MEDULLA: A 2D SIDESCROLLING PLATFORMER GAME THAT TEACHES BASIC BRAIN STRUCTURE AND FUNCTION

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Abstract

This article explores the design and instructional effectiveness of *Medulla,* an educational game meant to teach brain structure and function to undergraduate psychology students. Developed in the retro-style platformer genre, *Medulla* uses two-dimensional gameplay with pixel-based graphics to engage students in learning content related to the brain, information which is often pre-requisite to more rigorous psychological study. A pretest-posttest design was used in an experiment assessing *Medulla's* ability to teach psychology content. Results indicated content knowledge was significantly higher on the posttest than the pretest, with a large effect size. *Medulla* appears to be an effective learning tool. These results have important implications in the design of educational psychology games and for educational game designers and artists exploring the possibility of using a two-dimensional retro-style structure.

Introduction

Educational games that teach undergraduate psychology subject matter are rare. While countless games aim to improve cognitive function or other constructs studied by psychologists (e.g., Whitbourne, 2012; Lumosity, 2014), few focus on helping undergraduate psychology students learn the pre-requisite content that is required to succeed in their academic study. However, preliminary research on educational games and gamification in the psychology classroom shows these tools hold promise in motivating students to learn and retain course content over time (Landers & Callan, 2011).

The primary functions and locations of prominent brain areas is one example of content which is commonly required for the successful completion of introductory psychology courses—courses that are typically pre-requisite to enrollment in specialized classes. Students may be required to know, for example, that a primary function of the occipital lobe is processing visual information, and that it is located at the rear of the brain (Grill-Spector, 2003). This foundational knowledge enables students to understand more advanced psychological concepts and processes related to these areas of the brain.

To assist students in learning foundational psychology concepts, the field has engaged strategies such as active learning (Benjamin Jr., 1991; Mathie et al., 1993), collaborative learning (Johnson & Johnson, 2009), and problem-based learning (Dahlgren & Dahlgren, 2002; Reynolds, 1997). Games-based learning, such as through educational games, is one active learning strategy that builds on past research illustrating that students who receive scientific information through multimodal channels (relying on narration and animations) retain information better than students who received text alone (Mayer, 1997). Similarly, research by Moreno and Mayer (2000) indicated that students who played educational games that addressed the player using first- and second-person speech "remembered more and used what they learned to solve new problems better" than students who played games that addressed the player using third-person speech (p. 729). These findings show promise in the psychology classroom for the use of educational games that feature multimodal affordances such as text, sound, and animation in conjunction with narrative structures that directly address the student player through first- and second-person speech.

In this study, an educational game, *Medulla*, was designed, developed, and empirically tested with undergraduate students majoring in psychology at the University of Central Florida. A pretest-posttest design was used to assess content knowledge before and after gameplay to identify learning effects. This test assessed players' knowledge of the parts of the brain – the content that *Medulla* aimed to teach. It was hypothesized that across all participants, posttest scores would be significantly higher than pretest scores. The results supported this hypothesis. The active learning featured in *Medulla* aligns with current national recommendations for undergraduate psychology curricula, which aim to "incorporate more active learning of science … to maximize the important and varied outcomes" of the undergraduate learning experience (Perlman & McCann, 2005, p. 13). It also supports previous research illustrating the benefits of multimodal educational games that use narrative to help students retain and apply scientific knowledge. *Medulla* was not only successful as a learning game because it used features previously suggested as beneficial by research, but also because of its reliance upon a fantasy-based narrative that takes potentially dry technical content and weaves it into a storyline where players can save the world.

Developing *Medulla*

Medulla (Figure 1) is a two-dimensional platformer developed using Unity3D. The aesthetic is pixel-based, reminiscent of the retro genre and the games that inspired it. *Medulla* places the player in a world in turmoil. The evil Thor the Destroyer is wreaking havoc on the city of Medulla, inflicting maladies upon the minds of its citizens. The player must defeat him and his minions while curing the citizens' minds. *Medulla* has two primary mechanics: 1) Shooting brainwaves and 2) Curing citizens.

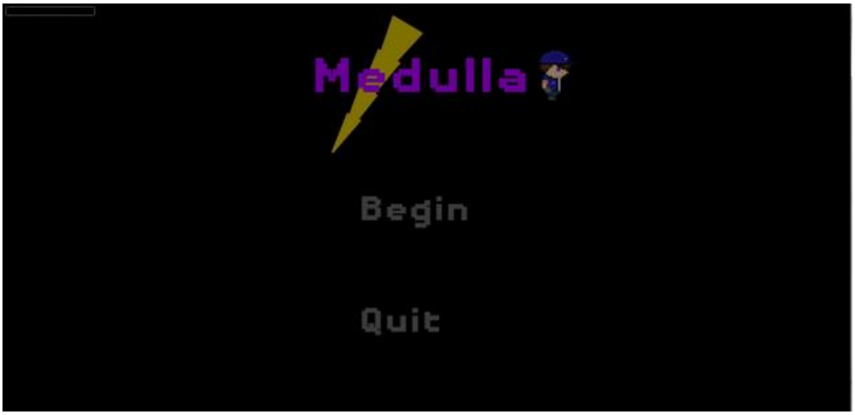

Figure 1. Medulla Title Screen

The final version of *Medulla* included between 34 and 76 minutes of gameplay (mean = 50.96) and was carefully designed (over 500 hours of development). Achievements were embedded to encourage participants' exploration of the game world; such achievements included "Pacifist," awarded to players who completed a level without killing anything; "Violent," given to players who attacked a well-meaning, friendly non-player character; and "Moonwalker," given to players who pressed both arrow keys at once (presumably to see what would happen).

While not intended as a direct teaching element, *Medulla*'s narrative incorporated domain-specific terminology to not only provide exposure and familiarity with these terms, but also to keep the names of people and places consistent with the game world. For example, various cities in the game are named after parts of the brain (e.g., the towns of Occipital and Parietal). Similarly, some characters' names are drawn from parts of the brain as well: conjoined twins Broca and Wernicke, who appear in Level 8, are named similarly to the language-processing areas of the brain (Broca's area and Wernicke's area). Balancing humor and scientific content, *Medulla* incorporated visual and textual narrative elements in order to improve immersion in the game environment (Schneider, Lang, Shin, & Bradley, 2004).

Procedure

Participants

20 undergraduate psychology students from the University of Central Florida (11 female, 9 male), between the ages of 18 and 31 (mean = 18.75, SD = 2.9), were recruited through a participant management system. Participants were screened for recent drug use—including alcohol, tobacco, caffeine, sedatives, antipsychotics, and antidepressants—and normality of vision—normal or corrected—in order to ensure consistency in visual acuity and dissuade performance differences due to inferiority of vision or the use of performance-altering drugs.

A pretest and posttest were administered to measure participants' knowledge of the brain structure and function information taught in-game; the pretest and posttest were identical to allow for comparison, and included two parts. The first assessed knowledge of the primary functions of each major brain region. The second assessed knowledge of the location of each major brain region.

Experimental Testbed: Medulla

Participants played *Medulla* on a standard desktop computer (1920 x 1080 pixels resolution) that was controlled for volume and monitor settings (e.g., brightness, contrast, color). A mouse and keyboard were used to interact with the game.

In *Medulla*, brainwaves function as the attacking mechanism. After right-clicking, a projectile emerges from the avatar's head and travels forward for a few fractions of a second before being destroyed (Figure 2). If the projectile collides with an enemy, the enemy is defeated and despawns.

Figure 2. Shooting Brainwaves to Defeat Enemies

Throughout the levels, players encounter and must cure ill citizens. Upon approaching a citizen, the avatar stops and movement and shooting controls are disabled. Fantasy-based dialogue appears as text at the bottom of the screen that relates to the affected portion of the brain (e.g., the occipital lobe for vision). An image of the brain appears, prompting the player to click the correct section (Figure 3). Correct clicks award the player with extra health (up to a maximum of two) and additional time (a time bonus was awarded for remaining time at the end of each level; additional time meant more points). Choosing incorrectly results in a second try. Failure on the second try decreases the player's health by one (death may result from loss of health) and does not award points. After either choosing correctly, or choosing incorrectly twice (death is certain), the player regains control and may proceed through the level.

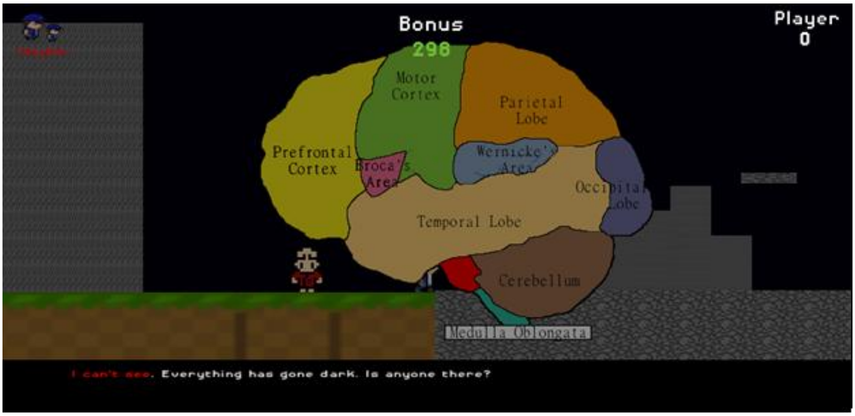

Figure 3. Clicking the Brain to Cure Ill Citizens

Medulla's gameplay feels most similar to a fusion between *Super Mario Bros*. and *Mega Man*. It includes a substantial amount of platforming-based gameplay, where the user is required to make precise jumps in order to progress through the level or collect points. However, the shooting element often requires players to slow their pace in order to avoid colliding with an enemy that must first be defeated. In this manner, enemies were used as tools to regulate the player's speed and progression to combine fast-paced gameplay with more deliberate thought-based play (Figure 4). This was done to encourage players to pause and think before responding, allowing additional time to consider the learning content before progressing.

Figure 4. Using Enemies to Control Pace of Gameplay

However, the ability of non-player agents to control pacing brought about its own challenge. The citizens that required curing placed players at an abrupt stop, forcing gameplay into the narrow constraints of a question-and-answer structure. When designing *Medulla*, the researcher realized the importance of a proper balance between this interruption of gameplay, which enabled practice of the learning content, and smoother, more continuous gameplay. While this interruption was not pervasive in the first level, where players only knew and practiced one brain area, it became an issue by the end of the game, when players needed to recall and practice nine areas within a single level. Front-loading and back-loading the learning content in each level was the solution. Evenly spacing ill citizens within a level would have resulted in interruptions every few seconds. By placing most of the ill citizens at the beginning and end of each level, with a few interspersed in between, the learning content became less of an intrusion on enjoyment (as determined from informal preliminary playtesting). As a result, more ill citizens could be placed, allowing for more time to be spent practicing the learning content while reducing the impact of interrupted gameplay. While this was an interesting effect that enabled more thorough use of a pervasive mechanic, substituting a more engaging mechanic would have been preferable, but there was difficulty identifying such a mechanic. This seemed to be the best way to address the limitation.

Yet another challenge was revealed through early playtesting—teaching the *desired* content. In the original design of *Medulla*, dialogue instantly appeared on screen when the player approached an ill citizen. In an instant, the players moved their mouse cursors in the direction of the correct brain area. While this may at first seem testament to the game's potential ability to teach psychology-based content, the time the player spent reading the dialogue, processing it, making a decision, and beginning the action of moving the mouse cursor seemed far too short. Players appeared to easily able to guess the appropriate response based on the narrative dialogue presented to them. That is, because the text for each brain area was always the same (e.g., the ill citizens in the city of Motor Cortex always said, "You! Please help! I can't control my body!"), the player became an instrument of efficiency, *associating the first few words* with the brain area, *rather than the function*. "You! Please help!" became associated with the motor cortex, instead of "I can't control my body" – the phrase that should have been responsible for prompting the student to consider which area of the brain is connected with bodily control. This became evident during completion of the posttest when the player could not associate the brain area with the function, despite her ability to quickly select it when playing the game. The game was teaching something, but not the desired content. Previous literature (Squire, Giovanetto, Devane, & Durga, 2005) has shown that well-designed games can prompt players' ability to learn factual knowledge such as timelines, specialized vocabulary, and historical terms; as such, thinking through the most effective game design elements to teach content was crucial. Similarly, Squire, Barnett, Grant, and Higginbotham (2004) showed that bringing specialized vocabulary into the game levels themselves and not just in cut scenes or easy-to-skip sections increases learning (p. 519).

A two-fold solution counteracted this. First, the relevant section of the dialogue, the learning content, was highlighted in red, while the remaining the text was unaltered (e.g., "You! Please help! I can't control my body!"). Highlighting is a strategy used to increase the saliency of target objects (Schultz, 1986) and facilitates attentional focus on the highlighted object (Tan & Fisher, 1987). This worked to improve the likelihood that the player, if trying to rapidly search the text and identify the relevant information, would set their focus on the learning content. The other part of the solution required implementing a waiting period before the player could select the brain. Initially, the brain and the text were displayed simultaneously, enabling the player to select before reading any text. The modification involved displaying the text immediately and waiting three seconds before displaying the brain. With this implementation, the player was forced to wait, whether or not they read the text. Three seconds was not deemed to be burdensome, but it did provide the player with free time in which reading was the only available action within the game. After incorporating these two solutions, the important information was now salient and the player had adequate time to find and read it.

Medulla concludes with a final fast-paced review in the form of a final battle against THOR THE DESTROYER (Figure 5).

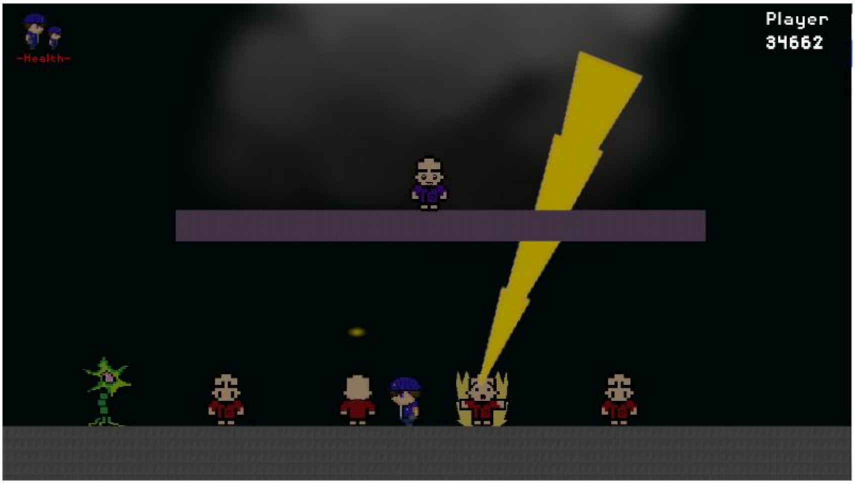

Figure 5. Final Review and Battle

In this battle, previously cured citizens assist the player. This is the in-game reason provided for their presence; the number of citizens is unaltered by the player's success. THOR stands on a platform above the player and citizens. The citizens shoot brainwaves upward at the platform in an attempt to destroy it, an act that would remove THOR's protection and force him to fall to the ground. Every few seconds, THOR inflicts illness upon one of the citizens—his sprite changes to a version of him with an evil grin and a lightning bolt strikes the citizen, forcing that citizen to face the camera and stop shooting. Clicking the ill citizen prompts the same familiar curing dialogue and process present throughout the game. Once cured, the citizen turns back around and resumes shooting the platform. The player cannot directly damage the platform; he must keep the citizens healthy so that they can continue to fight. As this process ensues, enemies walk across the screen from both sides, injuring the player if not defeated. Player death can occur, but does not reset the battle; it only delays the player's ability to cure citizens and complete the game. Once the platform receives enough damage, it disappears. THOR tumbles through the air until he hits the ground, head first. The screen goes dark as a year passes. A flash of light begins the final cinematic in which THOR explains, from his amnesia-clouded perspective, what happened over the past year. In this final battle, over 100 citizens are cured using all brain areas taught throughout the game. In this way, it serves as a grand review of the content.

Features

Aside from the aforementioned, *Medulla* was designed with two additional features in mind, narrative and achievements. To include narrative, *Medulla* narrated a fantasy-based story to provide context and meaning to the actions occurring in-game. Without this explanation, the player might have been left with questions like *Why is the player clicking a brain that appears when approaching a person? Why is the player defeating enemies? Why are the enemies trying to hurt the player?* Additionally, Leung (2012) described how more abstract elements such as "attraction, seduction, and engagement" are difficult to embed in the game design but are crucial for successful user experience (p. 9). This approach—what she terms the art of experience design—requires designers to think through level design from the perspective of the intended user and to test the levels (ideally early in the process as a form of formative rather than summative evaluation) with an audience of intended users.

The narrative was delivered primarily through text-based dialogue and a few simple animations presented in cinematics. Cinematics occurred at the beginning of the game, introducing THOR and presenting the hero's call to action; just before the boss fight, revealing THOR's true identity and introducing the citizens that will help in the fight; and the end of the game, describing THOR's fate after being defeated by the player. A short cinematic was also present just prior to the final battle.

Additionally, dialogue was presented at the beginning and end of every level, providing information on the current city (each level was considered a new city) and presenting new brain powers. New powers were awarded upon beginning a new level and each brain power was presented in the city of its origin (e.g., the occipital power was provided in the city of Occipital, or level 2). Below is an example of dialogue from the beginning of Level 7, Cerebellum (the cerebellum being the area of the brain that controls motor movement, balance, and posture):

-Hi friend! Welcome to Cerebellum!

-We're a little wobbly these days, but this was once the happiest place on Medulla!

– Of course, our spirits aren't down too much, but we do need some help!

– I don't think there's a person who doesn't know your name and the things you've accomplished.

– You're getting close to THOR THE DESTROYER's territory. Just push a little further.

– Before you go, take the Cerebellum power and help anybody who is having trouble with their balance.

-Thanks friend!

While inhabitants of Cerebellum were designed to be excessively friendly, each city had its defining quality. The cities and their inhabitants were named after elements related to the brain parts; this was done to increase exposure to the technical content in the narrative. For instance, Level 6, The Prefrontal Cortex Laboratory, introduced the player to one of THOR's enslaved researchers who supervised the facility that created THOR's minions. However, other cities and their inhabitants were not directly connected to the technical content; instead, these cities were written in a way that was intended to be intriguing to the players, enhancing the fantastical feel of the narrative. For example, Temporal was home to the Sky Beards—people who spoke in rhyme, lived in the sky, and had large beards. Parietal introduced the player to The Sergeant—A sadomasochistic sergeant who flings insults, yells his dialogue, and calls the player names, like “thin mint,” “scrawny toes,” and “milk muffin.” Other levels contained similarly developed characters. These narrative elements introduced humor to the game, encouraging players to explore the city and in some cases, as with the Prefrontal Cortex Laboratory level, increased exposure to the brain section names.

Throughout the game, players received achievements (e.g., Figure 6) for completing various goals. Unexpected achievements, or those which have requirements unknown to the player prior to earning, were used. Blair (2012) suggested unexpected achievements should be used to provide incentive to experiment or explore during gameplay as players attempt to identify their criteria. For players interested in achievements, this behavior may increase play time. Additionally, as achievements are commonly included in most modern games, their inclusion created another similarity between *Medulla* and the games the gamer participants were already playing.

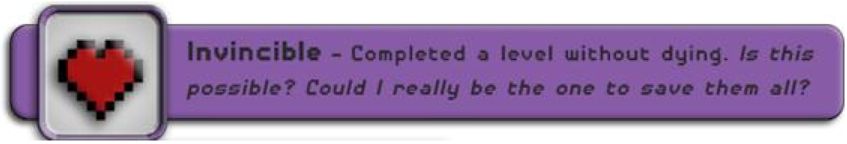

Figure 6. Example of an achievement that was used in Medulla

Achievements were given for:

- Completing each level,
- Curing citizens (achievements given for first cure, three in a row, 10 in a row, and curing all citizens in a level),

- Curing a citizen that was not between the player and the end of the level (i.e., curing the citizen was optional),
- Defeating enemies (achievements for defeating one, ten, and fifty),
- Completing a level without killing enemies,
- Attacking a friendly NPC,
- Completing a level with more time than was given at the beginning of the level,
- Completing a level without dying,
- Moonwalking (pressing both left and right arrow keys at once achieved this effect),
- Killing self while a minion of Thor (in one level, the player is turned into a minion. Jumping on spikes is required to unlock this achievement).

Upon completing the requirements necessary for unlocking an achievement, a small window appeared in the bottom right of the screen, and then disappeared after a few seconds (Figure 7).

Figure 7. Achievement Award Interface.

Thereafter, pressing the escape key enabled the participant to view their list of completed achievements (Figure 8). The criteria for unlocking the incomplete achievements were hidden from the player at all times; these achievements were displayed as "Achievement Locked."

Figure 8. Achievement List Interface

Methodology

Participants were asked to sit in front of the experimental computer and silence their mobile phones in order to reduce the potential for distraction. After drug screening, participants were provided with an IRB approved informed consent document. Following the consent process, participants completed a demographic questionnaire and took an 18-question pretest to assess prior knowledge. No feedback was provided on correctness to reduce the potential for learning effects outside of the gaming session.

Prior to playing *Medulla*, the experimenter presented a list of game controls on a sheet of paper. The controls were read aloud and participants were informed that they could refer to this list of controls at any time. Participants placed high-quality, surround-sound, noise-cancelling headphones over their ears and played *Medulla* in its entirety. If questions arose during gameplay, the experimenter provided an answer with the minimal amount of information necessary to progress. When requested, this feedback primarily consisted of instructions such as "run to the right," "go up," or "use the right mouse button to shoot the enemy instead of the left mouse button."

After gameplay, participants completed a posttest identical to the pretest.

Results & Discussion

The hypothesis predicted that posttest scores would be significantly higher than pretest scores. Table 1 provides a list of descriptive statistics for pretest, posttest, and difference scores, as well as difference scores between pretest and posttest. Posttest scores were significantly higher than pretest scores, $t(79) = -21.643$, $p < .001$, $d = 2.980$. See Table 2.

Table 1. Descriptive Statistics for Posttest and Difference Scores

Test	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Pretest	4	18	8.50	4.03
Posttest	13	18	17.40	1.27
Posttest – Pretest	0	14	8.90	3.74

Table 2. Pretest and Posttest Scores

	Mean	*St Dev*	*St Error Mean*	*95% Conf:Upper*	*95% Conf:Lower*	*t*	*dif*	*Sig.*
Pre-/Post	-8.90	3.74	.836	-10.650	-7.150	-10.642	19	.000

These results indicate the game's success in teaching the content. The effect size, d = 2.980, indicates that participants performed much better on the posttest than the pretest. In combination, these results support *Medulla*'s effectiveness as an educational game, and the strategies used in its design.

Conclusion

This study presented *Medulla,* an educational game. *Medulla* was empirically tested with undergraduate psychology students, the target population, to assess its effectiveness in teaching brain structure and function information. Results indicate that participants experienced significant and substantial learning through playing *Medulla.*

The brevity of gameplay was a choice the developer made specifically to make *Medulla* appealing to college students. That is, *Medulla* can be played quickly, appealing to students looking to rapidly study the material so that they can spend more time on advanced topics of study for which this knowledge is prerequisite. In contrast to opening a book or searching the Internet and then engaging in rote memorization, the participant can run the game, play for approximately one hour, and be able to recall the information with accuracy.

Similarly, the developer focused on offering design variety in *Medulla*. Few educational games are created in the style of pixel-based 2D sidescrolling platformers. In an era of complex, high-fidelity, three-dimensional games, retro-style games still hold relevance. While this has been exhaustively demonstrated in the entertainment industry with the success of games like *Risk of Rain* (Chucklefish, 2013) and *BIT.TRIP Runner 2* (Gaijin Games, 2013), it has received little attention in modern educational games. This study supports its effectiveness. This is important because retro-style 2D games are simpler to create than their 3D counterparts; the z-dimension does not require consideration during programming and art development. In a domain where resources are often limited, researchers, ambitious instructors, and developers can, in good conscience, make a more economical choice. As Kayali and Schuh (2011) assert, such object-oriented level design in retro-styled games can offer "varied gameplay while at the same time saving resources" (p. 11).

Further, this style of game may be more accessible to inexperienced gamers. While those who frequently play fast-paced three-dimensional games may feel comfortable in a variety of gaming environments, controlling an avatar in environments with a third dimension can prove challenging for inexperienced players (Beckhaus, Blom, & Haringer, 2005; Fong, 2006). This is important in an educational setting where there is no guarantee that all students will have the relevant experience.

Finally, *Medulla* illustrates that educational games that incorporate engaging narratives and directly address the player, inviting them into the action, may be successful learning tools. These results reinforce earlier assessments of multimodality (Mayer, 1997) and direct player address (Moreno & Mayer, 2000). As McQuiggan et al. (2008) have argued, the motivational benefits of narrative embedded within education games has substantial benefits for learners, such as increased presence, interest, self-efficacy, and control. Similarly, Rowe et al. (2011) have shown that no matter what prior knowledge or experience with games students bring to the classroom, narrative-centered learning environments helped students achieve improved learning outcomes and problem solving ability.

Of course, there is room for improvement. The learning mechanics used in *Medulla* are straightforward and similar to drill and practice learning. While the game was successful, and lessons were learned during its development, a need remains for better learning mechanics that do not feel intrusive to begin with. Moreover, it is difficult to isolate the specific elements which made *Medulla* successful. Future design-based research and experimentation should identify these elements, and advance the science on creating these games to maximize engagement and pedagogical effectiveness.

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