# Confirming the Taxonomy of Video Game Enjoyment

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**Abstract:** An empirical taxonomy that details the design features that influence player perception of video games can be a useful tool for guiding the creation of effective gameplay experiences. Building from previous exploratory work in identifying a taxonomy of enjoyment in video games (Quick & Atkinson, 2011; Quick, Atkinson, & Lin, 2012), a follow-up study was conducted to gauge the gameplay preferences of 326 undergraduate learners. A confirmatory factor analysis was employed to validate, refine, and expand the existing taxonomy of video game enjoyment. This analysis confirmed the six previously identified design factors and substantially expanded their specificity by incorporating several new underlying features. The analysis and its resulting taxonomy are presented.

## Introduction

In creating games to meet the needs of specific audiences, it is important to understand how design influences player perceptions of the gameplay experience. A game design can be described by its features. By understanding how certain features influence players' enjoyment of games, designers may be better able to create desirable experiences for players. This is particularly relevant in the field of serious games, where training, learning, health intervention, and other critical benefits are sought through gameplay.

Quick and Atkinson (2011) conducted an exploratory, data-driven study to determine which design features most influence undergraduate learners' enjoyment of video games. They reported a taxonomy of six key design elements, which included Challenge, Companionship, Competition, Exploration, Fantasy, and Fidelity (Quick & Atkinson, 2011; Quick, Atkinson, & Lin, 2012). Each of these design factors was defined by two to five underlying features, such as 3D graphics or exploring unfamiliar places. This taxonomy was compared to several preceding taxonomies of game design, including those offered by Hunicke, LeBlanc, and Zubeck (2004), Winn (2008), Yee (2006), and King, Delfabbro, & Griffiths (2010), among others. Upon finding strong correspondence between the past and present taxonomies, Quick and Atkinson (2011) concluded that the salient design features that influence player enjoyment are scientifically identifiable and that a convergence around these features was evident, in spite of the varied historical approaches taken to generating game design taxonomies.

A confirmatory follow-up study was conducted to validate the taxonomy of video game enjoyment (Quick & Atkinson, 2011; Quick, Atkinson, & Lin, 2012). In addition, it aimed to further expand and refine the taxonomy. Two primary research questions guided this pursuit.

1. To what extent is the taxonomy of video game enjoyment validated through a confirmatory factor analytic approach?
2. To what extent can the taxonomy of video game enjoyment be expanded and refined through a confirmatory factor analytic approach?

## Method

An online questionnaire was administered to 326 undergraduate learners at a large public university in the southwestern United States. The students came from a variety of disciplines and class levels. All were enrolled in an introductory computer literacy course and earned course credit for participating in the study.

The survey instrument contained 28 items that asked learners how important certain design features are to their enjoyment of video games. The items were scored on a scale from one (*Not at all important*) to five (*A must-have feature*). Eighteen of the items composed the taxonomy presented by Quick and Atkinson (2012). The remaining 10 items were added to expand, reinforce, and further specify the six game design factors. Three example items follow.

- The game is set in a fantasy world.
- The game features lifelike animations.
- The game requires me to cooperate with other players.

Questionnaire responses were examined using a confirmatory factor analytic approach. All analyses were conducted in *R* (R Development Core Team, 2010) using the *Lavaan* package (Rosseel, 2011a, 2011b).

**Results**

A confirmatory factor analysis was conducted on 326 questionnaire responses. A correlated traits model was examined, whereby a group of correlated latent variables are hypothesized to predict a set of measured variables. In this analysis, a group of six latent variables was hypothesized to predict 28 measured variables. The six latent variables correspond to the six game design factors that influence player enjoyment (Quick & Atkinson, 2011; Quick, Atkinson, & Lin, 2012). The 28 measured variables include the specific features that underlie these design factors and were gauged through the collected questionnaire responses.

This model demonstrated acceptable fit for its sample size and quantity of measured variables, with RMSEA = .058, SRMR = .058, CFI = .921, and $X^2_{(360)}$ = 758.474 ($p < .001$). To minimize Type I and Type II errors in identifying misspecified models, Hu and Bentler (1999) suggest a RMSEA < .06, SRMR < .08, and CFI > .95. Meanwhile, Hair, Black, Babin, and Anderson (2010) suggest that a RMSEA ≤ .08, SRMR ≤ .08, and CFI > .92 indicate good fit. Table 1 presents the loadings and standard errors for the model, as well as descriptions of the 28 measured design features. Figure 1 graphically depicts the accepted model. Note that this model contains correlated residuals for three item pairs (1 and 2, 4 and 28, 5 and 22). These paths were freed based on an examination of the model's modification indices. The correlated residuals between these items indicate that additional covariance exists amongst these items that is not fully explained by the model.

| Variable | Description | Unstd. Load | Std. Error | Std. Load |
|---|---|---|---|---|
| Challenge | | | | |
| 1 | Difficult to master | 1.000 | | .660 |
| 2 | Difficult to beat | 1.194 | .071 | .813 |
| 3 | Challenging difficulty | 1.140 | .092 | .811 |
| 4 | Obstacles to overcome | 1.153 | .101 | .811 |
| Companionship | | | | |
| 5 | Socialize with others | 1.000 | | .755 |
| 6 | Played by many at parties | .823 | .077 | .627 |
| 7 | More than one player | .998 | .085 | .701 |
| 8 | Cooperate with others | 1.021 | .077 | .779 |
| Competition | | | | |
| 9 | Display skills in public | 1.000 | | .657 |
| 10 | Best players recognized | 1.069 | .094 | .725 |
| 11 | Compete against others | 1.180 | .104 | .740 |
| 12 | Compare skills with others | 1.315 | .103 | .858 |
| 13 | Play with others online | 1.237 | .109 | .729 |
| Exploration | | | | |
| 14 | Explore unfamiliar places | 1.000 | | .708 |
| 15 | Discover unexpected things | 1.062 | .079 | .813 |
| 16 | Experiment with strategies | .850 | .075 | .685 |
| 17 | Search for hidden things | .978 | .086 | .678 |
| 18 | Explore inner workings | .916 | .084 | .657 |
| Fantasy | | | | |
| 19 | Fictional characters | 1.000 | | .649 |
| 20 | Abilities not from real world | 1.235 | .110 | .727 |
| 21 | Character other identity | 1.308 | .115 | .740 |
| 22 | Imaginary creatures | 1.321 | .103 | .845 |
| 23 | Character other species | 1.263 | .105 | .792 |
| 24 | Fantasy world setting | 1.401 | .110 | .850 |

| Variable | Description | Unstd. Load | Std. Error | Std. Load |
|---|---|---|---|---|
| Fidelity | | | | |
| 25 | Realistic sound effects | 1.000 | | .720 |
| 26 | 3D graphics | .786 | .088 | .529 |
| 27 | Lifelike animations | 1.102 | .088 | .805 |
| 28 | Realistic graphics | 1.055 | .084 | .800 |

***Table 1*: Descriptions, unstandardized loadings, standard errors, and completely standardized loadings for the correlated traits model. The first item of each latent variable was fixed to 1.000 to set the scale for the factor. The p-values for all estimated model components are < .001 and are suppressed to reduce redundancy.**

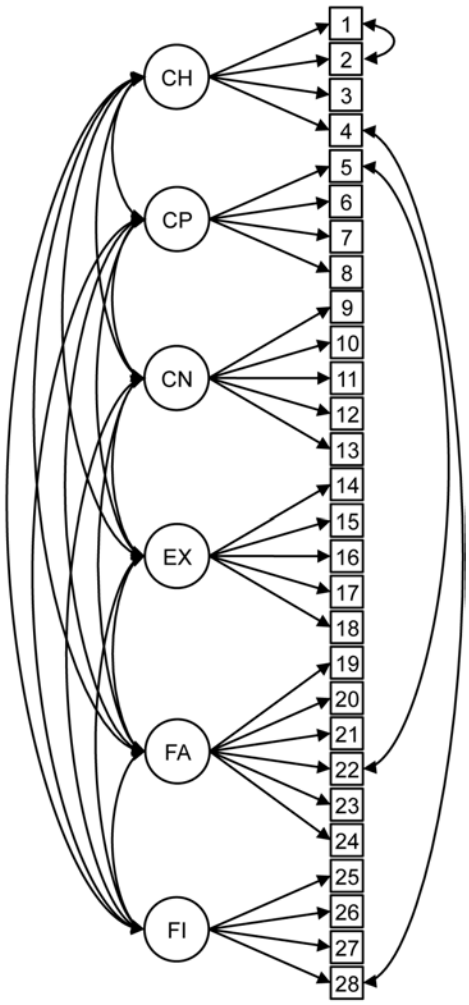


***Figure 1*: The correlated traits model describes how the latent factors of Challenge (CH), Companionship (CP), Competition (CN), Exploration (EX), Fantasy (FA), and Fidelity (FI) predict their measured design features (numbered 1 to 28). The error term for each measured variable has been suppressed to improve readability.**

**Discussion**

This analysis confirmed the overarching factors included in the taxonomy of video game enjoyment (Quick & Atkinson, 2011; Quick, Atkinson, & Lin, 2012). Whereas the original taxonomy was derived through exploratory means, a confirmatory analysis of the same six design features yielded a model with acceptable fit. This provides some evidence that the taxonomy of video game enjoyment is empirically and theoretically sound. In addition, this analysis expanded upon the taxonomy of video game enjoyment by increasing its measured variables to 28. This leads to design factors that are better defined and likely to be more reliable and valid in continued research and application. From this analysis, the six design features that influence player enjoyment of video games can be described as follows.

- Challenge: The enjoyment of mastering and beating difficult games, overcoming challenging obstacles, and games with challenging difficulty levels.
- Companionship: The enjoyment of socializing and cooperating with others through gameplay, multiplayer games, and games that can be played by many people at parties.
- Competition: The enjoyment of displaying one's skills publicly, competing against and comparing skills with other players, being publicly recognized as the best player, and playing with others online.
- Exploration: The enjoyment of exploring unfamiliar places, discovering unexpected things, searching for hidden things, experimenting with different play strategies, and exploring the inner workings of a game.
- Fantasy: The enjoyment of fantasy worlds, fictional characters, abilities that do not exist in the real world, imaginary creatures, and roleplaying as species and identities other than one's own.
- Fidelity: The enjoyment of realistic graphics and sound effects, 3D graphics, and lifelike animations.

**Conclusion**

This analysis has provided confirmatory evidence of the taxonomy of video game enjoyment, which was originally revealed through exploratory work (Quick & Atkinson, 2011; Quick, Atkinson, & Lin, 2012). In addition, it has fortified the six game design factors that influence player enjoyment by increasing the number of underlying characteristics to 28. Continued examination of these data should employ a structural equation modeling approach to test for the existence of an overarching second order latent variable, such as enjoyment, which may be predict the six latent game design factors. Furthermore, multiple structural equation models should be assessed and compared to ensure that the optimal solution is determined. An empirical taxonomy of the features that influence player enjoyment, such as the one presented here, may prove to be an important tool for effective game creation by educators, designers, and other stakeholders in the field of serious games.

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# *Operation BIOME*: The Design of a Situated, Social Constructivist ARG/RPG for Biology Education

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**Abstract:** The worked example described herein follows the design and development of a year-long, game-based biology curriculum, *Operation BIOME*. Built through a situated cognition theoretical framework, *Operation BIOME* capitalizes on the affordances of gaming rulesets, metacognitive reflection, and social constructivism to prompt a broader and deeper student understanding of science, technology, engineering, and mathematics (STEM). As an alternate-reality game wrapped around a role-playing game, *Operation BIOME* offers players (students) the opportunity to think, act, and behave like real-world scientists in ways that cannot be accomplished through simple science 'gamification'. This paper explores the benefits of the ARG/RPG structure for biology, specifically, and explains the theoretical underpinnings that make it a desirable, low-tech way to produce favorable student learning outcomes.

The notion of using games as learning tools has existed for millennia, extending backward through time to the beginnings of education itself. As noted by Travis (2011a), Plato's *The Republic* drew explicit attention to the relationship between 'playing pretend' and understanding learning as much as 2,500 years ago. This idea has persisted through educational psychology, influencing the works of Dewey (1938), Bruner (1961, 1966), and Gee (2003), arriving at a point where 3-dimensional, virtual worlds can now mimic real-world activities so well that learners can inquire, explore, and interact with an imaginary environment in ways that directly or nearly directly mirror direct experiences with the real-world. A wide number of studies have discussed the potential of gaming for improving overall student engagement, and while more work is needed to truly understand the power of educational gaming, there is an increasingly pervasive belief that game-based learning can change the way instructors and students interact with science content (Honey & Hilton, 2011; Johnson, Levine, Smith, & Stone, 2010; Johnson, Smith, Willis, Levine, & Haywood, 2011; Young et al., 2012).

Game developers have largely capitalized on the relationship between 'playing pretend' and learning in order to successfully market products to their consumer base. While *Grand Theft Auto*, *Super Mario Bros.*, *Halo*, and *Call of Duty* generally do not emphasize learning as a primary player objective, they contain the same basic elements that prompt metacognitive reflection, critical thinking, and problem solving commonly associated with successful academic learning environments. Salen and Zimmerman (2003) argued that these elements, as defining characteristics of the overarching ruleset for a great game, are what make 'playing pretend' valuable to the educational process over and above impressive graphics, sound effects, or other superficial qualities. Indeed, games place the player in rich contexts that require thorough exploration and investigation to resolve pre-defined conflicts much in the same way successful K12 and college classrooms do, making them useful for contextualizing information about problem solving in the real world.

Consequently, games have the potential to address the situated nature of learning for the betterment of student achievement outcomes. The core premise of situated cognition poses that interactions between the individual and the environment are the essence of learning, meaning that knowing is an active process rather than a solid block of facts, memories, and other internalized (and non-measurable) entities—that is, knowing is inseparable from doing (Brown, Collins, & Duguid, 1989). In recognition of this fact, Gee (2004) noted that, "deep learning requires an extended commitment [that] is powerfully recruited when people take on a new identity they value and in which they become heavily invested—whether this be a child "being a scientist doing science" in a classroom or an adult taking on a new role at work" (p.18). It would be prudent to address the context issues associated with learning by introducing games as an instructional methodology rather than attempting to modify current ineffective or environmentally impoverished instructional techniques. Given the relationship between game immersion and the desire to have students learn by doing, learning objective achievement may be readily accomplished through the development of game-based environments that transparently parallel real-world environments.

**Ensuring Rich Situativity of Games for Science Education**

Honey and Hilton (2011) described many of the affordances of game-based learning for science, technology, engineering, and mathematics (STEM) domains in their research for the Committee on Science Learning: Computer Games, Simulations, and Education, but found that while science simulations were a promising means of introducing students to the sciences, games, as a whole, were categorized as 'inconclusive' and in need of additional study. Their findings directly align with Young et al.'s (2012) meta-review on trends in video gaming for education in which only 19 empirical studies on video games for math and science could be identified across a total of 362 peer-reviewed publications linking games with academic achievement.

While this signals an important opportunity for educators and game developers alike, the potential for science-based game development and research does not represent a blanket justification for the gamification of STEM domains (i.e., the addition of superficial points, scores, ranks, badges, and/or 3D graphics to the content) (Deterding, 2011). Situated experiences that reflect the act of 'doing' science require more than the environment 'looking' a certain way or the student using a controller, keyboard, cards, or other gaming tools to make decisions on behalf of a character. Extant STEM gaming research provides little evidence that the use of gamified experiences improve student achievement outcomes, and only a small number of studies identify statistically significant gains in student performance after exposure to gamified science content (Annetta, Minogue, Holmes, and Cheng, 2009; Kennedy-Clark, 2011; Wrzesien and Alcañiz Raya, 2010).

Meaningfully introducing game-based learning into science education requires emphasis on sound pedagogical design and strict adherence to the instructional techniques associated with situated learning. Direct instruction-heavy games have the propensity to bombard players with impoverished, decontextualized information that deviates wildly from the situated paradigm. As Ke (2007, 2008) wrote after experimentation with the gamified math program *ASTRA EAGLE*, "most participants lacked a reflection process for performance analysis, new knowledge generation, evaluation, and integration" (2008, pp. 1615). Additionally, "when facing a poor game design where the learning activities were not deftly veiled within the game world, participants reacted by deeming learning as a foe and chose to simply bypass it" (2008, pp. 1614). The superficial elements promoted through gamification did little to stimulate student reflection, motivation, and self-efficacy toward being a better learner, thus neglecting the affordances that educational games with rich contexts, rulesets, and mechanics can provide as a form of problem-based learning.

Because problem-based learning (PBL) environments introduce students to content via inquiry and experimentation, it is advantageous for educational game developers to construct their offerings as alternate reality games (ARGs) and roleplaying games (RPGs) that rely on student exploration to reach the gaming and learning objectives. When aligned properly, the ARG/RPG PBL environment results in a mapping of game and learning objectives at a 1:1 ratio, creating a learning environment that extends beyond gamification to a context-rich learning experience (Travis and Young, 2010; Travis, 2011b, Young et al., 2012). Bruner's (1961) work serves as a platform from which educators and game designers may begin developing these kinds of game-based science PBL environments because of its emphasis on the story-telling elements that have facilitated human learning for centuries. Bruner's belief in the active construction of knowledge promotes teachers as facilitators to learning, assisting students with their movement toward the complex skills defined in the upper tiers of Bloom's Taxonomy. To achieve the best score, either as students or gamers, learners must organize their cognitive structures in order to assign meaning and organization to new experiences in a given content area (Bruner, 1961; 1966).

To that end, Bruner (1966) suggested adherence to four basic principles to promote the creation of effective constructivist, PBL pedagogy, including: 1) ensuring that the learning environment is experience and context-rich in a way that compels students to learn; 2) ensuring that instruction is well-designed such that it spirals along an accessible, cumulative path toward an end objective; 3) ensuring all learning is deliberately planned to remain open for extrapolation and further study by the learner; and 4) ensuring that all behaviors are reinforced with rewards and punishments to further encourage or discourage them. Game design typically follows these same guidelines, and as emphasized in Gee's (2003) 36 Learning Principles, both educators and game designers must encourage students and players to become invested in complex, self-directed processes in order to reach the final objectives with which they have been tasked. Ultimately, this is what will allow players (students) to receive constant feedback from the virtual world regarding their performance, powerfully shaping future learning, problem-solving, and conflict resolution (Rothman, 2010).

**Operation BIOME: A Worked Example of Continuous Embedded Formative Assessment**

*Operation BIOME*, a year-long, fully expanded biology curriculum, has been built to contextualize life science for the purposes of capitalizing on the educational potency of problem-based learning. The game's narrative structure pairs its embedded game objectives with learning objectives at a 1:1 ratio, thereby scaffolding a framework for continuous formative assessment (Table 1). Because the goals unambiguously require students to roleplay as expert scientists, the learning environment is shifted from teacher-centered to student-centered as the learners work in research groups, construct unique solutions to complex science problems, and directly participate in laboratory procedures. Through a blend of roleplaying game (RPG) and alternate reality game (ARG) elements, *Operation BIOME* enables students to develop creative solutions to authentic problems and promotes the experimental inquiry skills necessary to further their general understanding of biology.

<table>
<tr><th colspan="6">COURSE OBJECTIVE</th></tr>
<tr><td colspan="6">Evaluate how DNA serves as the driving mechanism for all life on earth.</td></tr>
<tr><th colspan="6">UNIT OBJECTIVE</th></tr>
<tr><td colspan="6">Explain how prokaryotic organisms and viruses interact with eukaryotic organisms.</td></tr>
<tr><th>EPISODE 2.1.a</th><th>EPISODE 2.1.b</th><th>EPISODE 2.2.a</th><th>EPISODE 2.2.b</th><th>EPISODE 2.3.a</th><th>EPISODE 2.3.b</th></tr>
<tr><td>Compare prokaryotic and eukaryotic organisms<br><br>Identify the similarities and differences between bacteria and viruses</td><td>Identify the structural similarities and differences of various bacteria and viruses<br><br>Describe the processes of binary fission and the lytic cycle</td><td>Examine how bacterial and viral infections are transmitted<br><br>Analyze case studies about patients with various bacterial and viral diseases</td><td>Define and describe the differences between yeasts and other organisms<br><br>Evaluate how microorganisms are used to produce food</td><td>Explain the role of antibiotics, vaccines, and sanitation in human health<br><br>Develop preventative measures for protecting against infection</td><td>Analyze the role bacteria and viruses play in life processes on earth<br><br>Analyze the role bacteria and viruses play in human disease</td></tr>
</table>

***Table 1:*** **Example of Layering Game and Learning Objectives**

The overarching story follows the crew of a fictional space vessel, the USS Van der Waals, headed by the plucky Dr. Cornelius Beakerstink and his graduate students, Autumn and Kalvin. Over the course of eight primary missions, students collaboratively work to recover a legendary artifact, the Genetic Codex, which contains the genetic information of every earthly organism that has ever existed. This makes the end task – interpreting the importance and influence of DNA on all life – the same from both the narrative and scholastic perspectives. While it is not a video game, per se, *Operation BIOME* exists within the framework of online text adventure, an ARG framing the students' day-to-day activities in the classroom and an RPG framing their online interactions with the characters and narrative content. This choice was made partly because a fully virtual world is, in many ways, too confining to adequately fit the needs of a teacher/student and partly because a high technological barrier to entry would prohibit technology-impoverished school districts from participating in its implementation.

Unlike projects that have simply "gamified" science, the developers began with the objectives/standards and used them as a guide for developing the narrative rather than the other way around – a design scheme reflective of the top-down approach often associated with strong curriculum development. This placed emphasis on the game's ruleset (i.e., how play happens) in order to bring students closer to doing the things real world scientists do: problem solve, critically think, examine existing literature, generate new questions, and, most importantly, collaborate toward realistic shared goals (e.g., "cure cancer"). Additionally, because the narrative follows the same trajectory as state and national standards, the story missions transparently align with the information students need to successfully complete high stakes tests. This means that the narrative is able to carry much of the weight that is usually attributed to direct instruction, allowing teachers to use the exploratory prompts as an introduction to the class content and class time for reflection/discussion of the concepts students are discovering outside the classroom.

The richness of the *Operation BIOME* experience is drawn from the social interactions that take place as a result of student participation in an *Archetype* (game character) team. On a day-to-day basis, each *Archetype* team, composed of three operatives in the ARG framework, enters the RPG through a web browser-based heads-up display (HUD) called the *Texto-Spatio-Temporal Transmitter* (TSTT; hosted via the teacher-student social networking site Edmodo) (Figure 1). The TSTT features a series of immersion sessions that play like media-enhanced text-adventures combined with a fictitious, but deeply science-based, story arc (for more information, see http://biome.practomime.com). The HUD in the immersion session contains hyperlinks to resources that the operatives (students) use to research their actions in the immersion-space via Wikipedia, the Discovery Channel, and various scientific journals, and they use their findings to co-construct the learning that occurs in the course.

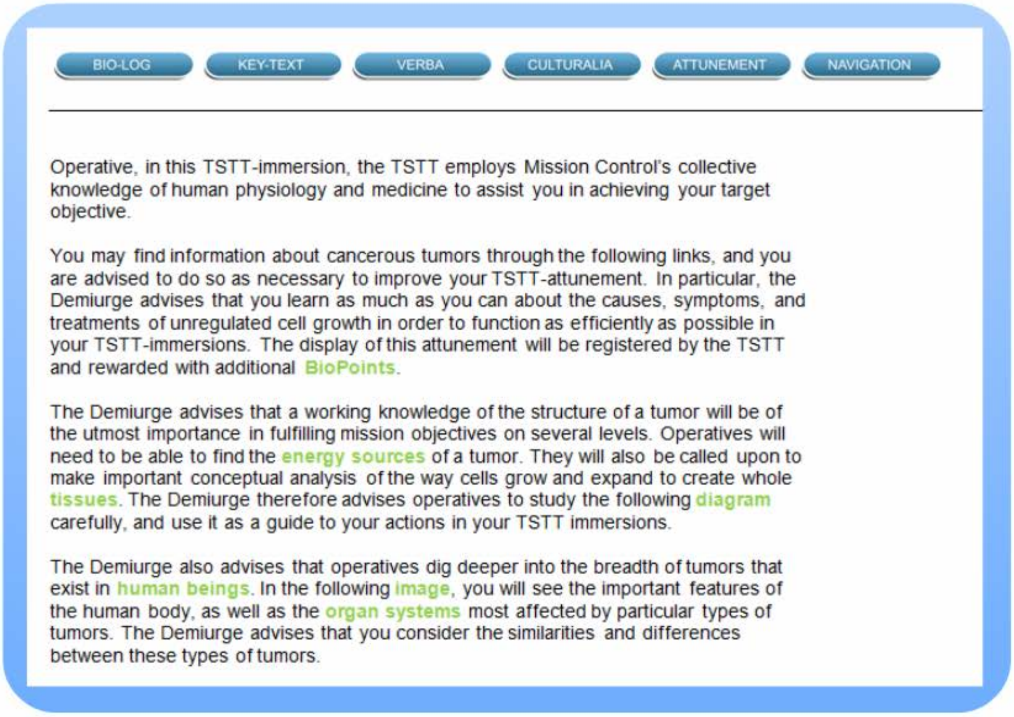


***Figure 1:*** **The TSTT HUD**

The continuous embedded formative assessment associated with *Operation BIOME* is rooted in the team-controlled *Archetype*. After viewing an objective-based prompt posted in the TSTT by the course instructor (Figure 2), the students collaborate with their teams to decide what actions their *Archetype* character will take in the RPG. This allows the instructor to evaluate the learners' thought processes such that emphasis is placed on the complex cognitive skills associated with being a successful biologist rather than just the *Archetype*'s response product or the basic rote information assessed by high stakes tests.

>Malignancy, City of Leus, Modern Day<

You reach the end of the corridor –a faint breeze chills your skin, and a large, empty chamber opens before you. Dante whispers with urgency.

*This, my friends, is it: **Malignancy**, bottommost Circle of Cell, and the point where all of **Eukaryota**'s malformed entities are sent to be destroyed. If your villain was going to bring the Codex anywhere, I imagine this would be it. Tread carefully.*

Suddenly, a familiar cackle breaks the chamber's silence.

The shadowy figure stands before you and gestures sharply with its right arm – you hear a shrieking tear as the air is ripped open before your eyes. With unnatural swiftness, the figure dives through the whirling, violet vortex, leaving only a small, glass vial that shatters as it hits the ground. From it sprouts a **tumorous** growth, rapidly expanding to develop bulbous appendages resembling arms and legs. It lumbers toward you, clearly intent on assimilating your body.

***Prompt:*** Subdue the Cellraiser.

***Figure 2:*** **Example Mission Prompt**

A typical *Archetype* dialogue for the prompt "*Subdue the Cellraiser*" might resemble the following:

*Student 1:* Hey guys, the new prompt was posted: "Subdue the Cellraiser." The last few prompts were about transcription and translation…We could focus on that. (Oh, and we could get bonus experience if we stop the Cellraiser using something from our worldview since transcription and translation deal with DNA.) So again, our worldview is in our PERSONA. It says: "Your character is a highly capable, but modest, young woman. She is devoted to her work on studying microscopic structures via their genetic code. She would like a chance to verify her historic work by handling and experimenting with the codex in person."

*Student 2:* This prompt is perfect for Rosa, plus we can talk about stuff we did earlier too! Cause our skill is that we can x-ray stuff, maybe we could see if there's a weak point inside like an artery or something. If there is, maybe we can cut it off to stop the O2 supply to the cells so they starve and can't divide anymore.

*Student 3:* Good idea. The key-text stuff also talked about radiation as one way to stop cancer. This thing is probably gonna keep getting bigger, so the sooner we kill it, the better. Maybe we should work on ending transcription and translation as a way to slow it down. We could break down and ruin the DNA with radiation so the thing won't be able to catch us, and then get rid of the blood supply to finish it off. We should check the links on the key-text again to find more information before we make our lead op post.

The student-to-student instruction conducted within the HUD allows the course instructor to facilitate the correction of misconceptions in real-time rather than providing direct instruction and waiting for summative assessments to dictate end of unit or whole course achievement. Feedback may include veiled critiquing through a character in the game's plot or direct intervention as the course instructor:

*Teacher:* Operatives, your thinking appears to be on track. You may want to consider reviewing the Culturalia again to get an idea of what will happen should you use the methods you're discussing (surgery and radiation) to treat the Cellraiser. There are some helpful links embedded in there that will lead you to American Cancer Society and the National Institute of Health for more information. Before making your team post, I recommend you consider the following questions: are there any side effects for patients who receive radiation therapy? How and why would therapies need to be combined to be more effective? How might the other Archetypes' special abilities complement what you're planning on doing to treat the tumor? I will continue to monitor your progress. Best of luck. Demiurge Epsilon out.

The long-term assessment of critical thinking and problem-solving occurs almost exclusively within online, personalized grading sheets hosted via Google Documents that the instructor uses to tabulate numerical grades via BioPoints (i.e., experience points, BP/XP). These templates act as a Research Description Framework Site Summary (RSS) feed of student growth and allow the teacher to provide pointed feedback about each online student interaction, thus affording a more robust assessment structure than is available through traditional forms of testing. Summative assessments exist as major prompts that focus on knowledge gains by placing learners in complex, problem-rich contexts that require application, creativity, and self-evaluation of learning. This permits the teacher to emphasize and evaluate action on all tiers of Bloom's Taxonomy rather than focusing on one or two at a time. In sum, the assessment process exemplifies the constructivist nature of the program by allowing students to piece together on-going portfolios that establish longitudinal, experiential knowledge growth over the breadth of the biology course, exhibiting the cumulative spiral effect described in Bruner's four governing principles of constructivist instruction (Young et al., 2012).

*Operation BIOME* utilizes the fundamental psychological principles that govern all games, including operant conditioning, constructivism, and social constructivism, to provide learners with engaging situated experiences that promote social collaboration, increase self-efficacy for "doing" science, build intrinsic motivation to continue studying the subject, and, most importantly, offer a data rich source of continuous embedded formative assessment. The underlying RPG and ARG rulesets governing gameplay emphasize the strengths of social learning and instructor facilitation in order to ensure that content mastery within the game's parameters can be applied in actual science settings such as laboratories or the field, thus reflecting the role played by actual scientists, mathematicians, and engineers in the real world.

**Leveling Up Biology Education**

*Operation BIOME* coalesces many well-documented elements of learning psychology into a powerful tool for structuring situated science education. Its application in the K12 biology classroom may prove to be a highly effective way to supplement and enrich high stakes and other forms of standardized testing so that educators can draw more meaningful conclusions about the student populations they teach. The overarching purpose of schooling has evolved from one of rote memorization to the development of highly complex cognitive skills necessary to remain competitive in a global, 21$^{st}$ century community. However, the practical implementation of game-based learning as a form of continuous embedded formative assessment will require the unadulterated passion of instructors dedicated to the expansion of accepted pedagogy. *Operation BIOME* can assist in ushering a transformation in pedagogical design that encourages teachers to craft stories that fit their curricula, seamlessly binding instructional objectives with the composite features of games that have given them lasting recreational appeal. With a revised, comprehensive, dual-formative-summative system of student assessment, educators will be able to generate a much clearer picture of what is expected of their students and, ultimately, create a new generation of life-long learners capable of complex, creative thought in the STEM fields.

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