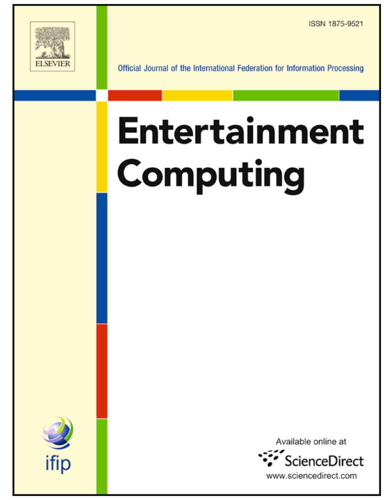
Accepted Manuscript



Adapting UX to the Design of Healthcare Games and Applications

Joseph R. Fanfarelli, Rudy McDaniel, Carrie Crossley

PII: S1875-9521(18)30021-1
DOI: https://doi.org/10.1016/j.entcom.2018.08.001
Reference: ENTCOM 271

To appear in: *Entertainment Computing*

Received Date: 31 May 2016
Revised Date: 9 April 2018
Accepted Date: 17 August 2018

Adapting UX to the Design of Healthcare Games and Applications

Joseph R. Fanfarelli (corresponding, joseph.fanfarelli@ucf.edu)[1], Rudy McDaniel[1], Carrie Crossley[1]
[1]College of Arts & Humanities
University of Central Florida
4000 Central Florida Blvd
Orlando, FL, USA
Carrie.Crossley@ucf.edu

***Abstract*—Games and simulations are used in healthcare for purposes including training, education, and promoting wellness. However, there is often disconnect between content creators and the healthcare providers or patients who use their products. This can result in negative experiences and perceptions. This article investigates research in user experience (UX) to examine how games and applications designed for use in healthcare are impacted by considerations such as design practices and users' attitudes. By exploring the design of healthcare games and applications through the lens of user experience, the authors analyze current practices and develop specific design recommendations to improve future game-based scenarios. These six design recommendations are then applied to an example game, Medulla, to investigate their utility in framing a real-world example.**

***Keywords*— user experience; ux; serious games; simulation; medical; user centered design**

***Abstract*—Games and simulations are used in healthcare for purposes including training, education, and promoting wellness. However, there is often disconnect between content creators and the healthcare providers or patients who use their products. This can result in negative experiences and perceptions. This article investigates research in user experience (UX) to examine how games and applications designed for use in healthcare are impacted by considerations such as design practices and users' attitudes. By exploring the design of healthcare games and applications through the lens of user experience, the authors analyze current practices and develop specific design recommendations to improve future game-based scenarios. These six design recommendations are then applied to an example game, Medulla, to investigate their utility in framing a real-world example.**

***Keywords*— user experience; ux; serious games; simulation; medical; user centered design**

1. INTRODUCTION

Technology health applications and game-based training (GBT) software are now commonplace in medical and healthcare contexts. Games in particular have been useful for many purposes, including assessing the interaction skills of children with autism spectrum disorder [1], teaching surgeons knee replacement surgery procedures [2], encouraging physical activity and proper personal hygiene [3], developing cognitive activities to combat dementia [4], and assisting patients with difficult decisions, such as making informed decisions when choosing between treatments for specific forms of cancer [6]. These games for health are part of a wider genre of games called serious games, "games whose primary purpose is to promote wellbeing, train and educate rather than provide pure entertainment" [7, pp. 94]. While many serious games are successful in teaching or improving treatment (e.g., [8]), others have fallen short. Further, even when games are effective, they are not always perceived this way. This is a problem because the perceived reputation of a training intervention is positively related to pre-training motivation [9]. This factor is positively related to learning and subsequent performance [10], [11].

There may be many reasons for the lack of acceptance toward a technology, including perceptions of ease of use and usefulness [12], computer self-efficacy, and system complexity [13]. Negative user experience (UX) may be another factor. UX encompasses a wide variety of considerations and has recently been studied in relation to game design from the context of entertainment computing [14], taking into account player experience and expectations as key factors in the evaluation of product success. While usability may be a more familiar term to some readers, and addresses topics like ease of use and system efficiency, UX also considers users' emotions and attitudes as they apply to a game or application. When these emotions and attitudes are negative, poor experiences often result, overshadowing the game's positive attributes.

Similarly, UX studies can yield surprising findings. For example, in their research analyzing two different field studies of gamers playing Super Monkey Ball and Bejeweled 2, [14] found that in regards to immersion, gamers earned significantly higher scores in the mobile scenario than the home scenario, leading the researchers to speculate that players exhibited increased effort to filter out the surroundings and focus on the game when in mobile settings. This is somewhat counterintuitive given that one might expect the opposite to occur; that is, having mobile scores lower as the result of outside environmental distractions. Since UX is so player-centered, it can be an effective technique for evaluation and assessment of game-based technologies.

A UX-based approach to assessment and evaluation means that simply creating a mechanically efficient solution is insufficient. The end product, whether an application or game, must be designed with its users centrally in mind – users that have both similar and unique qualities to one another, reflecting the nature of UX in general. After all, UX is dynamic, context-dependent, and subjective; these qualities mean that users will experience similar systems differently [15]. Such qualities necessitate the study of users in different fields, in order to identify unique UX design approaches.

Additionally, game development can be both costly and time consuming. Learning games are not an exception [16]. Game projects are often completed by multiple people and many hours of work. These resources are misused if the game is unsuccessful in its purpose. This situation is not only inefficient and disappointing; it can also contribute to the technology acceptance issue that was already described. After all, why allocate large amounts of resources to something that is likely to fail? This is a real concern when research shows only a moderate level of teaching effectiveness in medical education games [17]. Thus, steps must be taken to ensure a more consistent return on investment when it comes to healthcare games.

The present research explores this idea of a UX design heuristic more thoroughly, with a specific focus on the application of UX principles to the development process of video games designed for training or educating healthcare professionals and patients. It explores the unique qualities of the users in these areas, paying special attention to factors influencing users such as medical professionals and the general public. The paper concludes by generating six observations and actionable UX design recommendations for future serious game developers in the process of designing and developing games for health and medicine and then demonstrating how they can be used by examining their application to a real-world example of a brain-based educational game, Medulla.

2. User Experience

2.1. What is UX?

UX refers to one or more human beings' experiences of using a product. It has a number of different but related definitions, such as "the experience the product creates for the people who use it in the real world" [18, pp. 6] and "the creation and synchronization of the elements that affect users' experience with a particular company, with the intent of influencing their perceptions and behavior" [19, pp. 3]. The definition is further complicated by our nebulous understanding of experience itself – the notion of experience refers to a complex phenomenon, incorporating human (e.g., cognitive, emotional, social) and environmental (e.g., media, surroundings, distracting factors) factors. However, a central idea that joins these definitions is an acknowledgment of the centrality of design-based thinking [20] when developing products.

When healthcare application ignore or undervalue UX considerations, bad user experiences often follow. For example, one study measured nurses' attitudes about a new electronic healthcare record program [21]. Using the new software, charting patient information took the same amount of time and increased accuracy in over 50 percent of cases. On the other hand, the software was designed so poorly that nurses developed significant negativity toward the product, despite the fact that they felt positively prior to implementation and believed that the software was better for patients. In other cases involving web design and development, Garrett [18] explains more than one startup company went out of business after focusing too much on aesthetics and not enough on usability and functionality, other important dimensions of UX.

While functionality is an important aspect of UX, we must be careful to differentiate a game or application's functionality from its UX. As Garrett [18, pp. 6] notes, UX is "not about the inner workings of a product or service" but rather "about how it works on the outside, when a person comes into contact with it." He describes the difference between mechanical efficiency and efficiency in practice. While everyday consumer products like coffee makers, GPS systems, cash registers, gas pumps, and alarm clocks may be functionally sound and mechanically efficient, accidents and inconveniences can result if the UX with these products is not carefully considered. A coffee maker may include all the proper features for brewing coffee, but if the pot is too difficult to fill with water or the interface is too complex for a user to decipher, then that coffee maker is not user-centric and is likely to fail, or at the very least, to cause angst and irritation for the users of the product. However, even a beautifully designed and intuitive-to-use coffee maker will also fail if it cannot reliably brew a pot of coffee. As this simple example illustrates, UX is not simply aesthetics, usability, functionality, or efficiency. Rather, UX is the result of the interactions of these elements (and others) with the user's qualities when a product is put to use. Accordingly, a key goal in UX is improving the effectiveness and enjoyableness of product use and corresponding user experiences.

While this general definition is useful for a basic understanding of UX, establishing a research agenda around this practice requires understanding the components of UX in more precise detail. Alben [22] describes eight criteria for effective interaction design and high quality user experiences. These criteria include the following dimensions, each of which directly influences the quality of experience:

1. Aesthetic experience – UX must consider the impact of visual design on user interaction. Apple Inc., for example, has designed guidelines for the user experience of their mobile products running iOS and published a detailed design guide for how aesthetics should be consistent and visual themes should be applied in Apple's ecosystem. Among other things, Apple's style guide recommends a "minimal use of bezels, gradients, and drop shadows" in order to "keep the interface light and airy" [23].
2. Manageable – manageability refers to the holistic use of the product and its context. This dimension incorporates matters outside the functionality of the product itself. This may include product training, licensing, privacy, information storage, and so forth. Products that are functionally sound but difficult to manage are problematic for organizations to adopt and use because they are difficult to maintain and involve too much overhead. Facebook's development suite is a good example of a technology that facilitates manageability. Using their shared code base, other web sites can easily share Facebook functions including login, analytics, monetization, messaging, and image sharing capabilities [24].
3. Understanding of users – audience analysis is an important aspect of good design and good communication. One must know for whom one is designing or communicating, after all, and take the special needs of that audience into account. The same holds true for UX design. In order to design effective experiences that users will not mind repeating, one must first understand the needs, values, and habits of his or her audience. [3] report that two groups deserve special attention in the design of healthcare games and technologies: children and older adults. Children may show a special propensity for games and have more experience playing them, while older adults may possess ambivalence or negative attitudes toward games that should be factored into the design.
4. Learnable usable – products that are easy to learn and use are desirable. Functional products that require significant training and usability tweaking for users to be comfortable with them are less desirable. For example, [4] devised a simple, touch-based tablet game developed to run on a tablet for users with mild dementia. Users could browse through a quiz-based system responding to questions using a touch-based interface and receive feedback through both textual and auditory cues. By recording information about their players' touch, timing, shaking, and performance, researchers could collect data that might be useful indicators as alerts of cognitive deterioration.
5. Needed – is the product solving a problem that actually needs to be solved? Is it necessary, and, if so, what specific problems does it solve or what informational deficiencies does it help to address? Communicating the necessity of a product is often a challenge for UX designers, but there may be existing needs a designer can address by developing healthcare software with better user experience. For example, the large number of personal hygiene and hand hygiene games described in [3] suggests that there is significant need for better training in these areas. Usable games with carefully designed UX may be a mechanism for addressing that need.
6. Mutable – how does product evolve based on the changing needs of users? A product's malleability and ability to evolve over time as communication and interaction needs change is a strong indicator of its potential success with end user audiences. [4] notes the importance of personalization in individual patient needs. Mutable products are able to evolve according to the preferences and needs of their users.
7. Effective design processes – what specific design and evaluation methods were used to drive the design process, and were these methods carefully considered and executed with care? The best technologies may evolve over time in tandem with their users. For example, in their review of gamification design principles used in mHealth applications, [5] noted Jane McGonigal's game SuperBetter as an example of how technology can be used to drive effective design. Using a holistic approach to health informatics that combines background assessment with direct feedback from the player, the game first collects background information about players through a series of challenges and then allows the user to select a reason for playing the game, such as "depression" or "anxiety." Relevant future challenges are then provided based on that data.
8. Appropriate – does the product suitably solve problems using the correct types of users working on the appropriate types of tasks? Some products may work well, but are inappropriate due to the specifics of how an organization operates. For example, there may be credentials that must be used before access is granted to a new software system. If such credentials are not verified within the software, the product may function to solve a problem, but ultimately do more harm than good because of legal, organizational, or business restrictions. More research is needed to determine the appropriateness of many healthcare games and applications; for example, we currently know little about the efficacy of gamification mechanics for mobile health applications [5] and many other technology-based interventions also require more empirical evidence than we currently have.

Beyond Alben's [22] criteria, the components of UX can also be described along five planes: strategy, scope, structure, skeleton, and surface [18]. Order is important, here. Planes in the beginning of the list are more abstract; planes at the end are more concrete. For example, strategy concerns itself with overall strategic goals and user identification, while surface describes the concrete details involving the appearance and functionality of a product. In between these two poles are skeleton, structure, and scope planes which define features and their interactions at different levels of abstraction. The skeleton plane relates to the specific placement of user interface elements (e.g., buttons, controls, photos, and text blocks), while the structure plane is broader, describing how users discovered a piece of content and specified their options for subsequent interactions. Many of Garrett's guidelines effectively function beyond his original domain (web content) and also apply to other digital technologies.

Unger and Chandler proposed another method of classification [19], which divides its focus of UX into separate domains: tangible, individual, social, and digital. Tangible indicators refer to physical properties of a health device, such as comfort and utility of a biometric sports watch band. The individual domain follows the interactions of a single person with a designed product, while the social domain expands to include interactions between users. While the individual domain asks how an individual accesses menus and engages functions on the health device, the social domain asks how the device is used in social groups. For example, the device may used as a motivational tool to inspire progress amongst individuals competing for various health-related accomplishments, such as step counting or overall calories burned. In this context, the UX aims to accommodate social factors that may include the viewing of data, or accessing visual indicators of other users' achievements. Finally, the digital domain concentrates on the product's computational components such as electronic databases, web site pages, video games, and so forth. Dividing UX in this fashion shows the broad reach of these principles in considering healthcare technologies and how they frequently involve users in both physical, virtual, individual, and group-mediated contexts.

Based on the above synthesized work of [22], [19], and [18] we can group a preliminary set of healthcare-focused UX criteria into three categories which encompass users' perceptions: usability, adaptability, and efficiency. We will consider each of these categories in more detail in the next section.

2.2. Components of UX

To further deconstruct UX and consider how these frames of thinking about UX are useful to the design of health applications and games, we can group user perceptions of a product into three overarching categories which involve a product's usability, adaptability, and efficiency. Admittedly, these criteria are inherently interrelated and tend to influence one another. For instance, more usable products are often more adaptable and efficient. However, this classification remains useful for considering some major themes within UX that suggest how to productively use UX within healthcare and medical technologies, even if they do overlap to some extent. It is important here to restate the nebulous nature of experience itself; with this in mind, UX focuses on users' subjective experiences and thoughts rather than objective facts.

2.2.1. Usability

Usability encompasses the perceptions of users in relation to a product's structure and design: is the design straightforward, intuitive, and easy to navigate? Products that are difficult to use will likely require more expenses for maintenance and documentation. Refer again to the coffee pot example above. What factors of a coffee pot influence its usability? Obvious factors would include the physical dimensions of the product itself – the size and shape of the pot's handle, for instance, or the legibility and placement of buttons on the brewing station – but usability can also be found in associated ancillary materials, such as the instructions manual for the product and its online help forums. Usability includes both physical properties (e.g., the size and form factor of a mobile device and how well it communicates its functionality to users) as well as virtual properties (e.g., organization and ease of use of an online user registration page).

Healthcare products that are not usable may elicit feelings of frustration, annoyance, or even anger. These emotions can serve as barriers to designers hoping to create a product that maintains long-term interactions with users. Consider application for glucose level tracking. If the application requires ten different user interactions to display a control panel, it is likely going to be poorly received by users. Similarly, it may be useful to develop a series of usability questions aimed at acquiring a deeper understanding of usability through Garrett's five planes [18]. For instance, is the strategy itself usable, in addition to the lower level and more concrete features of the product itself?

2.2.2. Adaptability

Adaptability involves a user's perceptions of a product's value as it evolves over time. Do users believe that the product remains helpful even as their needs and environments change? While a straightforward coffee maker may work very well for circumstances in which a single individual arises from bed and brews a cup of coffee, what happens to that product's experience when the individual has guests over, all who may need their coffee at different points in the morning? Does the product still perform admirably, even as individual needs grow more complex and varied?

Consider an alternate example. In healthcare, a hospital's time tracking application used for part time employees working in a hospital that is growing its staff may find that the product works very well for managing small numbers of workers, but becomes cumbersome when its number of part time employees grows. This trait is directly related to the notion of mutability outlined in Alben [22], but also to his recommendations to follow effective design processes and consider long-term manageability when designing products.

It is also useful to consider adaptability from the five plane perspective of [18], especially when considering healthcare web sites. While the strategy plane may demonstrate adaptability and flexibility, the lower level planes such as skeleton, structure, and surface may generate challenges for designers to consider when thinking about future needs. Similarly, while a structure plane analysis may show flexibility for the future re-routing of user progression, the specific interface elements defined in the skeleton plane may not afford that facility of movement.

2.2.3. Efficiency

Efficiency in this context does not merely refer to efficiency in information processing, data storage, or mechanical operation, but rather the to the product's efficiency in meeting a designer's or audience's needs. This corresponds directly to the "needed" and "appropriate" categories identified by [22]. A product may be well-designed and enjoyable to use, but for a use other than its intended purpose. The world's most versatile coffee maker is functionally useless if it does not brew the simple cup desired by its user in a timely and intuitive fashion.

In terms of games, a cognitive rehabilitation game might use interesting and enjoyable game mechanics, but these mechanics could exist independently of the game's learning content. Another simple example is a sandbox-style game that also employs mini-games to provide the player with a distraction from the main missions. If the mini-game is fun and well-designed but the sandbox missions are uninspired and cumbersome, players might spend all their time within the mini-game and ignore the larger context of the game and its goals. This particular product could score well on usability, but low on efficiency.

Both the multi-plane strategy proposed by Garett [18] and the four components of UX design identified by Unger and Chandler [19] are useful for improving efficiency in healthcare games and applications. For example, designers and developers can determine how organizational needs are being addressed on one end of Garrett's scale at the strategy dimension, then investigate how those same needs are being met at the practical level of interface, buttons, and tasks on the surface plane. Similarly, a thoughtful designer can distribute key interactions between the physical and digital categories as well as between individual and social moments to more fully consider how effective an overall product meets the needs of diverse audiences.

2.3. Measuring UX

Despite the difficulty in developing a universal measurement of UX, a problem largely caused by its inherent subjectivity and diversity of possible applications and products, there are some established ways to measure UX in certain contexts. Often, these measures are closely tied to the success of a product and an audience's willingness to use that product. For instance, [12] notes that one objective measure of good UX for web applications is the conversion rate. In one context, conversion rate could measure the number of visitors to a web site that end up signing up for a subscription for a health-focused online newsletter. Ensuring that sign-up and registration features are easy to use is critical for garnering further commitment from users, whether these users are downloading fitness applications onto their smartphone devices or investing time playing an online game for learning about a newly developed health condition such as diabetes. Similarly, the newsletter will need to be adaptive (evolve both its content and form over time to adjust to the audience and market) and efficient (serve relevant content in an appropriate way) to maintain a positive UX after those subscriptions have been acquired.

Assessment and measurement of UX is a significant topic and a full treatment of this material is outside the scope of this paper. However, interested readers should consult the work of Garrett [18], Unger and Chandler [19], and [25] for additional ideas about evaluating UX.

3.METHODS FOR UX IN HEALTHCARE GAMES AND APPLICATIONS

A literature review was conducted to examine the factors influencing UX in healthcare games and applications. Qualities such as design practices, attitudes towards various learning methods, and demographic information (e.g., age, computer literacy) were observed. Through the literature review, we sought to explore the methodologies for measuring perceptions towards serious games and other new media applications in healthcare, such as surveys and usability testing. In addition to attitudinal studies, we searched for data describing the overall efficacy of game-based approaches for healthcare, specifically focusing on how to accurately measure success potential mediating factors.. We also sought to compare design methodologies and recommended practices with current implementations.

3.1. Methodology

The literature review obtained articles from the following databases: Academic OneFile, ACM Digital Library, CINAHL Plus, EBSCO, Google Scholar, MEDLINE, PsycINFO, and ScienceDirect. Search phrases included combinations and variations of the following key words and phrases, in addition to other, more general, terms: *serious games, healthcare, mHealth, simulations, medical, attitudes, perceptions, design, user experience, UX, nurses, doctors, patients, and computer literacy*. Reviewers also suggested additional relevant literature which we added to our data set. Audience characteristics were studied using a two-phase approach where one phase focused on healthcare providers (such as doctors, nurses, and educators) and the other on patients and the general public.

3.2. Findings

Analysis of the literature identified two important considerations for creating effective user experiences in healthcare games and applications: (1) users' attitudes toward new media technology and (2) specific design practices.

3.2.1. Attitudes toward New Media Technology

In order for new technology implementations to be successful, the development process must take into account attitudes and perceptions of the users. For healthcare games and applications, it is important to consider that attitudes and perceptions will vary across audiences – nurses and doctors have different experiences with and attitudes toward new media technology than the general public. Thus, UX considerations for a wellness game may be vastly different than those for a surgical simulator.

a) *Considerations for Healthcare Providers:* In an educational setting, perceptions of faculty and administration are critical, due to their potential to directly influence the success of an application . In a survey of faculty in D.O. and M.D. programs, Mason [26] found that administration in many medical school departments tend to believe new media learning is less effective than traditional methods. This finding is interesting in light of the extensive research that documents the effectiveness of game-based training (GBT) and simulation-based training (SBT) interventions in healthcare. For example, among nurses, well-designed simulation training has been shown to improve decision-making skills [27], increase clinical competency [28], reduce anxiety, and increase adaptability and knowledge transfer to real-life situations [29]. Game-based methods are also capable of increasing motivation through engagement [30], and have been described by medical students as more engaging than traditional forms of lecture [29].

Despite the evidence for the effectiveness of GBT and SBT, these types of interventions are not perceived as matured solutions. Many teachers still consider the future potential of these interventions, but are not necessarily convinced of their present utility [31]. Preconceived negative attitudes towards these instructional methods can cause educators to dismiss them before ever dedicating the required time and effort to implement them properly, a situation that often leads to low learner engagement and participation [26], consequently reinforcing educators' original negative perceptions and leading to a subpar student experience with the technology. Further, trainees are typically more motivated and attribute greater value to training interventions that have been positively endorsed by their organization [32] – if a trainer doesn't believe in the intervention, they may be less likely to positively endorse the it, thereby reducing trainee motivation.

Implementation issues were found to be common and have a prominent influence on students' perceptions of GBT and SBT. This is unfortunate, as most students want to engage in this type of training. In a study of over 200 medical students, 96 percent felt that educators needed to improve their use of new media technologies in the classroom [33]. However, even those educators that view GBT and SBT as useful are hindered by a lack of proper training to effectively support their use [29]. This result complements another study of medical school educators. Here, 40% of D.O. faculty and 60% of M.D. faculty had an appreciation for e-learning techniques, but felt that they did not have enough time or resources to implement these types of instruction in their own classrooms [26]. While many students and instructors have a desire to use these technologies, they are insufficiently trained, and do not have enough time to engage in proper implementation.

By emphasizing UX considerations during the design of healthcare applications, we can begin to overcome some of the barriers associated with the implementation of these technologies in healthcare education. If educators and students have positive perceptions related to UX (e.g., ease of use, utility, and efficiency) of GBT and SBT, they will be more likely to allocate resources for proper implementation, and thus more likely to benefit from an instructional game or application.

b) Considerations for the General Public: Using games and other new media technologies for health and wellness can improve patients' ability to obtain education and treatment. Among the general public, motivations to play games for health include low cost, emotional rewards, and opportunities for socialization [34]. These types of games can empower individuals by increasing accessibility of information, and engagement in its acquisition [35]. General characteristics that players enjoy in games include challenge, critical thinking, social interaction, and opportunities for creative problem-solving [31].

In a study of teenagers in Mexico, Arteaga et al. [34] found that personality traits (e.g., neuroticism, openness) influenced perceptions of various physical activity games. Depending on their traits, participants responded differently to various game elements and motivational phrases. This finding highlights the importance of considering personality traits as an influencing factor in UX – a factor that can mediate the relationship between user and software.

Additionally, GBT and SBT approaches require special considerations for certain demographics. For example, computer-based instruction scenarios risk excluding older patients due to their general lack of computer literacy and experience; among elderly patients, perceived complexity and lack of requisite computer knowledge were identified as the most common barriers to accessing computer-based healthcare information [36]. Design considerations are also needed for non-English speakers, non-verbal patients, and children [35, pp. 149]. These barriers can be overcome by utilizing UX principles to design simple, clear, and user-friendly systems for all audiences.

3.2.2. Design Practices

A substantial body of research exists on best practices for the design of games, simulations, and other applications in healthcare. A review of this literature illustrates that effective design approaches are related to fundamental principles of game design, instructional systems design, and UX design. UX is important both within a game or application, and within its peripheral components, the environments for both learning and performance, and the support (in terms of attitudes and resources) provided for its use in a learning environment [37].

a) *Game Mechanics:* When designing serious games or gamified training scenarios, the specific game mechanics used should be selected with purpose. In a study of a life support training game, the use of different design patterns such as scoring and timers significantly affected participants' knowledge gains [38]. Fundamentally, effective healthcare games and applications must provide player agency: the learner must be able to influence and direct their instruction through interactions with the software [39]. Additionally, to create an engaging learning experience, meaningful game mechanics should complement the style of learning and instructional goals [31].

The literature advocates the use of active learning, where the instructor is to encourage students to demonstrate self-motivation, while primarily acting as an educational facilitator [40, pp. 1143]. In order to create this type of experience, designers of SBT and GBT interventions should consider components of successful game design such as narrative, clear feedback, player choice, and scaling difficulty.

Additionally, the literature has uncovered simulation and game qualities that undergraduate pre-medical students find valuable [33]. Games and simulations should be enjoyable, and helpful for developing ability and comfort relevant to patient interaction. They should provide an understanding of the variations in the economics of differing healthcare systems. They should also provide learners with experiences authentic to the field. Additionally, Ellaway et al [41] identify that effective virtual patient scenarios will offer high degrees of interaction between the user and patient, clear, consistent, and frequent feedback, high degree of validity and fidelity, and appropriate complexity tailored to the individual student's skillset. These preferences suggest that medical students desire new media learning experiences that fall at an intersection between games and simulations; in other words, experiences that combine accurate models of real-world systems with fun and engaging gameplay mechanics. Of course, identifying user preferences in isolation is shortsighted. At some point, they must be integrated with existing design methodologies, or applied to create new methods.

b) Design Methodology: The literature highlights the importance of incorporating end-users into the design process. Many studies recommend an iterative design model focused on both user-centered and participatory design [31], [35], [36]. User-centered design focuses on considering the subjective experiences of users, while participatory design emphasizes directly involving users throughout the design process [35]. In other words, these design models focus on considering UX elements and perceptions regarding ease of use, utility, and efficiency. Creating good UX relies on frequently involving users through usability testing and making changes based on their experiences and feedback.

The literature revealed a few specific UX centered models, which we will briefly explain. Paulovich et al. [*35*] propose a *3-Corner Collaborative Design Model* for designing educational scenarios for patients. This approach is cyclical and focuses on incorporating feedback from patients, designers, and health professionals at every step in the creation process. The 3-Corner Model consists of seven steps:

1. Information Gathering – Designers visit the healthcare environment to gather information about patients, providers, and instructional context. Healthcare providers work with the design team to identify learning content and establish clear instructional goals.
2. Concept Development – Designers consolidate information and create a number of concepts to show healthcare providers. Healthcare providers choose the concept that fits best with their needs.
3. Design Development – Based on feedback from health professionals, designers expand the chosen concept and create a detailed design document. Health professionals review the design and provide feedback based on their own needs and the needs of their patients.
4. Prototyping – Designers create iterative prototypes based on feedback from health professionals.
5. Evaluation – The prototype is tested with patients. Health professionals or designers can take on the evaluator role depending on situational circumstances.
6. Re-design – Prototypes are changed and updated, incorporating feedback from patients and health professionals during the evaluation phase.
7. Solution – After iterations of steps 4-6, an acceptable final product is reached that benefits patients and health providers.

During all stages of the design process, Paulovich et al. argue that it is imperative for designers to frequently visit the health environment. Gathering information, interacting with users, and immersing themselves in the hospital environment allows game experts to better understand healthcare providers, integrating the user's perspective in the design approach [35].

Torrente et al. [31] propose another approach for creating healthcare games – the Educational Game Development Approach (EGDA). This approach is derived from the well-known ADDIE model commonly used in the field of instructional design, and consists of four major, iterative steps:

1. Analysis – Game experts collaborate with subject matter experts to establish clear learning objectives and performance goals. Specific characteristics of the learners, the performance task, and the environment are documented.
2. Game Design – Using the information established in the analysis phase, game experts create a design document outlining the specific features of the game. Tasks include designing an appropriate virtual world, establishing structures for clear feedback and decision-making support, and creating engaging game mechanics that support instructional content.
3. Implementation – Using the design document, developers create iterative, rapid prototypes of the game. The prototypes are frequently tested by subject matter experts and game designers to ensure that the gameplay is meaningful and the learning content is accurate.
4. Quality Assurance – Prototypes are tested with end users in order to ensure quality and identify areas for improvement. Users' perceptions of reliability, gameplay experience, usability, and educational value are examined. Feedback from testing is used to create new prototypes, and design decisions may be re-visited.

Similar to the 3-Corner model, EGDA advocates for the importance of participatory user-centered evaluation through frequent usability testing. Both models emphasize the use of a self-reflective process that is iterative in nature [35], and continuously improves design based on frequent feedback, testing, and information gathering.

c) Usability Testing: Usability testing is, as its name suggests, a category of methodologies for assessment. There are a number of approaches to evaluating health care information technologies using structured methodologies for usability testing. Such work is important for both providing end user input into the design process and for improving medical systems and user interfaces [42], and should combine the use of traditional usability tests, such as think-aloud tests, with cognitive task analyses and computer-supported video analysis as tools for evaluating medical information systems. While think-aloud testing asks the user to make their thoughts conscious and vocalize them as they interact with a system, cognitive task analysis measures the decision making and reasoning skills of participants to determine how they process information as they interact with the system and engage in problem solving.

In order to use cognitive task analysis within the context of a medical information system, Kushniruk [42] developed an eight step process that involved formulating a plan, selecting representative participants and tasks, setting up the environment and conducting the tests, analyzing results, making recommendations, and repeating as necessary to use iteration as a tool to improve design. Based on their research, they found that an approach that combined both usability engineering tactics with psychological measures of medical cognition led to rich data that was efficient to collect and analyze. They particularly found that considering such data within an iterative framework, where the data could directly impact the evolution of design, was beneficial. These researchers observed health care workers and their interactions with medical technology systems, but the same approach could be used to collect similar data from end users such as patients, or even the general public.

Another study [43] compared participant ratings of usability between an entertainment game (Counter-Strike: Source) and a serious game (Re-Mission). Results indicated that while the serious game had satisfactory usability ratings, the ratings were lower than the ratings for the entertainment game. The authors highlighted the importance of assessing usability in games, through targeted questionnaires, in order to improve interactions between users and interfaces.

4. RECOMMENDED DESIGN STRATEGIES

Although best practices for designing healthcare games and applications have been well-documented, in practice many GBT and SBT scenarios lack these effective design elements and UX considerations. The literature revealed a trend of disconnects between content designers and end-users; negative UX often stems from a lack of understanding of design principles by those who design and develop serious games for healthcare [44]. Additionally, despite advocacy for implementing engaging game design principles, particularly diverse interactivity and player choice, virtual patient experiences suffer from being "linear, limited, and constrained" [30, pp. 53] and surgical simulators are often tedious and lack mechanics that would make them engaging for learners [45].

Our analysis of the UX literature and literature focused on medical information systems, broadly considered, has led to the formulation of the following design recommendations for improving the UX of educational and training games and applications for healthcare procedures and associated or pre-requisite knowledge. The following recommended design strategies are presented in line with the recommendations from the findings presented in the previous section. Citations are included to more explicitly link the design strategy to the literature that inspired it:

1. Consider structured usability tests with robust frameworks, such as cognitive task analysis [42], as mechanisms to embed usability as a construct throughout the design process, not just at the end [35, 42, 31].

2. Determine how both formative [41, 38] and summative [38] models of evaluation might be helpful for studying how end users engage with the serious game [43].
3. Conduct front-end analysis to determine the specific needs and attitudes of end-users and (if applicable) instructors [31, 35].
4. Use iterative design strategies to allow games and applications to evolve and improve over time [35, 42, 31].
5. Actively involve end-users [35, 42] and healthcare providers [35, 42, 31] in the design process by frequently testing the product [35, 31] and implementing changes based on their feedback [35, 42, 31].
6. Establish clear instructional goals early in the design process in order to create meaningful game mechanics that complement learning outcomes [42, 31].

5. APPLICATION

In this section, to facilitate the use of the design strategies that were recommended, we demonstrate how they can be applied in action. To accomplish this, we conduct a post-mortem evaluation of the design processes used in the development of a serious game meant to teach brain structure and function, *Medulla*¸ in relation to the recommendations described in this paper. We chose this game in part because of its availability (being designed and developed by the first author) but also because brain-based games have previously been evaluated from the context of UX and entertainment computing, such as the brain-computer interface games evaluated in [46]. Additionally, brain structure and function knowledge is prerequisite for healthcare providers in many brain health subdomains. Medulla is both single-player and played individually rather than in social groups, making this current data unique as compared to prior studies. In applying our UX recommendations, we assess where the game meets expectations and where it falls short, and discuss the potential impact of the convergence or divergence of recommended design and implemented design. It is important to note that the primary purpose of this section is to show how the design strategies can be used for evaluation; Medulla is simply a vehicle for this purpose. Further, developers should be aware that different healthcare games subdomains may require modifications to the application of these strategies; this is simply one way in which these strategies may be applied. We begin with a description of the game, and proceed to the analysis of design.

5.1. Medulla

Medulla (Figure 1) is a two-dimensional platformer game developed to teach introductory psychology material to undergraduate students. Specifically, it aims to inform players about the major parts of the brain, their locations, and their prominent roles – knowledge that is preliminary to the study of many fields of psychology, including those related to mental health. As an example, players may learn that the occipital lobe is located at the rear of the brain and plays an important role in vision.

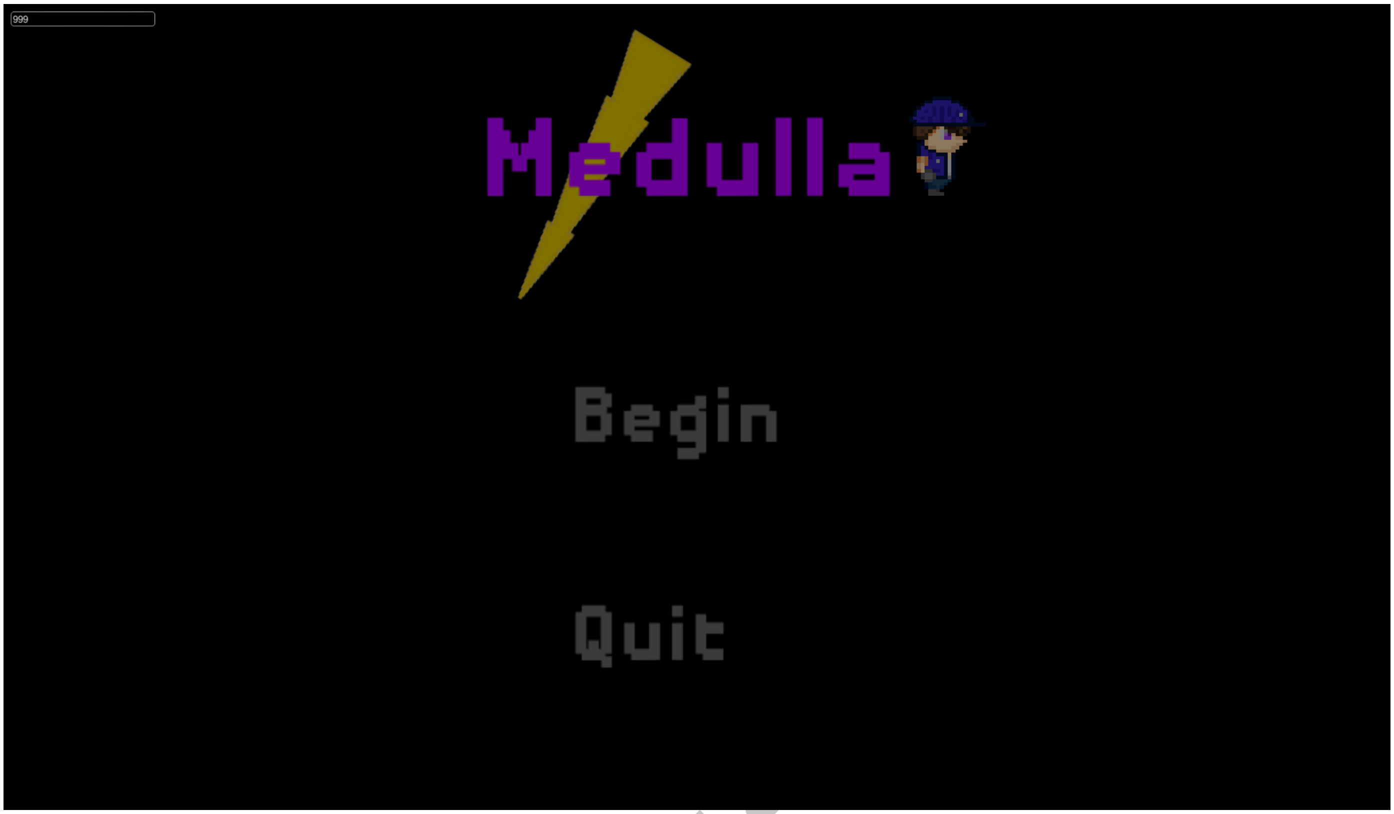


Figure 1. Medulla Start Screen

The gameplay takes place in a virtual world in turmoil, where the player is placed into the role of a young boy, yet to be named a hero. He is a common citizen, enlisted to save the world through a combination of magical powers – a new one bestowed at the beginning of each level. The powers are related to the areas of the brain (e.g., Temporal power), and are used to restore mental functioning to citizens who have been overtaken by the evil "Thor The Destroyer." The symptoms presented by these citizens are not meant to be representative of actual mental illness, but rather to be symptoms that clearly reflect the part(s) of the brain afflicted. For instance, if the player encounters a citizen who states they are unable to see, the player should select the occipital lobe. If the player encounters a citizen who jumbles their speech, the player should select both Broca's and Wernicke's areas. The player continues through the game, curing citizens and defeating enemies with projectiles (called "brainwaves") until she reaches the final battle against Thor. After Thor is defeated, the player is victorious, and the game ends.

A 2015 study implemented a pretest-posttest design to evaluate Medulla's effectiveness in teaching the proposed content [8]. Results were significant ($p < .001$), demonstrating the game's effectiveness in achieving its goal. While it was successful in teaching the content, it has not been formally assessed by end-users. Learning does not equate to UX and willingness to adopt the game, and, as described earlier, end-user perceptions are important to the success of the game. Thus, we examine Medulla in relation to our design recommendations for UX.

5.2. Analysis of Design

This portion of the paper will examine Medulla for the application of our 6 UX design recommendations. This analysis is perhaps less important for the actual evaluation of Medulla. Instead, it serves as a vehicle for demonstrating our recommendations in motion. We hope that the demonstration of our recommendations, as applied within a learning game, will help the reader to understand how to use them, in situ. If the recommended steps were conducted in Medulla, the specifics of their application will be described. If not, we take advantage of the opportunity to describe how they could have been applied. With this in mind, we begin our evaluation.

5.2.1. Recommendation 1 – Consider structured usability tests with robust frameworks, such as cognitive task analysis, as mechanisms to embed usability as a construct throughout the design process

Neither formal and extensive cognitive task analysis, nor think-aloud testing were implemented during the game's development. Resources were scarce, so nearly all testers were non-incentivized volunteers. To encourage voluntary participation, the testing process was designed to require minimal effort from the users, a practice that precluded processes like self-recording, uploading files (e.g., audio and video) over the internet, and sending via-email.

That is not to say that nothing was done. One tester was at the immediate disposal of the developer, and participated in more thorough testing. Specifically, the tester played the game while the developer watched. The developer observed how the game was played – what paths were chosen, where the user had difficulty, any bugs encountered, etc. – and took notes. After play was completed, the user was asked about their experience during the game – what did they like? What didn't they like? What did they feel was important to say about their experience and the game? What would they change? And, so on.

This did provide insight into the game's strengths and limitations, but more formal testing with a greater number of testers would have been more useful, reliable, and valid than a one person sample of convenience for this sort of testing. The employed methodology only identifies the perspective of one user – a user who happened to be a novice gamer. Thus, the results were novice-centric and failed to account for expert gamers. Moreover, there is likely to be further differences amongst novices, which may not have been reflected in the results of a single tester.

Additionally, more formal testing could have been beneficial, here. Ideally, think-aloud testing with multiple participants could have provided more insight into the thought processes and frustrations of users in real-time. Such a practice could have used direct observation or video-recording. By aggregating notes taken across all think-aloud sessions, the developer could have assessed common trends between the users and identified particular problem areas within the game.

Similarly, formal cognitive task analysis could have aided testing efforts. In a 2013 I/ITSEC paper, Patrick Gallagher and Shenan Prestwich discussed the application of cognitive task analysis to a video game [47]. They outline a very detailed methodology which cannot be completely described within this paper, but employing such a strategy would have been beneficial to understanding the cognitive needs of the user and how the elements of each level supports the satisfaction of those needs. For instance, identifying the cognitive steps (e.g., audio/video cues to be observed, decisions to be made, inference, deduction) require by each level, and each level's affordances (e.g., elements in the virtual environment with which players must interact in order to achieve the level's goal) could help to find parallels and inconsistencies in needs and provisions.

5.2.2. Recommendation 2 – Determine how both formative and summative models of evaluation might be helpful for studying how end users engage with the serious game

Medulla is built around formative assessment. Medulla's curing mechanic asks players to constantly practice the learning content. As the player moves through the levels and is faced with ill citizens, she must select the part of the brain most related to the presented symptoms. If the player chooses the correct part, the citizen smiles and thanks the player (i.e., feedback). The player is then rewarded with points and extra health. If incorrect, she has one more chance. If incorrect for a second time, the player loses health, the citizen's sprite does not change, and the player is told the correct answer within narrative-relevant text.

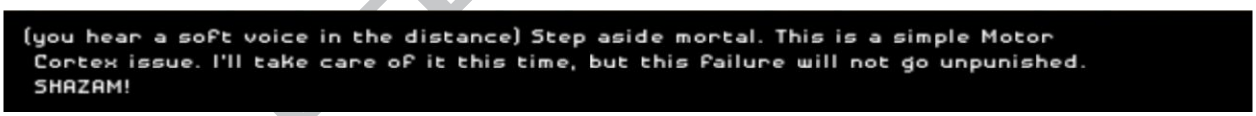


Figure 2. The player is provided with the correct answer upon choosing incorrectly, twice

Regardless of the player's correctness, she will receive feedback, allowing her another chance to learn the content and be correct next time.

Summative assessment in Medulla is a bit more complicated, yet present. At the end of the game, the player must fight Thor, the final boss. The citizens of Medulla aid the player in this fight, and continuously shoot the platform below Thor. He constantly afflicts the citizens with illness, causing them to cease firing while ill. The player cannot shoot the platform, but must continuously cure the citizens while fighting off the enemies, in order to keep them in the fight. All in all, the player must successfully cure around 100 citizens in order to destroy the platform and win the battle. Such a feat would take an extensive amount of time to do without knowledge of the brain areas. In this manner, this final fight serves as something of a grand assessment – those who finish the game, therefore, are likely to have mastered the pre-requisite knowledge.

Moreover, additional, more traditional summative assessment may take place after Medulla is completed. In a traditional classroom, an instructor may assign students to the playing of Medulla, either as a way to learn the content, or as a way to review the content. After students have played the game, a written exam may take place, providing a final assessment of student learning, with Medulla serving as learning or reviewing tool.

5.2.3. Recommendation 3 – Conduct front-end analysis to determine the specific needs and attitudes of end-users and instructors

Medulla's development included front-end analysis, primarily through the use of needs assessment. First and foremost, the goal and audience were defined. If we consider the goal on one end, and the audience on another, the needs assessment serves as the middle piece, connecting the two together. That said, without an understanding of the goal of the game, and who is playing the game, it can be difficult to ascertain what is needed to get that audience to the goal.

For Medulla, the audience included those who will eventually pursue advanced topics in Psychology. These students will primarily be found in introductory Psychology courses. Before advanced topics topics can be learned, students must learn the basics of brain structure and function. Thus, these students and their instructors (the ones who teach the foundational content to the students) became the target audience of Medulla. Then, the primary goal of Medulla was to teach brain structure and function information to students in introductory Psychology courses in an efficient and engaging manner.

With goal and audience defined, a gap remained. What were the needs and qualities of the audience members – instructors and students? To begin, introductory courses can be very large, totaling several hundred students per section. Therefore, the instructor would most likely be unable to provide one-on-one support. Therefore, instructors would need the game to stand by itself; to be effective without instructor intervention. Such a quality would likely be attractive to instructors, helping ease the burden on their already hefty workloads – hopefully increasing the likelihood that instructors would be willing to try it with their class, and ultimately adopt the software.

Students were likely to vary widely in many qualities. However, most were likely to be first year college students, as introductory psychology courses often fulfill a general education requirement. As new college students, it was possible that they have probably not yet developed advanced study skills, and may or may not have sufficient self-discipline and focus to maintain efforts on a task they perceive to be uninteresting. Medulla would have to guide the learning process while maintaining engagement if students were to find it worthwhile. Students were also expected to vary widely in gameplay ability. Some students may have been experienced gamers, but others may not have been. The game had to cater to both types of players equally, ensuring novice players could play the game without feeling overwhelmed, while ensuring expert players would not be bored with overly simplistic gameplay. Finally, of course, neither instructor nor student would find Medulla appealing if it did not teach the content in an efficient manner. The game would have to promote true learning. These identified qualities and needs would then serve as the backbone for user-centric design.

5.2.4. Recommendation 4 – Use iterative design strategies to allow games and application to evolve and improve over time.

Iteration has become a normal part of the software development lifecycle, in general, but especially so in game development. Medulla's development conformed to this standard. While a game design document was created before Medulla's development, the game went through several modifications before the game's final development stages.

For example, in Medulla's early stages, it only incorporated walking enemies. These enemies would walk back and forth, inflicting damage on any player that collided with them. It was believed that walking enemies would promote a suitable level of challenge for novice players, and tricky placement of enemies with modifications to speed and direction, and combining them with well-placed pits and other level hazards, could make them challenging enough for expert players. However, expert and novice players, alike, quickly figured out how to navigate these enemies, creating challenge that was too low for any player. As a result, two other types of enemies were introduced – those that walked, followed the player, and shot projectiles, and those that flew and followed the player. By incorporating projectiles in linear-moving enemies, and adding enemies that were not confined to linear boundaries, an appropriate level of challenge was attained.

As another example, the *feel* of the game's controls went through multiple iterations, throughout development. Here, we refer to sensitivity of controls, speed, jump height, gravity, etc., for both player and enemies. It is difficult to identify the right levels for each of these variables before playing the game with them in place. If a player moves too slowly, it can make the game feel sluggish and unexciting. Conversely, if the player moves too quickly, it can be difficult to control the character, and the controls may feel imprecise or otherwise unrefined. Speed can also affect game difficulty. In general, when a player or enemy is made to move faster, the player's reaction time must be higher in order to react to the event which now triggers quicker than it did when the player moved slower. For example, in a sidescroller game, only a portion of the game environment, immediately surrounding the player, is viewable at any given time. As the player runs to the right, more of the environment becomes visible, including enemies in that portion of the environment. The quicker a player moves, the quicker that environment is revealed, and the shorter the time period between when an enemy appears on screen and when the player collides with the enemy. This is a delicate balance that requires frequent iteration to fine-tune.

5.2.5. Recommendation 5 – Actively involve end users and healthcare providers in the design process by frequently testing the product and implementing changes based on their feedback.

Medulla did not quite follow this recommendation. Access to end users and healthcare providers was restricted at the time of its development, so no end users were included. That is not to say that the game was not tested, however. Testers included a psychology professor (more advanced courses), a game design professor (not part of the Medulla's design team), a games researcher, and several other people who did not have knowledge of the content presented in the game. The goals were to include expert input into the game's design, while also testing the content and game's engagement with those who may be representative of the end users, in the absence of true end users. Test users were incorporated for three purposes: to test for bugs, to self-report engagement during the game, and to confirm that the game's content was being taught effectively.

In addition to formal bug testing by the developer, bug testing was conducted by providing the game to the users to play at their leisure. They were also provided with JPEG images of each level, in entirety. Testers were asked to either circle the location where they encountered a bug, and/or write notes on the bug encountered, location, and how they suspected they triggered the bug. With this information in hand, the developer was able to reproduce the majority of these bugs and address them appropriately.

Test users were able to provide the developer with an initial understanding of the game's engagement potential. Users were asked to informally discuss their favorite and least favorite parts of the game, and provide a statement on their overall engagement level in the game. They were instructed to provide honest feedback for both positive and negative features, as honestly was required to gather the information needed to improve the game. The most commonly mentioned positive features were the game's music, ending sequence, and the game's ability to teach the content during the game's short timespan (gameplay typically ranged between 30 and 90 minutes, depending on gamer's expertise). Almost exclusively, negative features surrounded gameplay difficulty in particular areas of the game. The specific places that were overly difficult were identified and corrected, reducing enemies, lengthening platforms, or otherwise reducing the level of challenge to an appropriate level.

Finally, test users were tested for their learning. Users were given a test for the learning content. They were instructed to take the test once before playing the game, and that they should not ask for help or use any resources as they took the test. They should then play the game, and then take the test again. The answers were not provided to the users; instead, they were to send both sets of responses to the developer. The developer then graded both sets and compared the pretest to the posttest to evaluate learning. In addition to the responses, testers were also asked to send along a statement expressing if they felt like they learned, and why they feel they did or did not learn the information appropriately. The learning results, along with the perceived learning levels and reasoning were used to improve the game in subsequent iterations. For example, it was discovered that many users were not engaged by the text-based dialogue in general, the same place where the learning content was presented. As a result, many were skipping the dialogue entirely. In addition to rewriting and shortening much of the dialogue, measures were taken to make the learning content more salient (e.g., highlighting key words in red), so that it would stand out among the text that did not contain learning content (Figure 3).

Figure 3. Key words are highlighted in red to make the learning content more salient.

5.2.6. Recommendation 6 – Establish clear instructional goals early in the design process in order to create meaningful game mechanics that complement learning outcomes.

While the audience was fairly well-defined, the goal required further specification before it could be useful. "Brain structure and function" is broad. It would be a lofty goal to pursue teaching all of this with a single game that had not yet been prototyped or demonstrated plausible through a proof of concept. It seemed reasonable to identify several parts of the brain that had well-defined roles, to serve as the learning content for this game. If successful, more learning content could be included in future games. Thus, 9 parts were selected – Prefrontal Cortex, Motor Cortex, Parietal Lobe, Broca's Area, Wernicke's Area, Occipital Lobe, Temporal Lobe, Cerebellum, and Medulla Oblongata.

Thus, the game aimed to teach the location and primary purpose of each of these parts of the brain. Beyond teaching specific content, the game had to teach that content in an efficient manner. After all, the goal of this game was not to teach this content to independent individuals with a thirst for knowledge; it was meant to teach students in a college course, who had to meet deadlines for assignments and exams, so that they could move on to their next course with the pre-requisite knowledge. Teaching the information *efficiently*, then, became another instructional goal.

The instruction needed to be intertwined with the game's mechanics in order to avoid making the learning content and gameplay feel disjointed – like two separate experiences. The developer identified the specific tasks players should be able to achieve at the end of playing the game, before deciding upon mechanics. The player should be able to:

1. Label a diagram of the brain, identifying the correct location for the correct part.
2. Match the name of each part of the brain to a primary function.

Whichever mechanics were chosen would have to support these two post-game activities, while still fitting within the narrative and the game world.

It had already been decided that this game would follow the classic "evil villain attempts to take over the world" narrative, but the specifics of player interaction were yet to be determined. However, one goal was to intertwine the brain as a theme, in a somewhat exaggerated and fictionalized way, but without tarnishing the integrity of the learning content. For example, players would attack enemies by shooting *brain waves* as projectiles. Perhaps the evil villain could plague the brains of the world's citizens, and the player would be required to cure them. How could this be linked to the two specific tasks outlined above?

It was decided that, upon reaching an ill citizen, players would be presented with an image of the brain (Figure 4).

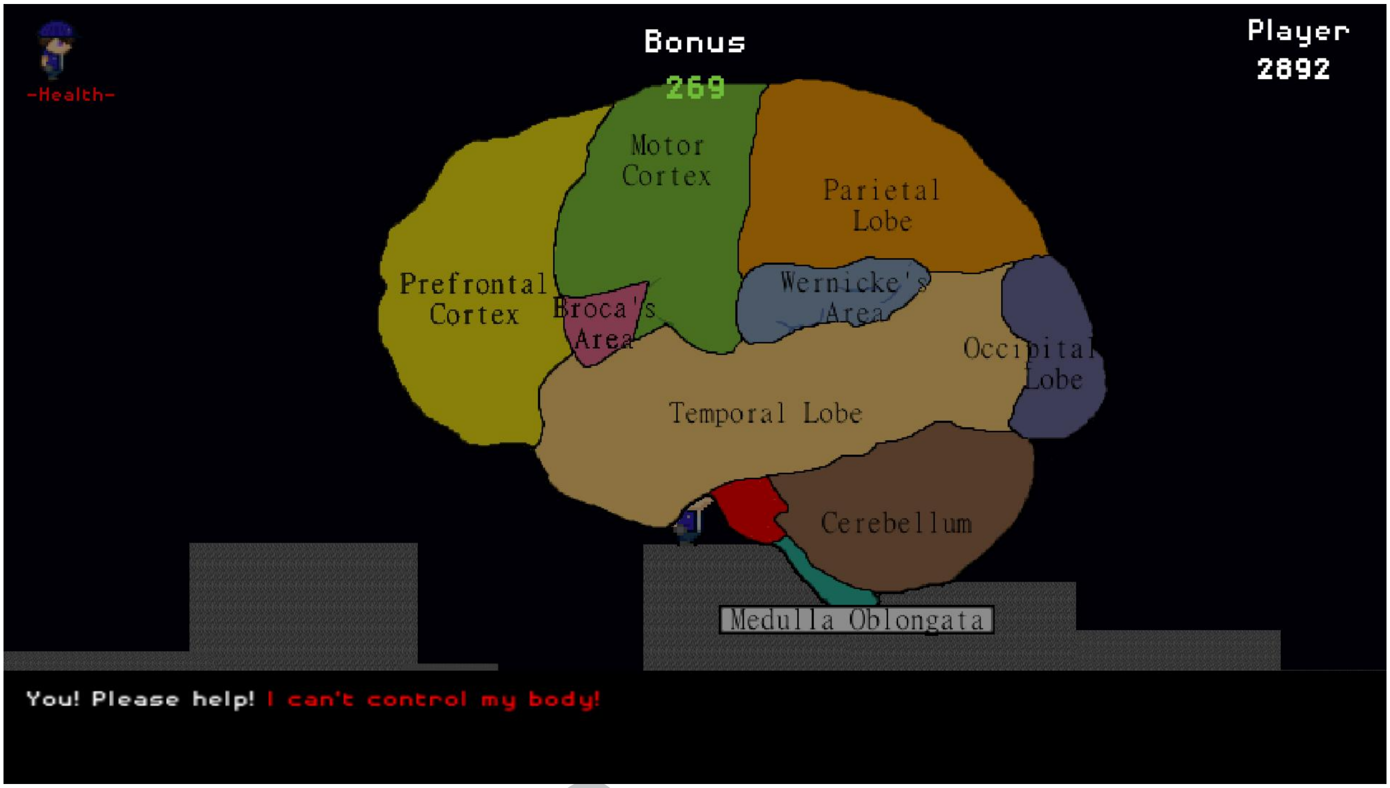


Figure 4. Players must click the brain to choose the appropriate power for curing citizens.

Clicking each region would use a different curative power. Matching the correct power to the correct symptoms would cure the citizen. This mechanic supported both tasks. When an ill citizen presented symptoms, and the player chose the correct part of the brain, it was very much like matching brain part to primary function. Moreover, the user would have to click the specific region of the brain, not a list of words, providing practice with location. With enough gameplay, it was hoped, the users would get used to moving their mouse to specific locations for specific powers to make gameplay more efficient, an effect that was observed during experimentation.

6. Conclusion

Although current studies allow us to establish general recommended design strategies, further research is needed to analyze the specific factors that influence UX in healthcare games and applications. Potential areas for further exploration include the relationship between personality traits and enjoyment of certain game mechanics or genres, the effects of specific game design patterns on knowledge gains in GBT, and more detailed studies describing the perceptions of doctors, nurses, and medical students towards new media learning strategies. By combining survey measures of demographics, attitudes toward technology, computer literacy, and gaming experience, future studies can begin to determine how these factors relate to each other and influence design strategies for games and simulations as a whole. Discovering these relationships will allow researchers to identify specific barriers to using healthcare games and applications, which can, in turn, contribute to better design and implementation of these experiences in the future. While this study engaged in a theoretical approach, future work should apply the proposed guidelines in a variety of different healthcare applications to see how they affect UX ratings. More concrete data will enable a better understanding of how to design healthcare games so that they more consistently fulfill their purposes, improving the efficiency of resources used to build the game, and acceptance of these technologies as a result of higher success rates.

References

[1] N.A. Bartolomé, A.M. Zorrilla, and B. G. Zapirain, "Autism spectrum disorder children interaction skills measurement using computer games," in *Proc. of the 18th Int. Conf. on Comp. Games*, Louisville, OH, 2013, pp. 207-211.

[2] H. Sabri, B. Cowana, B. Kapralosa, M. Porte, D. Backsteinc, and A. Dubrowskiee, "Serious games for knee replacement surgery procedure education and training," in *Proc. of the World Conf. on Edu. Sci.*, Barcelona, Spain, 2012, pp. 1322-1330.

[3] P. Pereira, E. Duarte, F. Rebelo, and P. Noriega, "A review of gamification for health-related contexts," in *Int. Conf. of Design, User Experience, and Usability*, Heraklion, Crete, Greece, 2014, pp. 742-753.

[4] S. McCallum, "Gamification and serious games for personalized health," *Stud. Health Tech. Inform*, vol. 177, pp. 85-96, 2012.

[5] A. Miller, J. Cafazzo, and E. Seto, "A game plan: Gamification design principles in mHealth applications for chronic disease management," *Health Informatics J.*, vol. 22, no. 2, pp. 184-193, 2016.

[6] L. Reichlin, N. Mani, K. McArthur, A.M. Harris, N. Rajan, and C.C. Dasco, "Assessing the acceptability and usability of an interactive serious game in aiding treatment decisions for patients with localized prostate cancer," *J. Med. Internet Res.*, vol. 13, no. 1, Jan. 2011.

[7] O. Danilina, A.L. Cox, A. Fonseca, and S. Johnson, "Serious video games as psychosocial interventions for psychosis," in *Proc. of CHI '17*, Denver, Colorado, 2017, pp. 93-99.

[8] J.R. Fanfarelli and S. Vie, "Medulla: A 2D sidescrolling platformer game that teaches basic brain structure and function," *Well Played*, vol. 4, no. 2, pp. 7-29, Aug. 2015.

[9] J.D. Facteau, G.H. Dobbins, J.E.A. Russell, R.T. Ladd, and J.D. Kudisch, "The influence of general perceptions of the training environment on pretraining motivation and perceived training transfer," *J. of Manag.*, vol. 21, no. 1, pp. 1-25, Spring 1995.

[10] T.T. Baldwin, R.J. Magjuka, and B.T. Loher, "The perils of participation: Effects of choice of training on trainee motivation and learning," *Pers. Psychology*, vol. 44, no. 1, pp.51-65, Mar. 1991.

[11] J.E. Mathieu, S.I. Tannenbaum, and E. Salas, "Influences of individuals and situational characteristics on measures of training effectiveness," *Academy of Manag. J.*, vol. 35, pp. 828-847, Oct. 1992.

[12] V. Venkatesh, "Determinants of perceived ease of use: Integrating control, intrinsic motivation, and emotion into the technology acceptance model," *Information Syst. Reearch*., vol. 11, no. 4, pp. 342-364, Dec. 2000.

[13] H. Bassam, "Examining the effects of computer self-efficacy and system complexity on technology acceptance," *Info. Resources Manag. J.*, vol. 20, no. 3, pp. 76-88, 2007.

[14] S. Engl and L. E. Nacke, "Contextual influences on mobile player experience–A game user experience model," *Entertainment Computing*, vol. 4, no. 1, pp. 83-91, 2013.

[15] E.L. Law, V. Roto, M. Hassenzahl, A.P. Vermeeren, and J. Kort, "Understanding, scoping and defining user eXperience: A survey approach," in *Proc. of Human Factors in Comput. Syst.*, Boston, MA, 2009, pp. 719-728.

[16] M. Begg, "Leveraging game-informed healthcare education," *Medical Teacher*, vol. 30, no. 2, pp. 155-158, 2008.

[17] I. Gourbanev, S. Audelo-Londono, R.A. Gonzalez, A. Corts, A. Pomares, V. Delgadillo, and … O. Munoz, "A systematic review of serious games in medical education: quality of evidence and pedagogical strategy," Medical Educ. Online, vol. 23, no. 1, 2018, doi: https://doi.org/10.1080/10872981.2018.1438718

[18] J. J. Garrett, *Elements of user experience, the: user-centered design for the web and beyond*.. San Francisco, CA: Peachpit, 2010.

[19] R. Unger and C. Chandler, *A Project Guide to UX Design: For User Experience Designers in the Field or in the Making*. San Francisco, CA: Peachpit, 2012.

[20] T. Lockwood, Ed., *Design Thinking: Integrating Innovation, Customer Experience, and Brand Value*. New York, NY: Allworth Press, 2009.

[21] K. Smith, V. Smith, M. Krugman, and K. Oman, "Evaluating the impact of computerized clinical documentation," *CIN: Computers, Informatics, Nursing*, vol. 23, no. 3, pp. 132-138, May 2005.

[22] L. Alben, "Defining the criteria for effective interaction design," *Interactions*, vol. 3, no. 3, pp. 11-15, May 1996.

[23] Apple Inc., 'iOS design themes', 2018. [Online]. Available: https://developer.apple.com/ios/human-interface-guidelines/overview/themes/. [Accessed: 30-Mar-2018].

[24] Facebook, 'Facebook for developers,' 2018. [Online]. Available: https://developers.facebook.com/. [Accessed: 30-Mar-2018].

[25] J. Gothelf and J. Seiden, *Lean UX: Applying lean principles to improve user experience*. Sebastopol, CA: O'Reilly Media, Inc., 2013.

[26] P.B. Mason, B.M. Turgeon, J.S. Cossman, and D.M. Lay, "The use of technology and perceptions of its effectiveness in training physicians," *Medical Teacher*, vol. 36, no. 4, pp 333-339, April 2014.

[27] S.G. Topkaya and N. Kaya, "Nurses' computer literacy and attitudes towards the use of computers in health care," *J. Nursing Interventions*, vol. 21, no. 2, pp. 141-149, June 2015.

[28] R. Hawkins et al., "A pilot study evaluating the perceptions of certified registered nurs anesthetists toward human patient simulation," *Amer. Assoc. Nurse Anesthetists J.*, vol. 82, no. 5, pp 375-384, 2015.

[29] E.J.Yeun, H.Y. Bang, E.N. Ryoo, and E Ha, "Attitudes toward simulation-based learning in nursing students: An application of Q methodology," *Nurse Educ. Today*, vol. 34, no. 7, pp. 1062-1068, Mar. 2014.

[30] J.A. Cannon-Bowers, C. Bowers, and K. Procci, "Using video games as educational tools in healthcare," *in Computer Games and Instruction*, Charlotte, NC: Info. Age Pub., 2011, pp. 47-72.

[31] J. Torrente, B. Borro-Escribano, M. Freire, A. del Blanco, E. J. Marchiori, I. Martinez-Ortiz, P. Moreno-Ger, and B. Fernandez-Manjon, "Development of game-like simulations for procedural knowledge in healthcare education," *IEEE Trans. on Learning Technologies*, vol. 7, no. 1, pp. 69-82, April 2014.

[32] K.A. Wilson, E. Salas, M. Rosen, J. Taekman, and J. Augenstein, "Games doctors play: Guiding principles for using simulations to train shared cognition," *Cognitive Technology*, vol. 13, no. 2, pp. 8-16, 2008.

[33] F. W. Kron, C. L. Gjerde, A. Sen, and M.D. Fetters, "Medical student attitudes toward video games and related new media technologies in medical education," *BMC Medical Educ.*, vol. 10, no. 50, Nov. 2010.

[34] S.M. Arteaga, V.M. González., S. Kurniawan, and R.A. Benavides, "Mobile games and design requirements to increase teenagers' physical activity," *Pervasive And Mobile Computing*, vol. 8 (Special Issue on Pervasive Healthcare), pp. 900-908, Dec. 2012

[35] B. Paulovich, "Design to improve the health education experience: using participatory design methods in hospitals with clinicians and patients," *Visible Language*, vol. 49, no. 1/2, pp. 144-159, April 2015.

[36] J. Jones, S. Cassie, M. Thompson, I. Atherton, and S.J. Leslie, "Delivering healthcare information via the internet: Cardiac patients' access, usage, perceptions of usefulness, and web site content preferences," *Telemedecine & E-Health*, vol. 20, no. 3, pp. 223-228, Mar. 2014.

[37] M. Scerbo, W. Murray, G. Alinier, T. Antonius, J. Caird, E. Stricker, and ... R. Kyle. "A path to better healthcare simulation systems leveraging the integrated systems design approach," *Simulation In Healthcare J. Of The Soc. For Simulation In Healthcare*, pp. 6S20-S23, Aug. 2011.

[38] S. Kelle, R. Klemke, and M. Specht, "Effects of game design patterns on basic life support training content", *Educ. Technology & Soc.*, vol. 16, no. 1, pp. 275-285, Jan. 2013.

[39] G. Chiniara, G. Cole, K. Brisbin, D. Huffman, B. Cragg, M. Lamacchia, and D. Norman, "Simulation in healthcare: A taxonomy and a conceptual framework for instructional design and media selection," *Medical Teacher*, vol. 35, no. 8, pp e1380-e1395, Aug. 2013.

[40] L. Berragan, "Learning nursing through simulation: A case study approach towards an expansive model of learning," *Nurse Educ. Today*, vol. 34, pp. 1143-1148, Mar. 2014.

[41] R. Ellaway, T. Poulton, U. Fors, J.B. McGee, and S. Albright, "Building a virtual patient commons," *Medical Teacher*, vol. 30, no. 2, pp. 170-174, Feb. 2008.

[42] A.W. Kushniruk, V.L. Patel, and J.J. Cimino, "Usability testing in medical informatics: Cognitive approaches to evaluation of information systems and user interfaces," in *Proc. of the AMIA Annu.. Fall Symp.*, American Medical Informatics Association, Nashville, TN, 1997.

[43] G.P. Tolentino, C. Battaglini, A.C.V. Pereira, R.J. De Oliveria, and M.G.M. De Paula. "Usability of Serious Games for Health," in *Proc. of Games and Virtual Worlds for Serious Applications*, IEEE Press, Athens, Greece, 2011.

[44] M. Graafland, M. Dankbaar, A. Mert, J. Lagro, L. De Wit-Zuurendonk, S. Schuit, and ... M. Schijven, "How to systematically assess serious games applied to health care," *JMIR Serious Games*, vol. 2, no. 2, pp. e11, July 2014.

[45] S. de Ribaupierre, B. Kapralos, D. Haji, E. Stroulia, A. Dubrowski, and R. Eagleson, "Healthcare training enhancement through virtual reality and serious games," *Virtual, Augmented Reality & Serious Games For Healthcare*, vol. 1, pp. 9-27, April 2014.

[46] H. Gürkök, A. Nijholt, M. Poel, and M. Obbink, "Evaluating a multi-player brain–computer interface game: Challenge versus co-experience," *Entertainment computing*, vol. 4, no. 3, pp. 195-203, 2013.

[47] P.S. Gallagher and S. Prestwich, "Cognitive task analysis: Analyzing the cognition of gameplay & game design," *in Proc. of I/ITSEC 2013*, Orlando, FL, 2013.

7. HIGHLIGHTS

- Investigates the role and application of user experience principles in the design of healthcare games and applications
- Analyzes current user experience practices
- Makes six design recommendations for incorporating UX in healthcare games and applications
- Demonstrates recommendations through the evaluation of a game and its incorporation of UX