Interactivity and reward-related neural activation during a serious videogame. *PLoS One*, *7*(3), e33909. https://doi.org/10.1371/journal.pone.0033909

Collins, K. (2013). *Playing with sound: A theory of interacting with sound and music in video games*. MIT Press.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*(2), 661–686. https://doi.org/10.1016/j.compedu.2012.03.004

Curci, A., Lanciano, T., Soleti, E., & Rimé, B. (2013). Negative emotional experiences arouse rumination and affect working memory capacity. *Emotion*, *13*(5), 867–880. https://doi.org/10.1037/a0032492

Dale, G., & Green, C. S. (2017). Associations between avid action and real-time strategy game play and cognitive performance: A pilot study. *Journal of Cognitive Enhancement*, *1*(3), 295–317. https://doi.org/10.1007/s41465-017-0021-8

Dale, G., Kattner, F., Bavelier, D., & Green, C. S. (2020). Cognitive abilities of action video game and role-playing video game players: Data from a massive open online course. *Psychology of Popular Media*, *9*(3), 347–358. https://doi.org/10.1037/ppm0000237

de Freitas, S. (2018). Are games effective learning tools? A review of educational games. *Journal of Educational Technology & Society*, *21*(2), 74–84. https://www.jstor.org/stable/26388380

Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin*, *125*(6), 627–668. https://doi.org/10.1037/0033-2909.125.6.627

Deveau, J., Ozer, D. J., & Seitz, A. R. (2014). Improved vision and on-field performance in baseball through perceptual learning. *Current Biology*, *24*(4), R146–R147. https://doi.org/10.1016/j.cub.2014.01.004

DeWall, C. N., Baumeister, R. F., & Vohs, K. D. (2008). Satiated with belongingness? Effects of acceptance, rejection, and task framing on self-regulatory performance. *Journal of Personality and Social Psychology*, *95*(6), 1367–1382. https://doi.org/10.1037/a0012632

Drossos, K., Floros, A., & Kanellopoulos, N.-G. (2012). *Affective acoustic ecology: Towards emotionally enhanced sound events* [Paper presentation]. Proceedings of the 7th Audio Mostly Conference: A

Conference on Interaction with Sound (pp. 109–116). https://doi.org/10.1145/2371456.2371474

Earl, S. R., Taylor, I. M., Meijen, C., & Passfield, L. (2017). Autonomy and competence frustration in young adolescent classrooms: Different associations with active and passive disengagement. *Learning and Instruction*, *49*, 32–40. https://doi.org/10.1016/j.learninstruc.2016.12.001

Ebbinghaus, H. (1885). *Über das gedächtnis: Untersuchungen zur experimentellen psychologie*. Duncker & Humblot.

Eimer, M., Kiss, M., Press, C., & Sauter, D. (2009). The roles of feature-specific task set and bottom-up salience in attentional capture: An ERP study. *Journal of Experimental Psychology. Human Perception and Performance*, *35*(5), 1316–1328. https://doi.org/10.1037/a0015872

Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Computers & Education*, *67*, 156–167. https://doi.org/10.1016/j.compedu.2013.02.019

Ericsson, K. A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 683–703). Cambridge University Press.

Ericsson, K. A., & Harwell, K. W. (2019). Deliberate practice and proposed limits on the effects of practice on the acquisition of expert performance: Why the original definition matters and recommendations for future research. *Frontiers in Psychology*, *10*, 2396. https://doi.org/10.3389/fpsyg.2019.02396

Fabbri, M., Natale, V., & Adan, A. (2008). Effect of time of day on arithmetic fact retrieval in a number-matching task. *Acta Psychologica*, *127*(2), 485–490. https://doi.org/10.1016/j.actpsy.2007.08.011

Fang, H., He, B., Fu, H., Zhang, H., Mo, Z., & Meng, L. (2018). A surprising source of self-motivation: Prior competence frustration strengthens one's motivation to win in another competence-supportive activity. *Frontiers in Human Neuroscience*, *12*, 314. https://doi.org/10.3389/fnhum.2018.00314

Ferraro, J. C., Mouloua, M., Mangos, P. M., & Matthews, G. (2022). Gaming experience predicts UAS operator performance and workload in simulated search and rescue missions. *Ergonomics*, 1–13. https://doi.org/10.1080/00140139.2022.2048896

Firaxis Games. (2005). *Civilization IV*. https://firaxis.com/

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 1030. https://doi.org/10.1037/0096-1523.18.4.1030

Galy, E., Cariou, M., & Mélan, C. (2012). What is the relationship between mental workload factors and cognitive load types? *International Journal of Psychophysiology*, *83*(3), 269–275. https://doi.org/10.1016/j.ijpsycho.2011.09.023

Gee, J. P. (2005). Learning by design: Good video games as learning machines. *E-Learning and Digital Media*, *2*(1), 5–16. https://doi.org/10.2304/elea.2005.2.1.5

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

Gee, J. P. (2004). Learning by design: Games as learning machines. *Interactive Educational Multimedia*, *8*, 15–23.

Gentile, D., & Gentile, J. (2008). Violent video games as exemplary teachers: A conceptual analysis. *Journal of Youth and Adolescence*, *37*(2), 127–141. https://doi.org/10.1007/s10964-007-9206-2

Goldhaber, M. H. (1997). The attention economy and the Net. *First Monday*, *2*(4), 519. https://doi.org/10.5210/fm.v2i4.519

Gozli, D. G., Bavelier, D., & Pratt, J. (2014). The effect of action video game playing on sensorimotor learning: Evidence from a movement tracking task. *Human Movement Science*, *38*, 152–162. https://doi.org/10.1016/j.humov.2014.09.004

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*(6939), 534–537. https://doi.org/10.1038/nature01647

Green, C. S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current Biology*, *20*(17), 1573–1579.

Greenfield, P. M. (1994). Video games as cultural artifacts. *Journal of Applied Developmental Psychology*, *15*(1), 3–12. https://doi.org/10.1016/0193-3973(94)90003-5

Groening, C., & Binnewies, C. (2021). The more, the merrier? – How adding and removing game design elements impact motivation and performance in a gamification environment. *International Journal of Human–Computer Interaction*, *37*(12), 1130–1150. https://doi.org/10.1080/10447318.2020.1870828

Gupta, A., Lawendy, B., Goldenberg, M. G., Grober, E., Lee, J. Y., & Perlis, N. (2021). Can video games enhance surgical skills acquisition for medical students? A systematic review. *Surgery*, *169*(4), 821–829. https://doi.org/10.1016/j.surg.2020.11.034

Hense, J., Klevers, M., Sailer, M., Horenburg, T., Mandl, H., & Günthner, W. (2014). Using gamification to enhance staff motivation in logistics. In S. A. Meijer & R. Smeds, *Frontiers in gaming simulation* (pp. 206–213). Springer International Publishing.

Hodent, C. (2017). *The gamer's brain: How neuroscience and UX can impact video game design*. Crc Press.

HopeLab. (2006). *Re-mission*. https://hopelab.org/product/re-mission/

HopeLab. (2012). *Re-mission 2*. https://hopelab.org/product/re-mission/

Howard, C. J., & Holcombe, A. O. (2010). Unexpected changes in direction of motion attract attention. *Attention, Perception & Psychophysics*, *72*(8), 2087–2095. https://doi.org/10.3758/BF03196685

Huang, T.-C., Chen, C.-C., & Chou, Y.-W. (2016). Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment. *Computers & Education*, *96*, 72–82. https://doi.org/10.1016/j.compedu.2016.02.008

Huxlin, K. R., Martin, T., Kelly, K., Riley, M., Friedman, D. I., Burgin, W. S., & Hayhoe, M. (2009). Perceptual relearning of complex visual motion after V1 damage in humans. *Journal of Neuroscience*, *29*(13), 3981–3991. https://doi.org/10.1523/JNEUROSCI.4882-08.2009

Infinity Ward. (2005). *Call of duty 2*. https://www.infinityward.com/games

Jackson, S. A., Kleitman, S., & Aidman, E. (2014). Low cognitive load and reduced arousal impede practice effects on executive functioning, metacognitive confidence and decision making. *PLoS One*, *9*(12), e115689. https://doi.org/10.1371/journal.pone.0115689

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(19), 6829–6833. https://doi.org/10.1073/pnas.0801268105

Jaeggi, S. M., Buschkuehl, M., Shah, P., & Jonides, J. (2014). The role of individual differences in cognitive training and transfer. *Memory & Cognition*, *42*(3), 464–480. https://doi.org/10.3758/s13421-013-0364-z

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics*, *43*(4), 346–354.

Kato, P. M., Cole, S. W., Bradlyn, A. S., & Pollock, B. H. (2008). A video game improves behavioral outcomes in adolescents and young adults with cancer: A randomized trial. *Pediatrics*, *122*(2), e305–e317. https://doi.org/10.1542/peds.2007-3134

Katz, B., Jaeggi, S., Buschkuehl, M., Stegman, A., & Shah, P. (2014). Differential effect of motivational features on training improvements in school-based cognitive training. *Frontiers in Human Neuroscience*, *8*(April), 242–210. https://doi.org/10.3389/fnhum.2014.00242

Kramer, A. F., Bherer, L., Colcombe, S. J., Dong, W., & Greenough, W. T. (2004). Environmental influences on cognitive and brain plasticity during aging. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *59*(9), M940–M957. https://doi.org/10.1093/gerona/59.9.M940

Kuhn, J. (2018). Minecraft: education edition. *CALICO Journal*, *35*(2), 214–223. https://doi.org/10.1558/cj.34600

Large, A. M., Bediou, B., Cekic, S., Hart, Y., Bavelier, D., & Green, C. S. (2019). Cognitive and behavioral correlates of achievement in a complex multi-player video game. *Media and Communication*, *7*(4), 198–212. https://doi.org/10.17645/mac.v7i4.2314

Lavie, N. (2010). Attention, distraction, and cognitive control under load. *Current Directions in Psychological Science*, *19*(3), 143–148. https://doi.org/10.1177/0963721410370295

Law, V., & Chen, C.-H. (2016). Promoting science learning in game-based learning with question prompts and feedback. *Computers & Education*, *103*, 134–143. https://doi.org/10.1016/j.compedu.2016.10.005

Lee, H., Boot, W. R., Basak, C., Voss, M. W., Prakash, R. S., Neider, M., Erickson, K. I., Simons, D. J., Fabiani, M., Gratton, G., Low, K. A., & Kramer, A. F. (2012). Performance gains from directed training do not transfer to untrained tasks. *Acta Psychologica*, *139*(1), 146–158. https://doi.org/10.1016/j.actpsy.2011.11.003

Lester, J. C., Spain, R. D., Rowe, J. P., & Mott, B. W. (2020). Instructional support, feedback, and coaching in game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of game-based learning* (pp. 209–237). The MIT Press.

Levens, S. M., & Phelps, E. A. (2008). Emotion processing effects on interference resolution in working memory. *Emotion*, *8*(2), 267–280. https://doi.org/10.1037/1528-3542.8.2.267

Liljedahl, M. (2011). *Sound for fantasy and freedom*. https://doi.org/10.4018/978-1-61692-828-5.ch002

Linnenbrink-Garcia, L., Patall, E. A., & Pekrun, R. (2016). Adaptive motivation and emotion in education: Research and principles for instructional design. *Policy Insights from the Behavioral and Brain Sciences*, *3*(2), 228–236. https://doi.org/10.1177/2372732216644450

Livingston, I. J., Gutwin, C., Mandryk, R. L., & Birk, M. (2014). *How players value their characters in world of warcraft* [Paper presentation]. CSCW '14: Proceedings of the 17th ACM conference on Computer supported cooperative work social computing (pp. 1333–1343). https://doi.org/10.1145/2531602.2531661

Logan, T., & Woodland, K. (2015). Digital games and mathematics learning: The state of play. In T. Lowrie & R. Jorgensen (Eds.), *Digital games and mathematics learning* (pp. 277–304). Springer. https://doi.org/10.1007/978-94-017-9517-3_14

Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology*, *18*(1), 62–78. https://doi.org/10.1080/09297049.2011.575772

Luis-Ruiz, S., Caldú, X., Sánchez-Castañeda, C., Pueyo, R., Garolera, M., & Jurado, M. Á. (2020). Is cognitive training an effective tool for improving cognitive function and real-life behaviour in healthy children and adolescents? A systematic review. *Neuroscience and Biobehavioral Reviews*, *116*, 268–282. https://doi.org/10.1016/j.neubiorev.2020.06.019

MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., King, B. G., Rosenberg, E. L., Sahdra, B. K., Shaver, P. R., Wallace, B. A., Mangun, G. R., & Saron, C. D. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science*, *21*(6), 829–839. https://doi.org/10.1177/0956797610371339

Macnamara, B. N., Hambrick, D. Z., & Moreau, D. (2016). How important is deliberate practice? Reply to Ericsson (2016). *Perspectives on Psychological Science: a Journal of the Association for Psychological Science*, *11*(3), 355–358. https://doi.org/10.1177/1745691616635614

Macnamara, B. N., & Maitra, M. (2019). The role of deliberate practice in expert performance: Revisiting Ericsson, Krampe & Tesch-Römer (1993). *Royal Society Open Science*, *6*(8), 190327. https://doi.org/10.1098/rsos.190327

Madigan, J. (2015). *Getting gamers: The psychology of video games and their impact on the people who play them*. Rowman & Littlefield.

Madigan, J. (2020). Forever questing and "getting gud". In R. Kowert (Ed.), *Video games and well-being: press start* (pp. 65–76). Springer International Publishing. https://doi.org/10.1007/978-3-030-32770-5_5

Mares, M.-L., & Pan, Z. (2013). Effects of sesame street: A meta-analysis of children's learning in 15 countries. *Journal of Applied Developmental Psychology*, *34*(3), 140–151. https://doi.org/10.1016/j.appdev.2013.01.001

Mayer, R. E. (2016). What should be the role of computer games in education? *Policy Insights from the Behavioral and Brain Sciences*, *3*(1), 20–26. https://doi.org/10.1177/2372732215621311

Mayer, R. E. (2017). Using multimedia for e-learning. *Journal of Computer Assisted Learning*, *33*(5), 403–423. https://doi.org/10.1111/jcal.12197

Mayer, R. E. (2020). Cognitive foundations of game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of game-based learning* (pp. 83–110). The MIT Press.

Mayer, R. E., & Estrella, G. (2014). Benefits of emotional design in multimedia instruction. *Learning and Instruction*, *33*, 12–18. https://doi.org/10.1016/j.learninstruc.2014.02.004

McKinley, R. A., McIntire, L. K., & Funke, M. A. (2011). Operator selection for unmanned aerial systems: Comparing video game players and pilots. *Aviation, Space, and Environmental Medicine*, *82*(6), 635–642. https://doi.org/10.3357/asem.2958.2011

McNeil, N. M., & Alibali, M. W. (2005). Knowledge change as a function of mathematics experience: All contexts are not created equal. *Journal of Cognition and Development*, *6*(2), 285–306. https://doi.org/10.1207/s15327647jcd0602_6

Mcquiggan, S., Sabourin, J., & Lester, J. (2010). Affective transitions in narrative-centered learning environments. *Educational Technology & Society*, *13*, 40–53. https://www.jstor.org/stable/jeductechsoci.13.1.40

Mekler, E. D., Brühlmann, F., Tuch, A. N., & Opwis, K. (2017). Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior*, *71*, 525–534. https://doi.org/10.1016/j.chb.2015.08.048

Mélan, C., Galy, E., & Cariou, M. (2007). Mnemonic processing in air traffic controllers: Effects of task parameters and work organization. *The International Journal of Aviation Psychology*, *17*(4), 391–409. https://doi.org/10.1080/10508410701527886

Mills, D. J., Milyavskaya, M., Mettler, J., Heath, N. L., & Derevensky, J. L. (2018). How do passion for video games and needs frustration explain time spent gaming? *The British Journal of Social Psychology*, *57*(2), 461–481. https://doi.org/10.1111/bjso.12239

Mitsuhara, H., Iguchi, K., & Shishibori, M. (2017). Using digital game, augmented reality, and head mounted displays for immediate-action commander training. *International Journal of Emerging Technologies in Learning*, *12*(2), 101–117. https://doi.org/10.3991/ijet.v12i02.6303.

Moreno, R. (2006). Does the modality principle hold for different media? A test of the method-affects-learning hypothesis. *Journal of Computer Assisted Learning*, *22*(3), 149–158. https://doi.org/10.1111/j.1365-2729.2006.00170.x

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, *19*(3), 309–326. https://doi.org/10.1007/s10648-007-9047-2

Munday, R. (2007). *Music in video games* (pp. 48–67). https://doi.org/10.3366/edinburgh/9780748625338.003.0004

Nelson, B., Kim, Y., Foshee, C., & Slack, K. (2014). Visual signaling in virtual world-based assessments: The SAVE Science project. *Information Sciences*, *264*, 32–40. https://doi.org/10.1016/j.ins.2013.09.011

Nelson, B., & Erlandson, B. (2008). Managing cognitive load in educational multi-user virtual environments: Reflection on design practice. *Educational Technology Research and Development*, *56*(5–6), 619–641. https://doi.org/10.1007/s11423-007-9082-1

Nelson, B., & Kim, Y. (2020). Multimedia design principles in game-based learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of game-based learning* (pp. 307–327). The MIT Press.

Nietfeld, J. L., Shores, L. R., & Hoffmann, K. F. (2014). Self-regulation and gender within a game-based learning environment. *Journal of Educational Psychology*, *106*(4), 961–973. https://doi.org/10.1037/a0037116

Nintendo, E., Nintendo, E., Miyamoto, S., Tezuka, T., Kondo, K., Boy, G., Advance, G. B., Nintendo, D., & Wii, U. (1986). *The legend of Zelda*. https://www.zelda.com/

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, *7*(1), 44–64. https://doi.org/10.1016/0010-0285(75)90004-3

Nunes, J. C., & Dreze, X. (2006). The endowed progress effect: How artificial advancement increases effort. *Journal of Consumer Research*, *32*(4), 504–512. https://doi.org/10.1086/500480

Nye, B., Core, M., Ghosal, A., & Walker, P. (2021). *Metrics for engagement in games and simulations for learning* (pp. 107–130). https://doi.org/10.4324/9780429282201-5

O'Neil, H. F., & Perez, R. S. (2008). *Computer games and team and individual learning*. Elsevier.

Peng, W., Lin, J.-H., Pfeiffer, K. A., & Winn, B. (2012). Need satisfaction supportive game features as motivational determinants: An experimental study of a self-determination theory guided exergame. *Media Psychology*, *15*(2), 175–196. https://doi.org/10.1080/15213269.2012.673850

Plancher, G., Massol, S., Dorel, T., & Chainay, H. (2019). Effect of negative emotional content on attentional maintenance in working memory. *Cognition & Emotion*, *33*(7), 1489–1496. https://doi.org/10.1080/02699931.2018.1561420

Plass, J. L., Heidig, S., Hayward, E. O., Homer, B. D., & Um, E. (2014). Emotional design in multimedia learning: Effects of shape and color on affect and learning. *Learning and Instruction*, *29*, 128–140. https://doi.org/10.1016/j.learninstruc.2013.02.006

Plass, J. L., & Kalyuga, S. (2019). Four ways of considering emotion in cognitive load theory. *Educational Psychology Review*, *31*(2), 339–359. https://doi.org/10.1007/s10648-019-09473-5

Possler, D., Kümpel, A. S., & Unkel, J. (2020). Entertainment motivations and gaming-specific gratifications as antecedents of digital game enjoyment and appreciation. *Psychology of Popular Media*, *9*(4), 541–552. https://doi.org/10.1037/ppm0000248

Przybylski, A. K., Rigby, C. S., & Ryan, R. M. (2010). A motivational model of video game engagement. *Review of General Psychology*, *14*(2), 154–166. https://doi.org/10.1037/a0019440

Rachmatullah, A., Reichsman, F., Lord, T., Dorsey, C., Mott, B., Lester, J., & Wiebe, E. (2021). Modeling secondary students' genetics learning in a game-based environment: Integrating the expectancy-value theory of achievement motivation and flow theory. *Journal of Science Education and Technology*, *30*(4), 511–528. https://doi.org/10.1007/s10956-020-09896-8

Radel, R., Pelletier, L., Baxter, D., Fournier, M., & Sarrazin, P. (2014). The paradoxical effect of controlling context on intrinsic motivation in another activity. *Learning and Instruction*, *29*, 95–102. https://doi.org/10.1016/j.learninstruc.2013.09.004

Radel, R., Pelletier, L. G., Sarrazin, P., & Milyavskaya, M. (2011). Restoration process of the need for autonomy: The early alarm stage. *Journal of Personality and Social Psychology*, *101*(5), 919–934. https://doi.org/10.1037/a0025196

Raith, L., Bignill, J., Stavropoulos, V., Millear, P., Allen, A., Stallman, H. M., Mason, J., De Regt, T., Wood, A., & Kannis-Dymand, L. (2021). Massively multiplayer online games and well-being: A systematic literature review. *Frontiers in Psychology*, *12*, 698799. https://doi.org/10.3389/fpsyg.2021.698799

Rebetez, C., & Betrancourt, M. (2007). Video game research in cognitive and educational sciences. *Cognition, Brain, Behavior*, *11*(1), 131–142. https://tecfa.unige.ch/perso/mireille/papers/Rebetez_Betrancourt_CognBra.pdf

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., Kane, M. J., & Engle, R. W. (2013). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology. General*, *142*(2), 359–379. https://doi.org/10.1037/a0029082

Reiners, T., Teräs, H., Chang, V., Wood, L., Gregory, S., Gibson, D., Petter, N., & Teräs, M. (2014). *Authentic, immersive, and emotional experience in virtual learning environments: The fear of dying as an important learning experience in a simulation* [Paper presentation]. Proceedings of the 23rd Annual Teaching and Learning Forum, Jan 30–31, 2014.

Rey, G. D. (2012). A review of research and a meta-analysis of the seductive detail effect. *Educational Research Review*, *7*(3), 216–237. https://doi.org/10.1016/j.edurev.2012.05.003

Rey, G. D. (2014). Seductive details and attention distraction—An eye tracker experiment. *Computers in Human Behavior*, *32*, 133–144. https://doi.org/10.1016/j.chb.2013.11.017

Rigby, S., & Ryan, R. M. (2011). Glued to games: How video games draw us in and hold us spellbound. In *Glued to games: How video games draw us in and hold us spellbound* (pp. xiii, 186). Praeger/ABC-CLIO.

Rockstar Games. (2010). *Red dead redemption*. https://www.rockstargames.com/reddeadredemption/restricted-content/agegate/form?redirect=https%3A%2F%2Fwww.rockstargames.com%2Freddeadredemption%2F&options=&locale=en_us

Rogers, R. (2017). The motivational pull of video game feedback, rules, and social interaction: Another self-determination theory approach. *Computers in Human Behavior*, *73*, 446–450. https://doi.org/10.1016/j.chb.2017.03.048

Rosser, J. C., Jr, Lynch, P. J., Cuddihy, L., Gentile, D. A., Klonsky, J., & Merrell, R. (2007). The impact of video games on training surgeons in the 21st century. *Archives of Surgery*, *142*(2), 181–186. https://doi.org/10.1001/archsurg.142.2.181

Rowe, J. P., Lobene, E. V., Mott, B. W., & Lester, J. C. (2013). *Embedded scaffolding for reading comprehension in open-ended narrative-centered learning environments*. https://www.intellimedia.ncsu.edu/wp-content/uploads/rowe-oeles-2013.pdf

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist*, *55*(1), 68–78. https://doi.org/10.1037//0003-066x.55.1.68

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion*, *30*(4), 344–360. https://doi.org/10.1007/s11031-006-9051-8

Sagi, D., & Tanne, D. (1994). Perceptual learning: Learning to see. *Current Opinion in Neurobiology*, *4*(2), 195–199.

Sailer, M., Hense, J., Mandl, J., & Klevers, M. (2013). Psychological perspectives on motivation through gamification. *Interaction Design and Architecture Journal*, *19*, 28–37.

Sailer, M., Hense, J. U., Mayr, S. K., & Mandl, H. (2017). How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in Human Behavior*, *69*, 371–380. https://doi.org/10.1016/j.chb.2016.12.033

Salen, K., Tekinbaş, K. S., Torres, R., Shapiro, A., Wolozin, L., & Rufo-Tepper, R. (2011). *Quest to learn: Developing the school for digital kids*. MIT Press.

Schanzer, E., Fisler, K., Krishnamurthi, S., & Felleisen, M. (2015). *Transferring skills at solving word problems from computing to algebra through Bootstrap* [Paper presentation]. SIGCSE '15: Proceedings of the 46th ACM Technical Symposium on Computer Science Education (pp. 616–621). https://doi.org/10.1145/2676723.2677238

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred days of cognitive training enhance broad cognitive abilities in adulthood: Findings from the COGITO study. *Frontiers in Aging Neuroscience*, *2*, 27. https://doi.org/10.3389/fnagi.2010.00027

Schrier, K. (2018). Guiding questions for game-based learning. In J. Voogt, G. Knezek, R. Christensen, & K. W. Lai (Eds.), *Second handbook of information technology in primary and secondary education* (pp. 1–20). Springer.

Schunk, D. H., & DiBenedetto, M. K. (2020). Motivation and social cognitive theory. *Contemporary Educational Psychology*, *60*, 101832. https://doi.org/10.1016/j.cedpsych.2019.101832

Scionti, N., Cavallero, M., Zogmaister, C., & Marzocchi, G. M. (2020). Is cognitive training effective for improving executive functions in preschoolers? A systematic review and meta-analysis. *Frontiers in Psychology*, *10*(January), 2812. https://doi.org/10.3389/fpsyg.2019.02812

Serge, S. R., Priest, H. A., Durlach, P. J., & Johnson, C. I. (2013). The effects of static and adaptive performance feedback in game-based training. *Computers in Human Behavior*, *29*(3), 1150–1158. https://doi.org/10.1016/j.chb.2012.10.007

Sharek, D., & Wiebe, E. (2014). Measuring video game engagement through the cognitive and affective dimensions. *Simulation & Gaming*, *45*(4–5), 569–592. https://doi.org/10.1177/1046878114554176

Shores, L. R., Hoffmann, K. F., Nietfeld, J. L., & Lester, J. C. (2012). The role of sub-problems: Supporting problem solving in narrative-centered learning environments. In S. A. Cerri, W. J. Clancey, G. Papadourakis, & K. Panourgia (Eds.), *Intelligent tutoring systems. ITS 2012. Lecture notes in computer science* (Vol. 7315, pp. 464–469). Springer.

Shores, L. R., Rowe, J. P., & Lester, J. C. (2011). Early prediction of cognitive tool use in narrative-centered learning environments. In G. Biswas, S. Bull, J. Kay, & A. Mitrovic (Eds.), *Artificial intelligence in education. AIED 2011. Lecture notes in computer science* (Vol. 6738, pp. 320–327). Springer.

Sony Interactive Entertainment. (2017). *Horizon: Zero dawn [Game].* Playstation.

Sony Online Entertainment. (1999). *EverQuest.* Sony Online Entertainment.

Stojanoski, B., Wild, C. J., Battista, M. E., Nichols, E. S., & Owen, A. M. (2021). Brain training habits are not associated with generalized benefits to cognition: An online study of over 1000 “brain trainers”. *Journal of Experimental Psychology. General*, *150*(4), 729–738. https://doi.org/10.1037/xge0000773

Sundararajan, N., & Adesope, O. (2020). Keep it coherent: A meta-analysis of the seductive details effect. *Educational Psychology Review*, *32*(3), 707–734. https://doi.org/10.1007/s10648-020-09522-4

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 Years later. *Educational Psychology Review*, *31*(2), 261–292. https://doi.org/10.1007/s10648-019-09465-5

Takacs, Z. K., & Kassai, R. (2019). The efficacy of different interventions to foster children ' s executive function skills: A series of meta-analyses. *Psychological Bulletin*, *145*(7), 653–697. https://doi.org/10.1037/bul0000195

Tamborini, R., Bowman, N. D., Eden, A., Grizzard, M., & Organ, A. (2010). Defining media enjoyment as the satisfaction of intrinsic needs. *Journal of Communication*, *60*(4), 758–777. https://doi.org/10.1111/j.1460-2466.2010.01513.x

Tanovic, E., Gee, D. G., & Joormann, J. (2018). Intolerance of uncertainty: Neural and psychophysiological correlates of the perception of uncertainty as threatening. *Clinical Psychology Review*, *60*, 87–99. https://doi.org/10.1016/j.cpr.2018.01.001

Thatgamecompany. (2012). *Journey*. https://thatgamecompany.com/journey/

Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & Psychophysics*, *49*(1), 83–90. https://doi.org/10.3758/BF03211619

Theeuwes, J. (1993). Visual selective attention: A theoretical analysis. *Acta Psychologica*, *83*(2), 93–154. https://doi.org/10.1016/0001-6918(93)90042-P

Traut, H. J., Guild, R. M., & Munakata, Y. (2021). Why does cognitive training yield inconsistent benefits? A meta-analysis of individual differences in baseline cognitive abilities and training outcomes. *Frontiers in Psychology*, *12*, 662139. https://doi.org/10.3389/fpsyg.2021.662139

Turatto, M., & Galfano, G. (2000). Color, form and luminance capture attention in visual search. *Vision Research*, *40*(13), 1639–1643. https://doi.org/10.1016/S0042-6989(00)00061-4

Turkay, S., Hoffman, D., Kinzer, C. K., Chantes, P., & Vicari, C. (2014). Toward understanding the potential of games for learning: Learning theory, game design characteristics, and situating video games in classrooms. *Computers in the Schools*, *31*(1–2), 2–22. https://doi.org/10.1080/07380569.2014.890879

Um, E., Plass, J. L., Hayward, E. O., & Homer, B. D. (2012). Emotional design in multimedia learning. *Journal of Educational Psychology*, *104*(2), 485–498. https://doi.org/10.1037/a0026609

Valve Corporation. (2011). *Portal 2* [Game [Windows]]. Valve Corporation.

Van den Broeck, A., Ferris, D. L., Chang, C.-H., & Rosen, C. C. (2016). A review of self-determination theory's basic psychological needs at work. *Journal of Management*, *42*(5), 1195–1229. https://doi.org/10.1177/0149206316632058

van Gog, T. (2013). Time on task. In J. Hattie & E. M. Anderman (Eds.), *International guide to student achievement* (pp. 432–433). Routledge/Taylor & Francis Group.

Van Gog, T. (2014). 11 – The signaling (or cueing) principle in multimedia learning. In *The Cambridge handbook of multimedia learning* (pp. 263–278). Cambridge University Press.

Vansteenkiste, M., Ryan, R. M., & Soenens, B. (2020). Basic psychological need theory: Advancements, critical themes, and future directions. *Motivation and Emotion*, *44*(1), 1–31. https://doi.org/10.1007/s11031-019-09818-1

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Watson, P., Pearson, D., Chow, M., Theeuwes, J., Wiers, R. W., Most, S. B., & Le Pelley, M. E. (2019). Capture and control: Working memory modulates attentional capture by reward-related stimuli. *Psychological Science*, *30*(8), 1174–1185. https://doi.org/10.1177/0956797619855964

Weitze, C. L. (2014). Developing goals and objectives for gameplay and learning. In *Learning, education and games: Volume one: Curricular and design considerations* (pp. 225–249). Carnegie Mellon University ETC Press.

Whitton, N. (2009). *Learning with digital games: A practical guide to engaging students in higher education*. Routledge.

Wigfield, A., & Cambria, J, (2010). Expectancy-value theory: Retrospective and prospective. In T. C. Urdan & S. A. Karabenick, *The decade ahead: Theoretical perspectives on motivation and achievement* (Vol. 16, Part A, pp. 35–70). Emerald Group Publishing Limited. https://doi.org/10.1108/S0749-7423(2010)000016A005

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation. *Contemporary Educational Psychology*, *25*(1), 68–81. https://doi.org/10.1006/ceps.1999.1015

Xi, N., & Hamari, J. (2019). Does gamification satisfy needs? A study on the relationship between gamification features and intrinsic need satisfaction. *International Journal of Information Management*, *46*, 210–221. https://doi.org/10.1016/j.ijinfomgt.2018.12.002

Yan, T., Conrad, F., Tourangeau, R., & Couper, M. (2011). Should I stay or should I go: The effects of progress feedback, promised task duration, and length of questionnaire on completing web surveys. *International Journal of Public Opinion Research*, *23*(2), 131–147. https://doi.org/10.1093/ijpor/edq046

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology. Human Perception and Performance*, *10*(5), 601–621. https://doi.org/10.1037/0096-1523.10.5.601

Yu, S., Levesque-Bristol, C., & Maeda, Y. (2018). General need for autonomy and subjective well-being: A meta-analysis of studies in the US and East Asia. *Journal of Happiness Studies*, *19*(6), 1863–1882. https://doi.org/10.1007/s10902-017-9898-2

ZeptoLab. (2020). *Bullet echo*. https://www.zeptolab.com/games/bulletecho

Zhang, R.-Y., Chopin, A., Shibata, K., Lu, Z.-L., Jaeggi, S. M., Buschkuehl, M., Green, C. S., & Bavelier, D. (2021). Action video game play facilitates “learning to learn”. *Communications Biology*, *4*(1), 1154. https://doi.org/10.1038/s42003-021-02652-7

About the Authors

Angela Pasqualotto received her Ph.D. in Cognitive Sciences from the University of Trento and is currently a postdoctoral researcher in the BavelierLab (University of Geneva). She is mainly interested on the design and the evaluation of innovative tools for students with special needs.

Jocelyn Parong is currently a postdoctoral research associate in the Learning and Transfer Lab in the Psychology Department at the University of Wisconsin – Madison. Her research focuses on how people can learn cognitive skills through computerized training and learn knowledge from multimedia lessons.

C. Shawn Green received his Ph.D. in Brain and Cognitive Sciences from the University of Rochester and completed post-doctoral training at the University of Minnesota before joining the psychology department at UW-Madison in 2011. His research focuses on how individuals' perceptual and cognitive skills can be improved via behavioral training.

Daphné Bavelier is an expert on how humans learn, and in particular, how the brain adapts to changes in experience. Her lab established that playing action-packed video games benefits several aspects of cognition. Moreover, her laboratory investigates how new media can be leveraged to foster learning and brain plasticity.