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AI, Computer Science and Robotics Technology

RESEARCH PAPER

Prisms of Neuroscience: Frameworks for Thinking About Educational Gamification

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Abstract

The mind, brain, body, and environment are inextricably interconnected. In the field of education, this neuropsychologically-backed claim suggests that to optimize learners' (1) educational experiences, (2) retention of knowledge, and (3) creative use and application of knowledge beyond the classroom walls, teaching practices in *all* content areas must align with *all* parts of what makes us human. Unlike hardwired computers, our neuroplastic brains change with environmental interactions via our bodies. This article examines technology as an extension of cognition, where gamification emerges as a fundamental rather than supplemental tool for educators to co-construct knowledge with students. Gamification supports student learning and holistic well-being when considering affective, social, and motoric entanglements with cognitive processes. This article creatively employs five neuroscientific "prisms" to support and explain this humanistic claim. When synthesized, these refracted dimensions provide a framework for thinking about how, why, and when gamification functions as a valuable 21st-century educational tool.

Keywords: gamification, embodied cognition, neuroscience, neuroeducation, multidimensional well-being, intrinsic motivation

Citation
Lisa Serice (2023), Prisms of Neuroscience: Frameworks for Thinking About Educational Gamification. *AI, Computer Science and Robotics Technology* 2023(2), 1–30.

DOI
https://doi.org/10.5772/acrt.13

Published
22 March 2023

1. Introduction

In November 1979, the English progressive rock band Pink Floyd released *Another Brick in the Wall* [1]. This single from their inventive rock opera concept album, *The Wall,* quickly garnered the number one spot on 14 international music charts, was nominated for a Grammy, and continues to make Rolling Stone Magazine's list of *The 500 Greatest Songs of All Time* [2]. As is often the case with art, the song's establishment-challenging lyrics stirred their fair share of controversy [3]. While it is not the objective of this article to deconstruct socio-political themes in a rock song (interesting as that would be!), one line in the tune serves as a psychological (if not memorable) springboard for the thesis of this article on educational gamification—the incorporation of game design elements in educational settings aimed at increasing learner engagement and motivation [4]. As the tune wraps up, the singer mocks a Dickensian schoolmaster shouting at a child, "*If you don't eat yer meat, you can't have any pudding! How can you have any pudding if you don't eat yer meat*?"

The song's catchy admonition stems from a familiar parental technique employed to coax children into eating the nutritionally dense elements of their meal by dangling dessert, the less nutritious—but perhaps tastier—food, as a reward. Known informally in psychology as "Grandma's Law," this behavioral modification practice follows the Premack principle [5]. The principle, developed by psychologist David Premack in 1965, states that "any Response A can reinforce any other Response B if the independent rate of A is greater than the independent rate of B" [5]. In other words, high-probability behavior is a tool to negotiate lower-probability behavior. Or, in the words of Pink Floyd, "*If you don't eat yer meat, you can't have any pudding*!"

So, what does "Grandma's Law" have to do with educational gamification? The aim of this paper is to answer this question creatively by providing teachers, parents, policymakers, and educational game designers with new ways to think about educational gamification's creativity-supporting strengths for 21st-century learners. Importantly, this article's contribution to the scholarly discourse is the use of a neuroeducation lens to understand how educational gamification serves as "meat" *and* "pudding" in learning applications.

Using the metaphor of a prism separating visible light into colors, the complex constructs impacting gamification are "refracted" into arrays of subconstructs through the lenses of neuroscience and neuroeducation. These arrays create frameworks to help educators discern if a gamification tool meets essential criteria for creating a holistic learning experience. Teachers, parents, policymakers, and educational game designers can use the framework in developing and using educational gamification.

2. *What is gamification?*

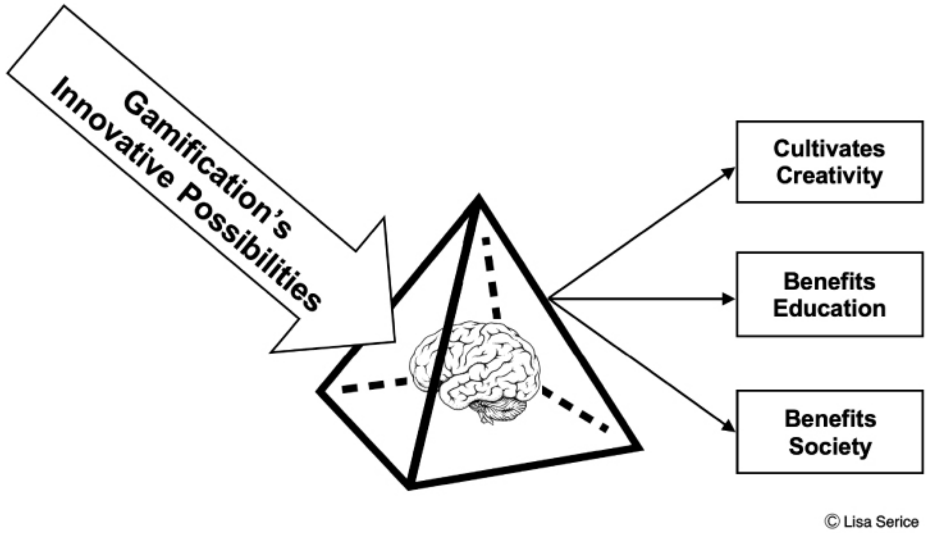
Gamification uses gaming elements such as game mechanics, aesthetics, and game thinking in non-game situations [6–8]. A game is designed for entertainment, while gamification is designed to "engage people, motivate action, promote learning, and solve problems" [7]. Some organizations gamify learning by simulating real-world situations for specific training [9]. Marketers use gamification to engage customer engagement and reward loyalty [10]. Educators apply game design elements in educational settings as a pedagogical approach to engage students, increase motivation, and improve learning outcomes [8]. In each of these scenarios, game mechanics, such as rewards, levels, high scores, badges, social interactions/sharing, and choose-your-own-adventure plots, help learners focus on activities and tasks that are not in themselves 'games' [11]. The following section offers a brief timeline of the history of gamification.

In the time continuum, the ability to gamify using technology is recent [12]. Nevertheless, the underlying concept of reward and penalty traces back to antiquity [13]. Whether technologized or not, gamification taps into human motivation systems and borrows cultural aspects of real life where people are promoted/rewarded for doing good/right and penalized for doing bad/wrong [14]. On Gamify.com, Shannon [12] tracks commercial gamification in the United States from 1896—when marketers first sold S&H Green Stamps to retailers to reward loyal customers—to 2018—when gamification's market value hit $5.5 billion U.S. dollars. This value represents more than double its 2016 market value of $2.8 billion U.S. dollars. A more detailed timeline tracing gamification highlights from the S&H Green Stamp initiative to the current $13.44 billion U.S. dollar gamification industry is found in this article's supplementary materials.

Techno-optimists like researcher and tech developer Jane McGonigal believe in harnessing the scalable power of gamification to solve complex global problems. In her TED talk on why gamification can make a better world, she identifies four characteristics of gamers that make gamification an unparalleled resource for creating the future [15]. These traits include (1) urgent optimism—a belief that epic wins are possible, (2) virtuosity at weaving tight social fabric, (3) blissful productivity—happiness at working hard, and (4) epic meaning—a love of being attached to awe-inspiring missions. Though various permutations of rewards and penalties will likely always exist in social systems like business, law, and the military [16], the following sections illustrate how gamification and alternate reality games (ARGs) trend toward broader scopes of social motivations—helping people extract more out of their real lives as opposed to escaping it [17].

3. Broad potentials of gamification

The technological novelty of gamification spurs innovative change in multiple contexts, including health, education, commerce, work, service sectors, marketing, governance, and sustainability [16]. Gaming is already globally established and familiar to consumers as a form of leisure and competition [16]. Consequently, this familiarity in essence supports gamification's smooth integration into non-gaming contexts. Prism 1 refracts gamification's innovative possibilities into three broad yet critical categories—the potential to cultivate human creativity, benefit education, and benefit society. The following sections illustrate a variety of processes leading to those outcomes.



Prism 1. Gamification's innovative possibilities.

3.1. Gamification cultivates creativity

The creative process involves biopsychosocial [18] interactions between cognitive abilities (biology), social factors (sociology), and personality characteristics (psychology) [18]. While debates continue to challenge how to judge the external validation of the value and utility of creative outcomes [19], experts across disciplines agree that the creative process includes imagining, generating, and sharing subjective mental representations or "intentional novelty" [20]. The "common denominator" [19] of all creative endeavors is the devotion of time and energy to put imagination into action to create something novel [21].

As such, creativity requires surpassing imitation and creating something new. Scientific research and human progress depend on this hallmark of creativity and its two requisite features—the allowance of pursuing multiple hypotheses and the allowance to be *wrong* [19]. However, despite creativity being integral to society's productivity, innovation, and sustainability, a deficit exists in the United States [22]. Furthermore, some research suggests that the uncertainty of creative innovation fosters negative biases about creativity among some members of society [23]. The consequence of a negative bias toward creativity is that people may subconsciously or purposefully suppress their creativity for fear of being "atypical, abnormal, or deviant" [24].

Eagleman and Brandt [21] use the lens of neuroscience to explain how creativity and innovation are part of the human brain's wiring. They describe how the neurological key to creative wiring is the distance between sensory inputs and motor outputs in the brain. Animals act reflexively to incoming signals, which are followed by forced responses. However, humans take in ideas, store them (memory), then manipulate them (creativity). This manipulation of ideas is the root of human creativity—the ability to simulate possible futures (or *what-ifs*) and evaluate them [21].

Additionally, the brain continually leverages the tension between novelty and familiarity [21]. Novelty catalyzes an increase in brain activity, which causes brains to become novelty seekers. However, when something novel is repeated (repetition suppression), the brain shows less activation [25]. In essence, the brain lives in a constant state of tension between novelty and boredom—if it encounters too much predictability, it tunes out; if it encounters too much novelty, it becomes disoriented. Schomaker and Wittmann's [26] research on novelty-seeking using virtual reality (VR) provides a thorough neuroscientific explanation of "synaptic tagging and capture" [p1]. It suggests that active exploration in novel situations may enhance temporally extended memory.

Significantly, innovations do not magically appear out of the blue but from smooth progressions and iterations of previously generated ideas [21]. In other words, ideas have a history. Eagleman and Brandt [21] offer a unique framework for understanding the primary means by which all creative ideas evolve by dividing the cognitive landscape into three brain strategies for manipulating ideas—bending, breaking, and blending. Bending is the twisting or modifying of a concept to generate something new. Breaking involves taking something apart (think: breaking it into pieces) to reconfigure it or make something completely new. Blending entails merging things to make something new or removing something from one context to apply it to another. Our brains apply these three operations to generate novel worlds from previous ideas.

The neuroscience behind creativity has implications for learning and proliferating novel ideas. The nature of gamification in non-gaming contexts offers the brain opportunities to bend, break, and blend the ideas of others (knowledge) to generate creative solutions to complex problems. Gamification also has the potential to facilitate creative thinking by removing barriers or established behavioral routines and norms by offering new realities and even rules. Alternate reality games allow learners to integrate cognitive abilities, social factors, and personality characteristics in low or no-stakes settings where they can experiment and proliferate many hypotheses to solve problems and share these ideas with permission to make mistakes.

In alternate realities, players adopt new roles, are liberated from social norms, gain insights from interactions with others, and freely explore their characters [27]. Conversely, in live-action role-playing games (LARPs), players act as themselves but reality changes around them [28]. For example, in a game called World Without Oil, researcher and game design expert Jane McGonigal shows how collective intelligence in gaming is a means for improving the quality of human life or solving complex problems [15]. In this game, the world slowly ran out of oil, and players were given updates about new oil strikes, shortages, and prices. These updates prompted players to ponder what these events would mean to them in their daily lives and how life would personally change. Insights were shared and aggregated into signals of change that could be used for long-term scenario planning in different industries.

In location-based games (LARGs), digital content in augmented reality applications is tied to the player's geographical location [29]. Portals are in these spaces where players must be physically present to interact with digital objects [30]. Intersecting digital and physical narratives create hybrid spaces—transferring meaning between virtual and physical worlds. Consequently, creativity generated in these games has the potential to (1) usher in new paradigms for community planning centering around the needs of people, (2) reinvent and democratize public places, and (3) fuse expertise between gamers and artists in art spaces. The popularity of LARGs is evidenced by *Pokémon Go,* a LARG that engages with sites of cultural significance.

Cyber-optimists like Stanford neuroscientist, author, and tech developer David Eagleman believe that the learners in this generation will be the smartest in human history due to the ability to use technology as an extension of their cognition [31, 32]. Eagleman's optimism derives from an understanding of memory, the importance of salience in memory, and the purpose of the brain. Thousands of years ago, humans had to memorize knowledge to access it. Eventually, books and filing cabinets stored information for retrieval, but now human beings have quicker access than ever to global knowledge in the smartphones in their pockets. Due to the biological limit of memory, offloading information into devices gives the brain a boost—allowing it to spend its energy reinforcing synaptic connections in creative endeavors, e.g., taking facts and bending, breaking, and blending them into something meaningful [31].

This creative meaning-making afforded by technology is crucial because neuropsychology shows that we remember things that have emotional valence or value associated with a stimulus [33]. Traditionally, the brain was thought of as a device to cogitate or think grand thoughts. However, this model is inaccurate. The reason for memory is to predict the future—make better simulations of what will happen and plan the subsequent actions [34, 35]. Studies in amnesia and memory loss show that memory and simulation are rooted in the same neural mechanisms [36]. In other words, the purpose of the human brain is to use memory to guide movement and action in a social world.

The neuroeducation takeaway from the affective neuroscience of emotional valence for gamification is that anything tagged with a high emotional valence will be written down in memory because that matters most for navigating our future [35].

From a learning perspective, smartphones, computers, and tablets serve as exo-brains that allow students to access global knowledge with unprecedented speed. With access to this virtually infinite knowledge bank, arguably, what becomes most important in the educational landscape is to connect learners with material in a way that matters to them while providing them with opportunities to bend, break, and blend it into novel solutions for complex problems. Generating this kind of creativity benefits education and society. The following sections further this discussion.

3.2. Gamification benefits education

There are neurological reasons humans are glued to their technological devices—people care about what is in them [32]. Gamification benefits education by leveraging affective neuroscience and neuroplasticity (the brain's ability to change) to boost learning by generating care and curiosity. To change the brain (i.e., learn), a particular cocktail of neurotransmitters needs to be present for content to stick [36].

Memory and recall are more accessible when curiosity and care are present because the body releases dopamine that helps it rewire [37]. This condition means that content learned during a brain primed with the right mix of neurotransmitters is like a seed planted in a fertile garden—more likely to take root and grow.

In educational gamification, learning content commingles with individuals' motivation [6, 11, 38]. Elements included in well-designed gamification foster engagement, structured motivation, improved teamwork, growth mindset, increased intrinsic motivation, positive competition, and immediate feedback for retention and recall of information [13]. Advocates of educational gamification argue that gamified learning tasks are more interesting and exciting because game aesthetics create enjoyment [11]. This enjoyment manifests in several ways, including "sensations of excitement and joy, the emotions of wonder and curiosity from the discovery of a new world that the game presents, the immersive narrative, the challenge that tests our abilities and boosts our confidence, or the chance to release stress and clear the mind from everyday worries" [11].

Gamification also benefits education when it incorporates evidence-based learning/study strategies that Brown and colleagues [39] identify as making knowledge "stick" (i.e., stored in long-term memory). Gamified instruction providing learners with *retrieval practice* or low-stakes self-quizzing helps learners focus on central precepts and meanings of information. *Low-stakes quizzes* provide the learner with immediate feedback on what has not been mastered. Gamified scenarios can incorporate *spacing* into the design—offering lots of practice with new concepts but with gaps between practice sessions. Similarly, gamification benefits education when designed to *interleave* topics or break up repetitive practice by commingling topics and ideas. Lastly, gamification is an educational learning tool when designs allow students to *elaborate* on concepts to find new layers of meaning and *reflect* on what has been learned. In aggregate, elaboration and reflection assist learners with *calibrating their learning by aligning judgments* about what is known and not known with objective feedback.

Additionally, evidence in the science of motivation suggests that the "attention-grabbling" power of technological gamification addresses a growing challenge in 21st-century education—the ability to capture students' attention and create the kind of engagement necessary for learning tasks [40]. Self-determination theory (SDT) posits that human beings are innately inclined toward psychological growth and consequently toward learning, mastery, and connection with others [41]. In other words, people innately *want* to learn, feel competent at tasks, and relate with others.

However, because these human tendencies are not considered "automatic" [41], they require robust supportive conditions to meet three fundamental human needs. These needs include autonomy (a sense of initiative and ownership of actions), competence (a sense of the ability to succeed and grow), and relatedness (a sense of belonging and connectedness). A growing body of SDT research demonstrates how the motivational draw of successful video games is due to gaming features that satisfy players' autonomy, competence, and relatedness needs [40, 42, 43]. Gamification-infused teaching can provide these robust supportive learning conditions.

The key takeaway is that through gamification, students are intrinsically motivated to take factual, conceptual, procedural, and metacognitive knowledge and put them into action in simulated experiences that are impossible to achieve without technology. In this sense, real-world simulations in gamification provide unique cognitive opportunities for students to engage in the actionable tenets of Bloom's revised taxonomy [44]. On a granular level, simulations create the opportunity to (1) remember (recognize, recall), (2) understand (interpret, exemplify, classify, summarize, infer, compare, explain), (3) apply (execute, implement), (4) analyze (differentiate, organize, attribute), and (5) evaluate (check, critique). Arguably, gamification's most significant strength is its unique ability to actualize Bloom's highest order of cognition—the opportunity for students to (6) create (generate, plan, produce). Simulations in gamification allow a human brain to practice and strengthen a uniquely human brain function—creativity. Why is creativity so important? Creativity, in various ingenious social, scientific, and artistic human endeavors, is the wellspring of all human progress, and human progress leads to human flourishing and the ease of human suffering.

3.3. Gamification benefits society

Gamification's strength is its power to capture peoples' attention, engage them in target activities, and influence behaviors [11]. This power suggests that gamification can function simultaneously in both self-improvement and social good when games are expertly designed to align fun and enjoyment with players' values and desires [45]. Several cultural examples illustrate the real-world power of how gamification behaviorally impacts recycling [46], automobile speed [47], walking [48], and energy saving [49].

One example of gamification changing people's walking behavior is the Volkswagen Piano Staircase Initiative [50]. Engineers wondered if they could get people to take the subway station stairs instead of the escalators by making the staircase look and sound like piano keys—in essence, making walking up and down the stairs seem more fun. The piano keys staircase was placed next to the escalator; indeed, during data collection, 66% more people chose the stairs over the escalator.

In another example, engineers converted a glass recycling bin into an arcade-style game where one of the six lights lit up after pressing start, indicating where to insert the bottle. If a person got the bottle into the slot on time, they scored points [46]. Nearly 100 people used the Bottle Bank Arcade during the night, while only two people used the conventional bottle recycling bin stationed nearby. These real-world scenarios reveal how gamification can motivate and enable people to change their behavior on chosen goals.

Movement and exercise gamification also has the potential to improve multiple dimensions of health and wellness by helping people manage their exercise behaviors using motivation and engagement strategies [51]. In 2020, only 25% of adults (18+) met physical activity guidelines for aerobic and strength activities [52]. Furthermore, 45% of American adults lack sufficient activity levels necessary for achieving health benefits, tying inadequate physical activity to $170 billion in annual health care costs [53].

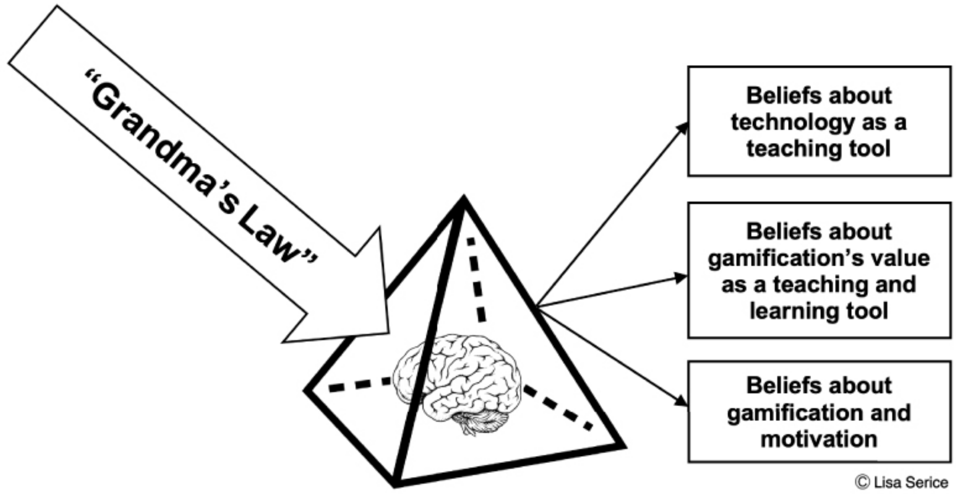
Bradley Prigge, a wellness exercise specialist at the Mayo Clinic Healthy Living Program, observes that some people intimidated by going to a gym are open to fitness apps because they allow them to find ways to move that are relevant to their needs [54]. The use of gamified apps in conjunction with wearable devices shows that gamification can increase the physical activity levels of sedentary workers by adding a layer of engagement and enjoyment beyond just tracking activity [55]. Office workers (n = 146, ages 21–65) who sit at least 75% of their workday were divided into two groups. Over ten weeks, all participants were given Fitbit activity trackers. However, only one group used Fitbit along with MapTrek—"a web-based game that moves a person's digital avatar along Google Maps based on their number of steps" [54]. Game users competed against each other in weekly walking challenges. Compared to the Fitbit-only group, the gamers walked 2,092 more steps daily and engaged in 11 more minutes of physical activity each day. Interestingly, gamers reported that playing the game motivated them to wear their Fitbit more often.

In a similar study, researchers conducted a clinical trial among adults (n = 200) from 94 families enrolled in the Framingham Heart Study to test the effectiveness of a gamification intervention designed to enhance social incentives within families to increase physical activity [56]. During the 24 weeks of the study (12 weeks of intervention and a 12-week follow-up), participants tracked daily step counts using a wearable device or a smartphone app. All participants established a baseline and selected a step goal increase. Each person was given feedback on their step count via text or e-mail over the 24 weeks. During the intervention phase, half of the families were placed in a family game where each member worked to earn points—moving through levels and competing to see who could surpass each other in the number of steps. The game was designed to enhance accountability, collaboration, and peer support. The control group continued only to track daily steps. The gamification group achieved a statistically significant greater proportion of steps and a significantly greater increase in daily steps (compared with baseline) than the control group. Notably, in the 12-week follow-up phase of the study, both groups' physical activity levels dropped. However, the group participating in the gamified leg still had a significantly greater number of steps than the control group [56].

These studies imply that gamification design can leverage brain science to create serious games for health that potentially shift people's fitness and health-promoting lifestyle behaviors. It is, therefore, critical for designers and consumers of gamified health and fitness solutions to use neuroeducation lenses to align game design and use with the (1) right "why" of what motivates individuals to be active and (2) what sustains behavior change [57–59]. The following section circles back to explore the question posed in the introduction: *What does "Grandma's Law" have to do with educational gamification and cognition?* This section examines how beliefs about gamification can serve as bridges or barriers to the use and misuse of gamification and why considering this matters in educational contexts.

4. "Grandma's Law" and beliefs: bridges and barriers to gamification

Beliefs are cognitive processes—the brain's way of navigating and making sense of a complex world [60]. The mental scaffolding provided by belief systems assists human beings in explaining new observations, appraising environments, and constructing shared meanings of the world. Interestingly, studies in neuroimaging and lesions show that beliefs have neural underpinnings [61]. While no dedicated brain systems are singularly devoted to specific social beliefs, core sets of regions within the prefrontal cortex in association with the reward circuit, anterior temporal lobe, and limbic regions appear to mediate them [61] critically. The key neuroscience objective for this article is not to become mired in the weeds of understanding the complex neuroscience but to firmly illustrate how cognitive



Prism 2. "Grandma's Law" and beliefs affecting gamification use in educational settings.

processes are constant entanglements of a person's body with the physical and social world surrounding them. This reality of embodied cognition has learning and well-being implications and is discussed further in later sections. On a practical level, because beliefs are held as personal truths, and personal truths guide actions—including shaping accepted educational practices in schools—they are consequential [62]. A teacher's, parent's, or policy-maker's beliefs and understandings potentially serve as bridges or barriers to educators incorporating gamification in the classroom [63]. For example, suppose a teacher, parent, or policy-maker is biased towards devaluing educational gamification or lacks an understanding of how gamification enhances learning. In that case, these beliefs and misunderstandings create barriers to integrating gamification in the classroom. Furthermore, misunderstandings about the difference between intrinsic and extrinsic motivation and their learning relationships may lead to the potential misuse of gamification—for example, focusing too heavily on extrinsic rewards, which can diminish a sense of autonomy [41]. There is a missed opportunity to deepen student engagement and learning using technology in both scenarios.

Prism 2 refracts the complexity of the intersection of "Grandma's Law" and gamification into beliefs that affect gamification's use or misuse. Teacher beliefs and biases separate into an array of three practice-impacting subconstructs: (1) beliefs about technology as a teaching tool, (2) beliefs about gamification's value as a teaching and learning tool, and (3) beliefs about gamification and motivation. The following subsections briefly discuss how "Grandma's Law" (the Premack principle) introduced at the beginning of the article [5] might impact teachers', parents', or policymakers' practices (1) using technology as a teaching tool, (2) valuing gamification as an educational tool, and (3) understanding gamification's dual motivational role as educational "meat" and "pudding."

4.1. "Grandma's Law" affects beliefs about technology as a teaching tool

"Grandma's Law" may affect beliefs about using technology as a teaching tool because the education system still includes influential teachers, parents, and policymakers whose childhood education did not include digital technology. Occasionally described as digital *immigrants*, this population was not born into a digital world but later integrated and adapted technology into their lives [64]. Understandably, digital immigrants growing up without technology possess varying levels of comfort, confidence, and experience with technology, and hold various beliefs and biases about technology use depending upon the context [65].

Digital *natives*, on the other hand, are characterized as those born into a digitized world concerning information and communication technology [65]. Cell phones, video games, computers, and various digital products surrounded this generation from birth. Adaptations to new environments and situations are highly variable. However, in keeping with the immigrant/native metaphor and comparing digital use to a language, it stands to reason that the digital immigrant may retain some level of their "digital immigrant accent" or foot in the past [64]. In the digital world, this may look like a person reading a manual for using a new program rather than "assuming the program itself will teach us to use it" [64]. In other words, a digital immigrant may seek information in non-digital formats before turning to the internet.

To navigate the intersection of Grandma's Law with technological gamification, consider the environment of 21st-century classrooms as technological brackish waters of knowledge flow. In nature, brackish water occurs in environments where freshwater and seawater commingle [66]. Brackish water is not as salty as seawater but a bit saltier than fresh water. In other words, the brackish ecosystem represents a unique habitat of intricately shared chemical properties of contributing bodies of water.

Similarly, in today's classrooms, learning occurs in digitally brackish environments where digital immigrants and natives commingle to create a unique learning habitat of intricately shared social properties. Learning spaces are collaborative and influenced by culture, and knowledge is co-constructed between learners and more knowledgeable others (MKOs) [67]. Traditionally, teachers are thought of as being the MKO in classroom settings. However, in the case of digital use, it is possible that in some applications, the student is the MKO.

Like brackish water, the classroom ecosystem becomes an environment that no longer solely reflects the experiences of the teacher who may have grown up in the pre-digital era and must now integrate the social reality of students who never lived in a world without smartphones. In summary, belief in "Grandma's Law" may adversely impact classroom technology integration if teachers, parents, or policymakers believe that the traditional, lecture-based, teacher-centered, non-technologized classroom methods [68] they grew up with are the only "meat" in lessons and anything gamified only serves as "pudding."

4.2. "Grandma's Law" affects beliefs about gamification's value as a teaching and learning tool

Belief in "Grandma's Law" also affects teachers', parents', and policymakers' beliefs about gamification's value as a teaching and learning tool. Earlier sections illustrated how SDT and neuroscience support gamification use in 21st-century classrooms. The beauty of educational gamification is that it simultaneously serves as "meat" and "pudding"—cognitively, creatively, and motivationally [41, 69]. "Grandma's Law," however, implies a hierarchy—not only in timing ("meat-before-pudding", "this-before-that", or "work-before-play")—but also in value (this is more important/valuable than that). Without understanding the relationship between gamification, learning processes, and intrinsic motivation, it is impossible to understand that gamification is a valuable teaching tool with a built-in intrinsic reward system. Consequently, an opportunity to deepen holistic learning that leads to creative, educational, and social benefits is missed.

The relationship between game and play and the belief in the role of play in educational contexts is complex. Games are a subset of play, but play is an element of games [70]. Twentieth-century philosopher Santayana [71] defines play as "whatever is done spontaneously and for its own sake" (p. 19), while Soviet psychologist Lev Vygotsky [72] describes play as a "purposeful activity" and a "source of development" which "creates the zone of proximal development of the child" (p. 16). The zone of proximal development is a psychological concept in education representing the distance between what a learner can do without the support of a MKO and what they can accomplish when supported by an MKO [67]. Santayana and Vygotsky's descriptions of play are harmonious in the framework of SDT [41] as they are vital ingredients in educational gamification's success. In gamification, students are intrinsically motivated *to* play and intrinsically motivated *by* play.

For *digital immigrants* [65], gamification as a building block of learning might feel counterintuitive to their experiences and training. After all, the word *game* sounds like play, and play (pudding) might traditionally be viewed as educationally frivolous—something a student should do *after* the *real* lessons are done (meat). However, the evidence in the previous and following sections refutes this thinking.

4.3. "Grandma's Law" affects beliefs about gamification and motivation

If educational gamification is viewed or designed narrowly through a behaviorist lens of outcome-focused rewards and penalties [73, 74], it misses out on some of gamification's meaningful contributions to learning. Qualitative research by Mogavi and colleagues [75] suggests that "misuse of gamification could negatively influence users' learning aptitude and capacity, well-being, and even threaten their ethics" (p. 188). This may in part be due to the risk of reducing students' intrinsic motivation. Intrinsic motivation is the degree to which a person chooses to engage in an activity for the pleasure derived from participation rather than for any external rewards [41].

When an activity is intrinsically motivating, a learner has a personal desire to play, master, explore, and enjoy it. In other words, intrinsic motivation is the *result* or *consequence* of the activity and aligns closely with creative urges that engender a sense of participating in something uplifting and worthwhile. This mental state has been described by some as "enchanted" or positively engaged, as opposed to "retained" or negatively engaged [76]. Intrinsic motivation is also associated with higher student engagement—a predictor of higher academic achievement [41]. However, Ryan and Deci [41] caution that academic outcomes should never supersede students' psychological growth and wellness.

Intrinsic motivation is likely responsible for human learning across the entire lifespan—not just in externally mandated school years [77]. However, because "Grandma's Law" is based on the behaviorist Premack Principle [5] and operates on extrinsic reward (i.e., you get *this* when you do *that)*, it presents a slippery motivation slope in gamification use. Gamification systems frequently include extrinsic rewards, such as leaderboards, achievements, badges, adding points, and reaching levels. While appropriate in some short-term applications, extrinsic rewards do not foster long-term behavior changes and may interfere with intrinsic motivation [41, 45].

Extrinsic motivation exists on a spectrum of four subtypes. The first, *external regulation,* concerns controlled, and non-autonomous behaviors driven by external rewards and punishments. The second, *introjected regulation* is external regulation that has been partially internalized, i.e., regulated by self-esteem during success and avoidance of shame, guilt, or anxiety for failure. In school settings, this manifests as "internally controlled" regulation—when a student's self-esteem is contingent upon achievement outcomes [41]. The third, *identified regulation,* occurs when a student identifies with the value of an activity and consequently experiences a high degree of willingness to participate. The fourth, and most autonomous form of extrinsic motivation, is *integrated regulation,* where not only does a student identify with the value of an activity but also finds the activity aligning with other personal values and interests.

Though both are highly volitional, the primary and consequential difference between integrated regulation and intrinsic motivation is that behaviors in integrated regulation are based on values. In contrast, intrinsic motivation is based on interest and enjoyment. The integrated regulation flavor of extrinsic motivation means that a valued activity may be worthwhile even if it is not considered enjoyable. Interestingly, researchers in affective neuroscience find that in complex behaviors (e.g., exercise, learning), intrinsic motivation is the strongest predictor of sustainability during triangulated choice points. Choice points occur—when what we *must* do rubs up against what we *should* and would *enjoy* doing [57, 78].

Aside from misuse of motivation, adherence to "Grandma's Law" risks missing the opportunity to use gamification for expanding teaching practice. MIT professors and Education Arcade directors Eric Klopfer and Scot Osterweil have come to bristle at the word gamification in education because it often consists of winning points for practicing school subjects like math and spelling [79]. Both professors cite that schools already overemphasize learning facts and formulas and "right answers" for standardized tests. Unfortunately, many versions of gamification replicate that model instead of changing it. Klopfer and Osterweil identify the problem as not just the drill and practice design of the games themselves but that "teachers predominantly use games as a reward or reinforcement, rather than a starting point for learning"—basically, "Grandma's Law." The professors believe that this "drill and practice" or "shooting flashcards" form of gamification undermines the opportunity to transform education radically. Both cite Math Blaster as one example of a gamified "drill and practice" game that does not require players to "use math in any real sense."

To move beyond "drill and practice," the professors developed the Radix Endeavor game. Working with scientists and engineers, they created a platform where students could explore a fictional world ruled by "evil, science-hoarding overlords," meet beleaguered citizens of the fictional world, embark on various quests (like finding a cure for a deadly disease), or using math to reinforce dangerously weak buildings—all while evading the evil overlords. The game offers four freedoms that Klopfer and Osterweil deem integral to good design—freedom to experiment, fail, assume different identities, and mix effort (e.g., go full-throttle or relax). The professors contrast their version of gamification with other math gamifications by saying, "It's not about solving this math problem, so you get a magic wand that can make this building stronger. It's figuring out how to learn the math, so you can *use* that understanding to keep the building from collapsing" [79]. The key takeaway is that Klopfer and Osterweil aim to reduce extrinsic motivation, increase intrinsic motivation, and make gamification meaningful.

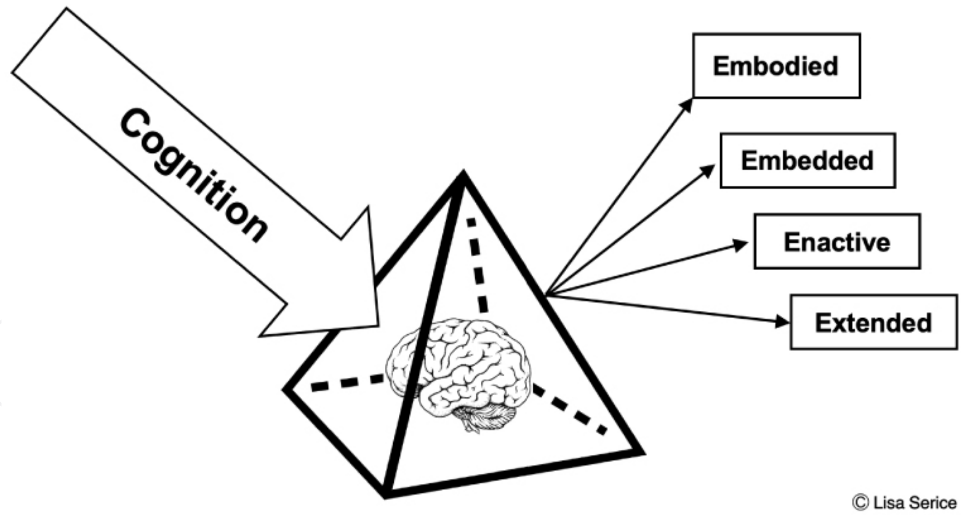
The concept of *meaningfulness* is highly individual. Therefore meaningful gamification would include game design elements centered on long-term goals and create systems that help users find their reasons for engaging with the behavior based on intrinsic motivation [45]. Meaningful gamification aligns with Mezirow's model of transformative learning when learners connect a new experience with previously held beliefs to transform them and foster long-term change [80]. Meaningful gamification also aligns with Universal Design for Learning [81] when providing various experiences, choices, and ways of engaging in raising the chances that each learner can find something meaningful and demonstrate mastery in various ways [45]. Lastly, meaningful gamification aligns with Organismic Integration Theory [82] when it supports the humanistic belief that intrinsic motivation engenders a more positive outlook on performing an activity than extrinsic motivation. In educational contexts, gamification steeped in intrinsic motivation creates an opportunity to frame a student's outlook on learning as personally meaningful.

5. *Gamification's value from a neuroeducation perspective*

Learning is not "one-size-fits-all." As such, the final section of this article bridges research and practice by proposing three practical neuro-prisms, named as a framework by the author of this paper, that educational stakeholders (e.g., parents, teachers, and policymakers) can use to think about gamification's value in their contexts holistically. These practical prisms include three key constructs impacting holistic learning—cognition, well-being, and intrinsic motivation. In all good scientific research, asking the right questions is paramount to developing proper methods, understanding results, and implementing effective, evidence-based solutions. Therefore, the purpose of refracting cognition, well-being, and intrinsic motivation into more detailed sub-construct arrays is to assist stakeholders in asking the right questions about gamification use in context. The first prism refracts cognition into embodied, embedded, enactive, and extended [83]. The second prism refracts well-being into social, physical, emotional, cognitive, lifestyle, and spiritual [84]. The final prism refracts intrinsic motivation into competence, usefulness, tension reversed, relatedness, importance, choice, and enjoyment [41, 85]. When synthesized, these prisms offer a practical guide for teaching praxis and food for thought for educational gamification designers.

5.1. Cognition is embodied, embedded, enactive, and extended

The notion that cognition is "radically" embodied [86] is an ongoing debate in cognitive science. Advents in neuroscience support radical embodied cognitive science (RECS), which proposes that from an evolutionary standpoint, cognition is



Prism 3. Cognition is embodied, embedded, enactive, and extended.

for guiding organismic action in the world [87]. This view of cognition means that how we learn and develop expertise is "shaped, constrained, and enacted through exploration and interaction with our physical environment" [83]. The critical implication for teaching is that cognition and creativity do not happen in a vacuum devoid of a material environment, bodily activity, and sociocultural context [88]. The radical notion is that the body and environment do not merely *contribute* to cognition. They are *part* of it [89]. The following sub-constructs (Prism 3) offer fresh perspectives to think about cognition as embodied, embedded, enactive, and extended when designing teaching and gaming methods.

5.1.1. Cognition is embodied

Embodied cognition is based on the fact that the body and brain co-evolved and, as such, are intrinsically coupled [83]. The brain is only part of a more extensive cognitive system, including sensorimotor capabilities and the body's central nervous system [87]. Since body schema is an implicit sensory-motor system shaping perception—which is fundamental to cognition—separation of body and brain is impossible. This paradigm goes against traditional descriptions of cognition as only abstract mental processes.

5.1.2. Cognition is embedded

Embedded cognition refers to coupling with physical, socio-cultural, and socio-material environments [83]. Inspired by ecological theory [90], embedded cognition suggests that people perceive environments as opportunities for action (affordances). Simply stated, embedded cognition emphasizes the intricate relationship between cognitive processes and external artifacts [91].

5.1.3. Cognition is enactive

Enactivism is an emerging perspective in cognitive science and psychology that argues that action is the purpose of cognition [87]. This thinking may seem counterintuitive to traditional teaching practices that silo cognition as an abstract process designed for "thinking." In enactivism, organisms create experiences by initiating action in their environments—transforming the outer world into a place of personal value, meaning, and salience. This radical notion suggests that an objective reality cannot exist since each human being's experiences in the physical world shape a unique perspective within their unique neural biology.

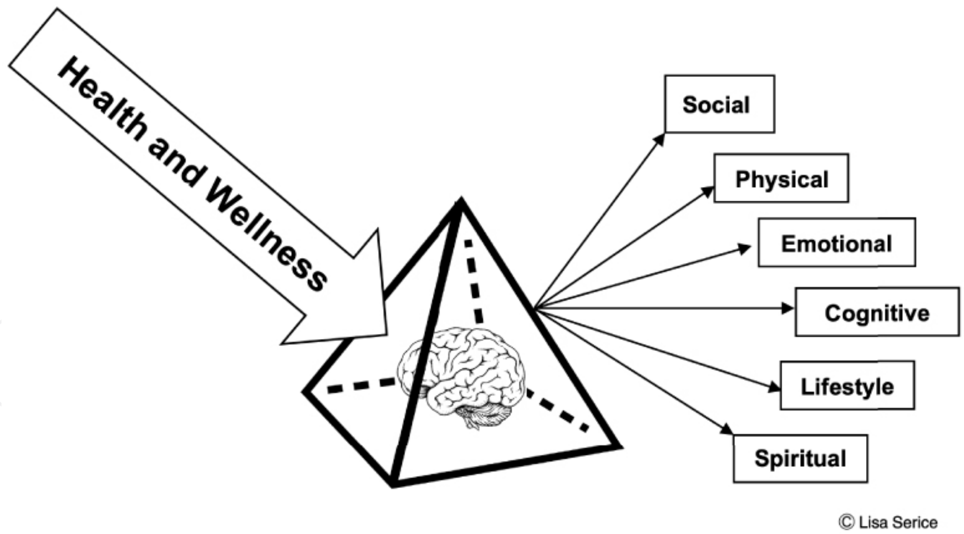
5.1.4. Cognition is extended

Lastly, extended cognition claims that human thinking is distributed beyond the body [91]. The radical notion implied here is particularly relevant to gamification since it suggests that non-biological agents (think technological devices) are functionally equivalent to processes inside the brain, making them part of cognitive processes. Humans integrate non-bodily aspects of cognition to create something unique [92]. Lastly, extended cognition proposes that this cognitive integration of non-bodily aspects of cognition is non-linear, dynamic, reciprocal, and ongoing [93].

5.2. Human well-being is multidimensional

Learners are not brains on sticks where students passively sit back while teachers pour knowledge into brains detached from their bodies and the environments surrounding them [94]. Adopting this assumption means that learning must recognize the whole learner's needs, including what brain-bodies require for multiple dimensions of wellness. The Oxford online dictionary defines wellness (interchangeable with the phrase well-being) as a state of being in good health. However, health can be conceptually murky if not viewed as a multidimensional construct.

In its constitution, the World Health Organization (WHO) recognizes health as a multidimensional construct and defines it as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" [95]. Because the sub-constructs of health are inextricably interconnected, effective teaching—and for this article, gamification—must consider what those constructs are and how they are reflected in pedagogy (or andragogy—adult education) and game construction. The following subheadings offer operational definitions of social, physical, emotional, cognitive, lifestyle, and spiritual wellness to consider in praxis and design since each aspect of well-being affects embodied, embedded, enactive, and extended cognition and consequently human flourishing. One way to use prism four (Prism 4) is to ask the question, "In what ways does this [gamified situation] help or hinder the student's [fill in each sub-construct]?



Prism 4. The multiple domains of health and wellness.

5.2.1. Social wellness

Social wellness "measures the degree to which one contributes to the common welfare of one's community. This emphasizes the interdependence with others and with nature" [96]. Significantly, social wellness involves continually developing and maintaining social networks and friendships. Previous sections in this article indicated that human brains are neurologically wired for sociality for survival and that relatedness is a basic human need leading to intrinsic motivation [41].

5.2.2. Physical wellness

Physical wellness "measures the degree to which one maintains cardiovascular/metabolic fitness, flexibility, and strength, and measures the behaviors that help one to prevent or detect early illnesses." [96]. In other words, the state of the body affects cognition because the mind, brain, body, and environment are inextricably connected. In a domino effect, what affects one part affects all parts.

5.2.3. Emotional wellness

Emotional wellness "measures the degree to which one has an awareness and acceptance of one's feelings. This includes the degree to which one feels positive and enthusiastic about oneself and life. It measures the capacity to appropriately control one's feeling and related behavior, including the realistic assessment of one's limitations" [96]. Affective neuroscience reveals that emotions are complex bodily experiences affected by a human being's interactions in the world that affect behaviors and learning [35]. As stated in the previous section on neuroscience, emotions impact the intrinsic motivation necessary for learning and are considered the foundational teaching target in the Brain-Targeted Teaching Model [97]. It is essential to consider that human beings have biases and previous experiences with what they have socially been taught about emotions [35] that may conflict with the evidence of affective neuroscience and the biology of emotions. These biases may impact praxis.

5.2.4. Cognitive wellness

Cognitive or intellectual wellness "measures the degree to which one engages his or her mind in creative, stimulating mental activities. An intellectually well person uses the resources available to expand his or her knowledge in improved skills, along with expanding potential for sharing with others" [96]. It is important to note once again that cognitive wellness is entangled with the body and environment, meaning it can be biologically affected by diseases of the mind and brain (e.g., Alzheimer's Disease) and sociologically affected by isolation.

5.2.5. Lifestyle wellness

Lifestyle wellness is defined as "establishing healthy behaviors to improve multiple domains of wellness that result in wellness promotion and ultimately decreased chronic illness and death" [84] Chronic metabolic illness and poor mental health are tied to lifestyle behaviors like inactivity, smoking, sustained stress, and poor nutrition. Promoting sustainable lifestyle behaviors that improve multiple domains of wellness can result in decreased chronic illness and increased perceptions of well-being. Including domains beyond traditional physical health in alternative educational approaches can promote multiple dimensions of human flourishing and valuable coping strategies. Narratives in gamification offer opportunities to scaffold evidence-based wellness models [96, 98, 99].

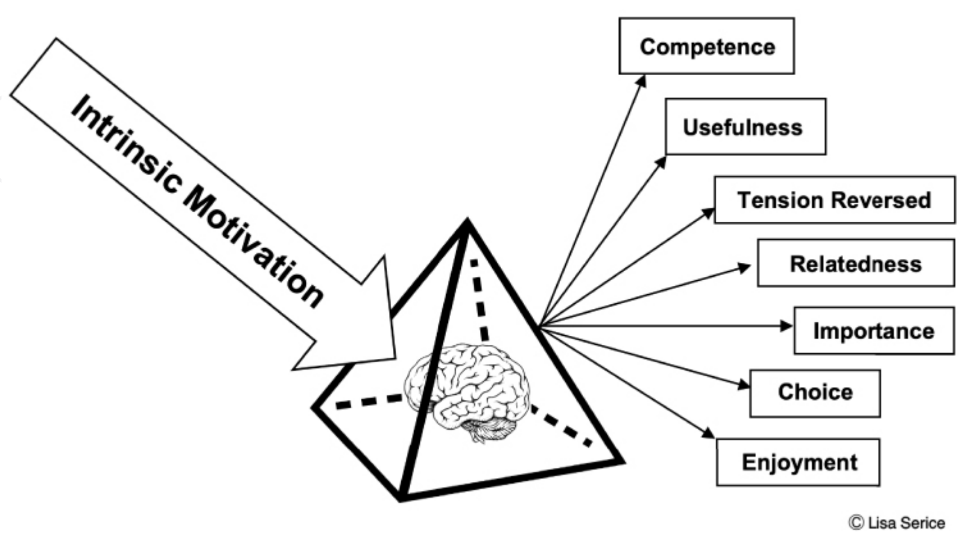
5.2.6. Spiritual wellness

Spiritual wellness "measures one's ongoing involvement in seeking meaning and purpose in human existence. It includes a deep appreciation for the depth and expanse of life and natural forces that exist in the universe" [96]. Spirituality encompasses universal themes, including wisdom and truth, life after death, love, altruism, and compassion. Awe is an emotion rising from encounters with something strikingly vast that provokes an update of mental schemas. People who experience awe are more willing to volunteer to help others, prefer experiences over material things, experience greater life satisfaction, and subjectively feel they have more available time [100]. Awe gives people a sense of interconnection with others and something much more significant than themselves. Experiences of awe bring people into the present moment, which alters time perception, and positively mediates decision-making and a sense of well-being.

Interestingly, research suggests that people who frequently experience awe show lower tissue levels of interleukin 6, a pro-inflammatory cytokine associated with the risk of heart disease [101]. Lower levels of interleukin-6 were associated with awe more than other positive emotions, including amusement, contentment, and joy. Experiencing awe promotes curiosity and exploration rather than withdrawal and isolation and mitigates stress. This mind-brain-body-environment entanglement is yet another illustration of the complex relationships between physical and mental domains. Gamification narratives and simulations can promote spiritual wellness by providing awe-inspiring components like breathtaking vistas, great works of art, and other experiences that generate awe.

5.3. Intrinsic motivation arises from multiple antecedents

Previous sections of this article explored intrinsic motivation—its neurological basis and critical necessity in learning applications that meet learners' basic psychological needs of competence, autonomy, and relatedness [41]. In this final prism, intrinsic motivation is further refracted into antecedents that, when met, lead to intrinsically motivating experiences [85]. The seven antecedents discussed below (Prism 5) include competence, usefulness, tension reversed, relatedness, importance, choice, and enjoyment. These antecedents are non-cognitive because people perceive or *feel* them as opposed to rationalizing or *thinking* about them. As with the six subdivisions of the wellness construct, these seven subdivisions of intrinsic motivation offer a practical guide to asking the right questions about pedagogical (or andragogical) gamification applications. One practical way to use this prism is to ask the question, "In what ways does this [gamified situation] help or hinder the student's perception of [fill in each intrinsic motivation sub-construct]?



Prism 5. The antecedents of intrinsic motivation.

5.3.1. Competence

Competence refers to a perception of mastery [39, 41]. Importantly, competence involves the sense that one can succeed and grow. Well-structured learning environments with affordances for positive feedback, optimal challenges, and growth opportunities foster competence.

5.3.2. Usefulness

Perceived usefulness is related to value and the previously discussed neuroscience of salience in learning. An activity that engenders a perception of usefulness catalyzes a sense that the activity will be personally beneficial within the context of one's life. Gamification offers an opportunity to entwine facts, knowledge, and skills into narratives and scenarios that offer the learner experience with how that knowledge fits into a bigger picture.

5.3.3. Tension reversed

Productive struggle, or the "Goldilocks zone" of challenge that is not too easy, yet not too difficult, aligns with learning sciences [39]. Gamification can assist with excessive pressure reduction in learning applications. As this article discusses in the neuroscience section, cortisol is a necessary neurotransmitter for staying sharp, but a chronic excess of cortisol is deleterious for health [102, 103].

5.3.4. Relatedness

Relatedness is a basic human need to feel connected to others and to perceive a sense of belonging [41]. Conveying caring and respect facilitates these perceptions. Gamified situations that promote relatedness would offer opportunities to interact and collaborate in situations fostering trust and connection with other players.

5.3.5. Importance

Importance is also related to value and usefulness [85]. Importance refers to a learner's sense that the activity is not only useful in the context of their life but that doing well at the task consequentially matters to them. Gamification presents an opportunity to take seemingly disparate skills and pieces of knowledge into scenarios that foster the importance of mastering them for practical purposes.

5.3.6. Choice

In SDT, choice is an antecedent of the basic need for autonomy [41]. Autonomy is the sense of having initiative and ownership. Experiences of being externally controlled undermine a sense of autonomy, whether through rewards or punishments. Conversely, experiences of interest and value support autonomy. Choices create paths toward autonomy—doing something because one *wants* to rather than *must*. This construct can be tricky to negotiate in the context of learning.

However, gamification can creatively support autonomy by building choices, options, alternatives, and workarounds into the design, where students can work at their own speeds, make choices, and take individual initiatives [104].

5.3.7. Enjoyment

Lastly, but of primary importance to intrinsic motivation is the sense of enjoyment. Enjoyment comes from within and is the feeling of pleasure and satisfaction derived from an activity. The enjoyment derived from an activity is the strongest predictor of intrinsic motivation and activity sustainability [85]. Gamification design and implementation should consider that a sense of enjoyment is highly individual and varies from person to person.

6. Conclusion

The primary purpose of this article was to synthesize theoretical and empirical literature to create a holistic framework for thinking about how, why, and when gamification functions as a valuable 21st-century educational tool. It advances neuroeducation initiatives by bridging neuro- and learning science research with educational practices. Crucially, these five "neuro-prisms" offer educators and game designers a practical new tool for understanding that (1) gamification benefits creativity, education, and society, (2) "Grandma's law" affects beliefs about gamification, (3) students' cognition is embodied, embedded, enactive, and extended, (4) wellness is social, physical, emotional, cognitive, lifestyle, and spiritual, and (5) intrinsic motivation is achieved through competence, usefulness, tension reversed, relatedness, importance, choice, and most importantly, enjoyment.

6.1. Implications for practice

Teachers interested in implementing educational gamification can use these "neuro-prisms" to discern whether a particular gamification strategy or software package adds value to their learning environment. Conversely, teachers opposed to using educational gamification can use the prisms as inflection points on changing assumptions about gamification's use and value. Additionally, educational software engineers can use the prisms to incorporate theoretical and evidence-based elements that foster holistic learning using multiple dimensions of well-being and intrinsic motivation for student engagement. Because these frameworks are grounded in embodied cognition and neuroscience, myriad learning contexts outside of traditional education could use these prisms to guide practice (e.g., public health education, employee training, sustainable exercise.)

6.2. Implications for research

This article's "neuro-prism" frameworks synthesize theoretical constructs with neuroscience research. Critically, these frameworks heed the call of educational gamification researchers to develop new ways to understand gamification's value beyond learning/training outcomes. These novel "neuro-prisms" creatively consider student engagement, well-being, and learning satisfaction [8]. However, these prisms are still at the theoretical status and require further empirical research to understand and evaluate how the research manifests in practice or "in the wild." For this reason, this article serves as a virtual baton handed off to gamification researchers who will implement the "prisms" in multiple contexts for mixed methods studies.

Ideally, future studies would include understanding the process and evaluation outcomes of using the prisms in four separate contexts, (1) teachers discerning which gamification strategies best suit the needs of their learners, (2) teachers who are not fans of gamification but use the prisms as inflection points for changing their points of view on gamification's value, (3) software developers using the prisms as a guide for technology design, and (4) various student learning, well-being, and intrinsic motivation outcomes using gamification strategies that address all constructs in the prisms.

Conflict of interest

The author declares no conflict of interest.

Supplemental materials

Supplementary materials are available at https://cdnintech.com/articles/175/supplements/acrt2022013-s001.pdf

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