ARTICLE
Effects of Gamification on Student Success and Perception of Instruction in Neuroanatomy: A Retrospective Analysis

Benjamin R. Fry
Burnett School of Biomedical Sciences, University of Central Florida, Orlando, FL 32816.
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As a subset of active learning, gamification involves the application of gaming principles as a means of improving student outcomes in the classroom. Recent work has shown that such active learning strategies may be particularly effective at reducing the rate of failure in STEM courses. In this retrospective case study, I examined the effects on student exam performance, rate of failure, and perception of instruction following a semester-long course improvement project that involved implementing a novel tabletop style roleplaying game (*Build-a-Zombie*) during lab sessions in an undergraduate neuroanatomy course. The game I developed tasked students with using their knowledge from lecture to design their own pathological zombie nervous system. When compared to a previous cohort, students in the gamified version of the course showed significantly increased exam scores, a trend toward decreased rates of failure, and a more positive perception of instruction, even though lecture and exam content remained the same.

Key words: neuroanatomy; gamification; active learning

Within the realm of active learning, gamification is a relatively new phenomenon. A literature search via Google Scholar using the terms “Gamification in Education” shows a spike in articles discussing how to employ game design principles in pedagogical practice beginning in the year 2011 (e.g., Cohen, 2011; De Freitas and Liarokapis, 2011; Lee and Hammer, 2011) and continuing at a steady pace up to the current year (e.g., Zeybek, N., and Saygı, 2024). As previously described by Majuri and colleagues (2018), gamified aspects of courses typically include one or more of the following elements: achievement and progression (e.g., accumulation of experience points, challenges or quests, medals, progress bars, levels, and difficulty), immersion (e.g., character creation, narration, world-building, and role-play), social aspects (e.g., team-based cooperation and/or competition, peer rankings, and leaderboards), and game-based rules (e.g., virtual currency, penalties, health points, and in-game rewards that modify abilities and rules). These elements combine with the goal of enhancing student engagement and course outcomes. Bolstering these claims is evidence from fMRI studies that have shown gamification during learning activities is associated with deactivation of the default mode network (Howard-Jones et al., 2016); noteworthy, given that off-task behavior is associated with default mode network activation (Mason et al., 2007; Christoff et al., 2009). While some educators may have been quick to embrace gamification as a new pedagogical tool in their arsenal, others have taken a more cautionary approach and attempted to highlight potential downsides (e.g., Toda et al., 2017). Presently, there is a paucity of literature reporting on the use of gamification in neuroscience education specifically (though see Sandrone and Carlson, 2021 and Edwards et al., 2023 for two recent examples), however, recent work has shown that active learning techniques including gamification are associated with improved student success outcomes and reductions in rate of failure in the life sciences more generally (Freeman et al., 2014; Majuri et al., 2018; Kalogiannakis et al., 2021).

Considering the potential for gamification to increase student engagement in particular, in the Summer of 2023 I began considering how I might use gamification in a redesigned version of my Clinical Neuroanatomy (ZOO4743C) course. Briefly, ZOO4743C is a 4-credit lecture with a lab targeted to Biomedical Science majors at the University of Central Florida (UCF). The course comes with a prerequisite of either ZOO3744 (Neurobiology—our introduction to neuroscience) or ZOO3733C (Human Anatomy) and class is held three days per week (two lectures at 1 hour 20 minutes each; one lab for 1 hour 50 minutes). Student learning outcomes are as follows:

1) Identify and name every structure in the human nervous system
2) Explain the clinical relevance ofthese structures
3) Discuss the human nervous system within the conceptual matrix of functional systems
4) Describe the common signs and symptoms of nervous system dysfunction and their underlying mechanisms
5) Identify the location and suspected pathophysiology of common nervous system lesions
6) Demonstrate the ability to design your own functional nervous system (this latter learning outcome I added to the gamified version of the course)

As a behavioral neuroscientist by training, I will admit that neuroanatomy is not my favorite course to teach. It is not because of the sheer volume of information, but rather the type of information and the way it is traditionally presented. As I recently lamented to a colleague, there are only so many ways with which I can explain the spinocerebellar tract; at the end of the day, *you just have to know it*. This contrasts with other courses I teach that overlap more with my areas of expertise. For instance, if I am giving a lecture on the neurobiology of schizophrenia, there is room for me to move from discussing specific neurochemical imbalances to the phenomenology of hallucinations, and the manner in which the brain makes predictions about incoming sensory information—perhaps this is merely a reflection of my personal interests, but I tend to find the latter lecture far more engaging than the former on ascending spinal tracts. Put simply, neuroanatomy is a course that seems to lend itself more to rote memorization than conceptual understanding, particularly given the limited experience undergraduates have with these topics. This in mind, I began to ask myself if there might be some way in which I could enhance student conceptualization of the nervous system, not just by discussing pieces of it in isolation (the traditional neuroanatomy experience), but rather by asking them to consider its function as an integrative whole. What follows is a retrospective case study analysis of student success and perception of instruction in my ZOO4743C course following a redesign of the lab portion to include a novel active learning game of my design in which students are tasked with building their own pathological nervous system (*Build-a-Zombie; BaZ*). The rules of the game were based heavily around popular tabletop roleplaying games (RPGs) with a central focus on gradually developing a character's attributes to improve their performance in a final game day, during which student groups were pitted against each other in a choose-your-own adventure style story, complete with mathematically derived combat scenarios. The task? Build a zombie, survive the longest, and eat the most brains. Each week of lab, students worked in groups to earn their choice of perk points which affected their zombie's particular powers, movement, health, strength, etc. Perks were based around modifying particular aspects of the nervous system, e.g., feeding circuits, cognition, aggression, movement, sensory systems, and autonomic systems. To earn a particular perk, students needed to come up with a hypothetical mechanism by which their zombie pathology could cause the effects described by the perk; then they had to give an impromptu chalk talk and face live questions from myself and the TAs. Despite not altering any other aspect of the course (including lecture and exam content), the results of adding the gamified element to lab were stark: a 13.5% reduction in the overall rate of exam failure (defined as grades less than 70%) and improved student perception of instruction (SPI) scores on 8/9 metrics when compared to the previous semester's non-gamified cohort. While this represents a single case study, the results are in line with the previous literature (Freeman et al., 2014) and suggest that undergraduate neuroanatomy education is ripe for gamification.

MATERIALS AND METHODS

The methods used for this retrospective analysis of course improvement were approved by the UCF Institutional Review Board.

Subjects

This course improvement project took place during the 2023 academic year. Data from one cohort of students in the non-gamified Spring 2023 version of the course (n = 28) and one cohort of students in the gamified Fall 2023 version of the course (n = 30) are presented. In the Spring, student majors included Biomedical Science (n = 21), Health Science (n = 5), Chemistry (n = 1), and Interdisciplinary Studies (n = 1). For the Fall, student majors included Biomedical Science (n = 22), Health Science (n = 6), Psychology (n = 1), and Chemistry (n = 1).

Course Content

The course explores a medically oriented view of the nervous system beginning at the basis of the resting potential and ending with anatomy of the blood vessels that supply the brain. Individual lecture topics include neurons and glia, nerve fibers and peripheral innervation, spinal cord, brain stem, cerebellum, cerebrum, cortex, reticular formation, limbic system, basal ganglia, cranial nerves, thalamus, hypothalamus, autonomic nervous system, meninges, ventricular system, neurodevelopment, and blood supply to the brain. These topics overlap with lab presentations on specific disorders affecting these regions (e.g., Huntington's disease, myasthenia gravis, etc.) as well as weekly BaZ modules described in the following section.

Build-a-Zombie Modules

BaZ contains (5) unique modules, each containing (3) available perks, one of which can be earned per module. Modules are scheduled to follow weeks of overlapping lecture content. Each module is included below along with instructions and perk descriptions.

<u>Mode of Infection</u> (Module 1): Describe how your zombies come to be affected by your hypothetical pathology: is it a virus, bacteria, drug, aerosol, fungus, aliens, etc.? How does this exogenous thing enter the body, how does it travel to and begin to hijack the central nervous system. Bear in mind that whatever you come up with needs to include a hypothetical mode of transmission as well in order to create new zombies following successful attacks. Be creative here and give as much detail as possible; if the science sounds plausible, we can do it. Describe what areas of the body/brain are affected first, what receptors, cell types, systems, etc. Your group's answer determines your virulence stat.

Mode of Infection Perks: "Like Wildfire" — high virulence pathology perk means your zombies burn hot and fast, you make more new zombies with every successful attack compared to groups with low virulence; however, high virulence also means you decay quicker (3 HP lost per day). Consider the mechanism for pathologies like Rabies and bacterial meningitis if you are interested in proceeding along this route.

"The Middle Road" — medium virulence perk; successful attacks that result in nonfatal damage to the target have a 50% chance to infect after 2 days. Zombies decay at -2HP per day. Infectious prion diseases that lead to death within a year, e.g., Creutzfeldt-Jakob and Bovine Spongiform Encephalopathy provide potential examples of mechanisms to consider.

“Time Tested” — low virulence perk; your pathology is able to take control of the nervous system but keep things running for longer before the death of the host. Decreased transmissibility following successful attacks, but decreased HP decay over time (1 HP lost per day). Consider the mechanism of diseases like Toxoplasmosis, fungal infections, etc.

<u>Movement</u> (Module 2): This week, you have a chance to earn perks which modify your movement, thus affecting attack and defense stats. The explanation your group comes up with needs to fit with the symptoms described by the perk. Groups that score the highest on this assignment will have presentations that include a visual schematic of the pathways and nervous system regions involved, as well as a detailed explanation of how your hypothetical pathology affects specific groups of neurons, receptors, molecular signaling pathways, etc. in order to achieve the effect.

Movement Perks: "Slow and (un)Steady Wins the Race" — Your zombie has the classic movement pattern from films like *Dawn of the Dead* (Romero, 1978) - shambling, shuffling, uncoordinated, parts of the body may be paralyzed - but don't discount the slow zombie, in a large horde they overwhelm, and little can be done to dissuade their ceaseless march. +5 to all defense rolls.

"Speed is the name of the game" — The basic fast zombie (e.g., *28 Days Later*; Boyle, 2002) - your zombie has increased agility and moves at a faster than normal rate, almost as if its muscles never fatigue. +2 attack, +2 defense

"Berserker" — These zombies are a force to be reckoned with, their hyperkinetic attack patterns are difficult to evade, though their inability to stop themselves once initiating a pattern of movement makes them vulnerable as well. +5 attack, -5 defense

<u>Feeding, Cognition, and Aggression</u> (FCN; Module 3): This week, you have a chance to earn perks which modify your executive function, memory, homeostatic drives, and/or aggression. The explanation your group comes up with needs to fit with the symptoms described by the perk.

FCN Perks: "Insatiable Hunger" — Your appetite knows no bounds, you feed for longer following a successful attack and have a 30% chance to gain a +5 defense buff in your next combat, at a cost of decreased undead recruits gained (if successful, round down during transmission phase).

"Ceaseless Fury" — Whereas some zombies still show evidence of a memory and emotions related to their past life (e.g., *I am Legend*; Matheson, 1954; *The Walking Dead*; Darabont et al., 2010-2022), your zombies are completely unaware of the past; they are fearless in combat, and are driven only by the desire to consume. 20% chance for a critical hit in combat, multiplying your damage output by 1.5x; -2 to overall defense

"Lich Lord" — Zombie, vampire, or something in between? There's something different about the undead in your horde - they seem to have decreased appetite relative to others, instead they demonstrate a singular focus on turning individuals to their side. When attacking, these zombies show a level of impulse control and decision-making that is absent in others, less driven by hunger they tend to leave more of their victims intact, increasing the number of infected recruits for the horde. Successful attacks have a 30% chance to yield an additional undead recruit during the transmission phase; when this happens, your defensive rolls gain (-5) in the next combat.

<u>Sensory Systems</u> (Module 4): This week, you will have a chance to earn perks which modify sensation and perception. The explanation your group comes up with needs to fit with the symptoms described by the perk.

Sensory Systems Perks: "No Pain All Gain" — Your zombies are nigh unstoppable, they feel no pain, or perhaps they feel it but don't care about it (you decide but note that these are two different neural mechanisms to argue for). +5 base HP buff to all zombies in your horde.

"Blindsight" — Your zombie pathogen has a particular affinity for disrupting the visual pathways of the brain, yet other sense(s) are somehow heightened (e.g., *The Last of Us*; Naughty Dog, 2013)—make sure to describe how your pathogen affects the visual systems of the brain AND enhances others to be awarded this perk—Allows you to use your heightened powers of perception to draw an additional scenario card for your group, you may only use this ability once.

"Sleight of Hand" — You feel everything more acutely, touch and proprioception is heightened, but also pain. 20% chance to sneak and gain first-strike combat priority. -1 to all attack rolls.

<u>Peripheral Nervous System</u> (Module 5): This week, you have a chance to earn perks which modify the functions of your peripheral nervous system (i.e., autonomic and somatic). The explanation your group comes up with needs to fit with the symptoms described by the perk.

Peripheral Nervous System Perks: "Reanimator" — describe in specific detail how your zombie pathogen alters the process of peripheral nerve regeneration to win this perk. Function to damaged extremities post combat quickly recovers. 20% chance to heal 20% of your base HP after at the end of a scenario in which the horde has sustained damage.

"HPA Overdrive" — early on in the outbreak, in the ruins of a destroyed laboratory, a notebook is found; the pages are badly stained with blood and torn, little remains. Enough is present to ascertain that a scientist had captured a "living" zombie and was examining it. On a page with a much longer writeup, you are able to read the words "abnormally high level of circulating epinephrine" — there is much more to the description, but the page is damaged. Your zombies have constant tunnel vision and time seems to flow slowly around them, allowing for the ability to evade incoming attacks more effectively. +2 defense, -2 attack

"What Happens in Vagus Stays in Vagus" — autonomic axes are altered, digestion and heart rate slowed. Zombie decay rate tied to virulence is permanently negated.

Build-a-Zombie Stats

Following the completion of all BaZ modules, I held a final game day: groups' zombies were pitted against each other in a choose-your-own adventure style game complete with combat scenarios. The goal of the game was to survive the longest and create the largest zombie horde. Players add to their horde based on damage dealt during combat scenarios and probability modified by their stats. Each zombie has the following stats:

Hit Points (HP) - All zombies have a base HP of 5; as your zombie horde grows, so does your overall HP. HP determines the amount of damage you take following a successful hit in combat—it also influences your power level. If your zombie horde's HP is reduced to zero, you lose.

Virulence - Determines the rate of decay and likelihood of transmission following a successful attack by your zombie horde against human survivors. All zombies face a static loss of HP each day due to decay, higher virulence = higher loss, but more success in gaining new zombies post-combat.

Attack - Determines your success rate in combat. Add your attack score to your D20 roll and compare against enemies' defense; if equal or higher, the attack is successful; proceed to damage phase.

Defense - Determines your likelihood of avoiding attacks. The higher the defense, the higher the enemy must roll in order to score a hit.

Power - Determines how much damage to HP you do following a successful attack. Power = (HP + Attack) / 2. Growing your zombie horde increases your HP, thus increasing your power.

Build-a-Zombie Combat Mechanics

Combat in BaZ flows in the following manner:

1) Draw a scenario card. Read scenario text of card, enemy stats, and other unique information. If the card presents a choice(s); allow groups to vote on how to proceed.
2) Roll (2) six-sided dice (2D6) per group to determine whether group attacks enemy first or attacks happen at the same time (note sneak perk that buffs this roll for certain groups).
3) Begin combat phase. Enemy/Group rolls against Defense (D20+Attack, if D20+A > than Defense, proceed to damage roll.)
4) Damage roll. (D6 + Power) - HP = loss of HP
5) Transmission phase. Determine how much damage was dealt to target as a percentage of survivors (humans have 5 base HP just as zombies do). Ex: if the scenario is a fight against 10 survivors (50HP total) and 25 damage is dealt, you gain 5 infected recruits (add to zombie horde HP accordingly)
6) Decay phase. Determine modifier for HP loss after each scenario based on virulence stat.

Course Assessments

For both Spring and Fall semesters of the course, assessments took the form of exams (four midterms with 45-questions each and a cumulative final with 75-questions; all questions are based on lecture content), lab presentations of nervous system disorders, lab quizzes (these involve drawing and labeling various parts of the nervous system and/or MRI images), and lab attendance. The Fall version of the course adds two new assessment categories: Build-a-Zombie (BaZ) Chalk Talks, and BaZ final write-up. Lecture exams made up a total of 70.5% of the students' grade in the Spring semester, and 72% in the Fall semester.

Build-a-Zombie Chalk Talks

The core of the gamified neuroanatomy experience revolved around the BaZ chalk talks. I split the class into 6 groups of 5 to work as teams for the semester. Together, they had to come up with a general theme and backstory for their zombie, including a hypothetical mode of infection (e.g., virus, bioweapon, alien parasite, etc.) to work from; this complete, students worked each week to earn one of three different perks on offer. Each week was themed to highlight a different aspect of the nervous system corresponding to the week's lecture content (e.g., systems and circuits governing movement, sensory systems and cranial nerves; autonomic systems, cognition, feeding, aggression, etc.). Perks differed in the various abilities they conferred upon the zombies (e.g., during movement week, some perks were associated with slowness and rigidity of movement but increased defense; others were associated with rapid, hyperkinetic movement and increased attack, etc.), all of which contained a unique perk description with key terms to guide the group in their design. Students were given one hour to work in their groups and come up with a unique mechanism by which their zombie pathology caused the described perk/effect in the nervous system; the last 50 minutes of the course were dedicated to data blitz style chalk talks (5 minutes to present, 2 minutes for questions). To ensure equal participation, students had to elect a different speaker for the group each week. Groups were assessed along the following dimensions: Pathophysiology (25%; For the perk selected, does the pathophysiology presented match the symptoms? Would the theoretical mechanism your group came up with cause the symptoms described by the perk?), Visuals (25%; Are the presenters able to convey their argument with the aid of schematic drawings of brain regions, connections, images, etc.), and Depth of Explanation (50%; Is the presenter able to answer questions about the various structures, circuits, cells, neurotransmitters, and/or molecular signaling pathways involved in the system they are manipulating?).

Build-a-Zombie Final Write-up
While the students received grades as a group for the BaZ chalk talks, the final BaZ assessment involved an individual APA style write-up. I instructed the students to imagine themselves in the role of a neuropathologist that has captured a zombie from the outbreak. Their task was to submit a case study describing the nervous system pathology along each domain covered during the chalk talk weeks. They received an equal percentage of points for successfully describing in detail the observable symptoms and underlying pathophysiology for each aspect of the nervous system affected in their zombie. Points were deducted for failure to describe either outward symptomology or pathophysiology along a given dimension. There were no page limits for the assignment, only the requirement that the student utilize APA style citations wherever applicable.

Student Perception of Instruction
Student perception of instruction is assessed each semester by the University of Central Florida in an anonymous manner with an 11-question survey. Nine of the 11 questions utilize a 5-point Likert scale with 1 indicating poor, 2 indicating fair, 3 indicating good, 4 indicating very good, and 5 indicating excellent. Likert scale questions are as follows:

1) Effectiveness of the instructing at organizing the course
2) Effectiveness explaining course requirements, grading criteria, and expectations
3) Effectiveness communicating ideas and/or information
4) Effectiveness showing respect and concern for students
5) Effectiveness stimulating interest in the course
6) Effectiveness creating an environment that helps students learn
7) Effectiveness giving useful feedback on course performance
8) Effectiveness helping students achieve course objectives
9) Overall effectiveness of the instructor

The remaining two questions on the SPI questionnaire are free response with the first being “What did you like best about the course and/or how the instructor taught it?” and the second being “What suggestions do you have for improving the course and/or how the instructor taught it?” UCF releases the results of the questionnaire each semester to instructors in aggregate form.

Data Analysis
Student Perception of Instruction
SPI reports are released to the instructor-of-record each semester in aggregate form. While they show the number of students responding per question, they do not show individual responses; unfortunately, this precludes one from conducting an inferential statistical analysis. For this article, I evaluated and present the results in descriptive form with sample size, Likert response means, and standard deviations.

Exam Scores
In order to determine the potential impact of gamification on student performance in Clinical Neuroanatomy, scores for each of the five exams in the course were compared using one-way ANOVA with between-subjects variable of semester (Spring vs. Fall). Levene’s test was used to examine homogeneity of variance. Alpha criterion for significance was set at .05; all analyses were conducted using the open-source statistical package *Jeffreys’s Amazing Statistics Program* (JASP; University of Amsterdam).

Rate of Failure
Exam rate of failure (D or F) was calculated per student and defined as (*number of exam grades ≤ 69.9% / number of exams*). It should be noted that not all students took the final exam, therefore the rate of failure for some students is reflected out of 4 exams, while for others it is out of 5 exams. Levene’s test was used to examine homogeneity of variance; after which, rates of failure were compared using a one-way ANOVA with between-subjects variable of semester (Spring vs. Fall). Alpha criterion for significance was set at .05 and all analyses were conducted using JASP.

Other Assessments
While BaZ and the lecture exams were the central focus of the course, other metrics of performance assessment included required lab attendance checks, lab presentations, and lab quizzes. Other than lab attendance, these assessments occurred during lab period prior to BaZ; thus, it is expected that BaZ would not lead to differences on these assessments between cohorts. Further, it should be noted that some lab quizzes (No-BaZ had n = 13 lab quizzes; BaZ had n = 9 lab quizzes) and lab presentations (No BaZ had n = 2 presentations; BaZ had n = 1 presentation) were dropped in order to make room for BaZ. The means for overlapping lab quizzes and presentations were compared using a one-way ANOVA with between-subjects variable of semester. Attendance was calculated as a percentage of total available attendance points on an individual basis and compared across cohorts. Alpha criterion for significance was set at .05 and all analyses were conducted using JASP.

RESULTS
Student Perception of Instruction
For the Spring (non-gamified) semester, n = 18 out of n = 28 students participated in the SPI questionnaire; in the Fall, n = 17 out of n = 30 students completed the questionnaire. Mean scores increased in eight out of nine categories, with category six (“Effectiveness in creating an environment that helps students learn”) showing a small decrease. Means and standard deviations are reported in Table 1.

For the free-response questions, two comments specifically mentioned the gamified element of the course in response to the “What did you like best about the course and/or how the instructor taught it?” prompt and are reported here verbatim:

“I believe the BaZ assignment was an amazing way to test our knowledge of neuroanatomy." "Build a zombie project, which gave students an excellent opportunity to work together as teamwork because whether a student will pursue a career as a clinician or a scientist he/she needs to understand the importance of teamwork."

Exam Scores

Analysis of variance revealed significantly increased exam scores in the Fall (gamified) relative to Spring (non-gamified) semesters for exam 1 $F(1, 56) = 4.69$, $p = .03$, while exam 2 $F(1, 56) = 3.59$, and exam 3 $F(1, 56) = 3.09$ both trended toward significance with *p's* < 0.1; there was no significance difference in scores by semester for exam 4 or the final exam (*Fs* < 1), nor was there a difference in mean total exam scores $F < 1$ (*figure 1a-b*).

Rate of Failure

Levene's test revealed that the data for rate of exam failure by semester lacked equality of variance, $F(1, 56) = 5.28$, $p = .02$; as such, Welch's ANOVA was used to correct and modify the degrees of freedom. Rates of failure trended toward a 13.5% decrease in the Fall (gamified) semester relative to the Spring, $F(1, 51.037) = 2.81$, $p = 0.1$ (*Figure 1c*).

Other Assessments

Required lab attendance was strong for both semesters (> 94%) and did not differ as a function of cohort (F < 1). Overlapping presentation and lab quiz grades also did not differ (Fs < 1).

DISCUSSION

In this retrospective analysis, I examine the effects of a semester-long course improvement project on student perception of instruction and performance in Clinical Neuroanatomy at a large R1 university located in the southern United States. Based on recent studies in the field of pedagogical theory which showed that active learning improves course performance in STEM fields (Freeman et al., 2014; Majuri et al., 2018; Kalogiannakis et al., 2021), I elected to add a novel game-based element to the lab portion of my course. Students worked in teams utilizing their knowledge from lecture to build a zombie nervous system and competed against each other during a final game day with rules based largely off tabletop RPGs such as *Dungeons and Dragons*. While gamification in education has been a hot topic for some time now (Cohen, 2011; De Freitas and Liarokapis, 2011; Lee and Hammer, 2011; Toda et al., 2017; Zeybek, N., and Saygı, 2024), there has been a paucity of data coming specifically from neuroscience education (Sandrone and Carlson, 2021). Here, I show that gamification led to significant improvements in exam scores, increased student perception of instruction, and a trend toward a reduction in rates of failure. This makes sense in light of recent data which shows that gamified learning activities enhance student engagement and correlates with decreased activation of the default mode network (Howard-Jones et al., 2016). That said, there are some limitations with regard to the case study at hand which should be acknowledged.

Given that the gamified semester was my second time teaching the course, this meant that I had only one semester of non-gamified student data to draw from (Spring 2023). I elected to show trending data as it is clear that these results are in line with previous work (e.g., Freeman et al., 2014) which showed improved outcomes and reduced rates of failure. While my analysis may have benefited from increased statistical power, I do not intend to teach the course in a non-gamified version again, thus limiting interpretations. This in mind, one might also argue that I simply taught the course in a more skillful manner the second time around, however, SPI scores for the non-gamified Spring semester were still quite strong overall, reducing the likelihood of this explanation. Another explanation could be that students in the BaZ cohort (which occurred in Fall 2023 compared to Spring 2023 for the No-BaZ cohort) were simply better prepared for the challenges of this course as a result of word-of-mouth between peers. The neuroscience-track within our major is quite small and ZOO4743C is a required course, thus Fall students were

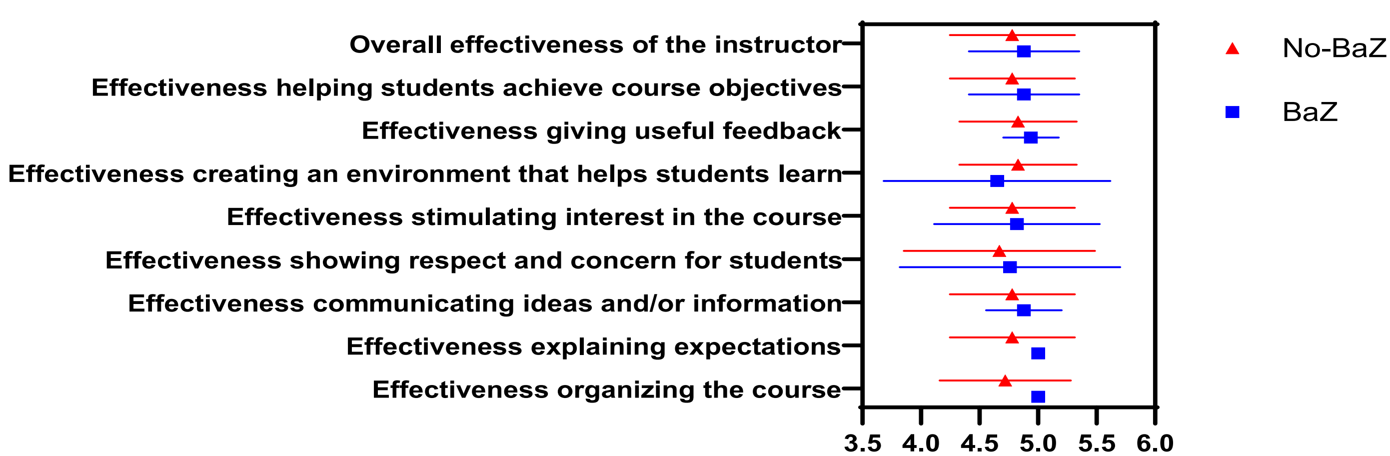

Figure 1. Student perception of instruction graphed by means and standard deviations on a 5-point Likert scale. Overall, students felt I was highly effective as an instructor in both semesters across all categories; however, in the gamified semester, mean perception of effectiveness increased for all categories except #6.

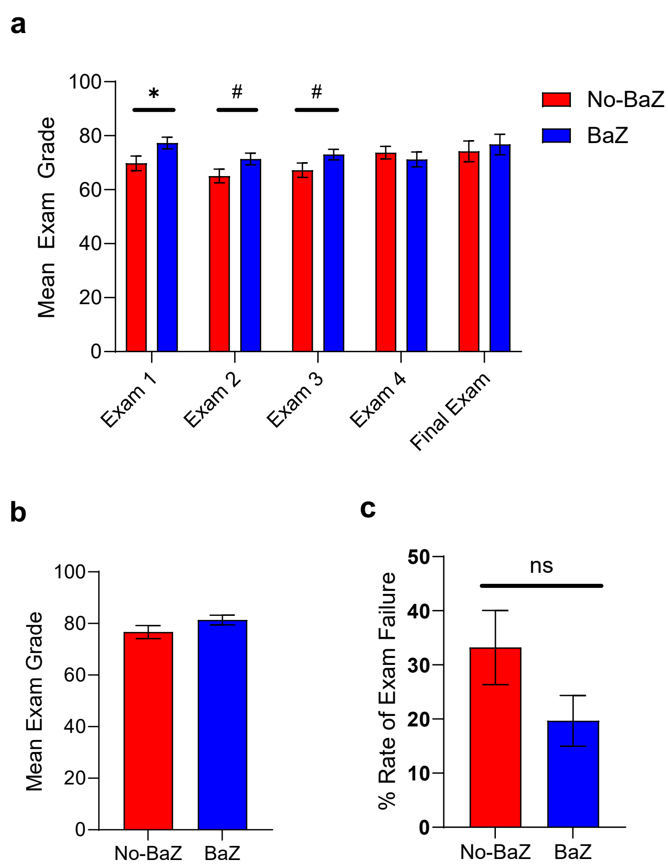

Figure 2. Impact on Exam Performance. Students in the gamified (BaZ) version of the course showed significantly improved exam 1 scores, and a trend toward increased exam 2-3 scores *(a)*; however, this did not translate to a significant difference in the overall mean exam grade *(b)*. Individual rates of exam failure for the course showed a trend toward reduction by 13.5% *(c)*. $^{*}p < .05$; $^{\#}p < 0.1$ $^{ns}p = 0.1$

likely to have encountered students from Spring. It is no secret that students share information with one another both from and about courses they have taken. Perhaps my Fall cohort, with more accurate expectations regarding the level of rigor they were about to encounter, simply devoted more time to studying for exam 1 as a result. Further, it is worth noting that the pre-requisite for ZOO4743C is ZOO3744 (Neurobiology). For the No-BaZ cohort in the Spring of 2023, all of these students took Neurobiology with a different professor (I did not start teaching neurobiology until Spring 2023). In the BaZ cohort (Fall 2023), however, these students had taken neurobiology with me. This suggests again that they may have been better prepared for the level of assumed knowledge in the neuroanatomy course (because they learned the pre-requisite information from me). Exam 1 in particular contains a great deal of material that is review from my version of the neurobiology course (e.g., basis of the resting potential, action potentials, etc.).

Other factors to consider include the fact that some course activities (e.g., additional lab quizzes and student presentations) that were present in the non-gamified semester were removed from the gamified semester to make room for additional time spent on BaZ. Analysis of these other assessments (specifically, lab quizzes and presentations that were retained), including attendance showed no difference in scores between cohorts. While this helps to rule out differences in attendance and academic ability between cohorts as a potential explanation for significant differences in exam performance, it is nonetheless possible that the loss of these additional activities in the gamified semester may have confounded comparisons between cohorts. This in mind, only exam 1 was significantly different in the gamified semester, while exams 2, 3, and the cumulative final trended in the same direction, and exam 4 was non-significant. Rather than weakening the interpretation of results, however, I think this speaks more to the content of the weekly BaZ modules and their overlap with lecture. Exam 4, for instance, focuses heavily on blood supply to the brain and the consequences of various cerebral infarctions, a topic which, admittedly, I did not include in the weekly BaZ activities. Meanwhile, exam 1 had the highest amount of content overlap with BaZ relative to others. Given the positive impact shown, this makes for fruitful ground to continue improving lecture/lab integration through the BaZ game.

If we are to move forward with the assumption that differences in exam performance between cohorts are solely the result of BaZ, it would be useful to consider what it is specifically about BaZ that may have been so impactful. Is there something special about gamification, or would any additional form of active learning yield similar results? In their seminal text on the topic, Meyers and Jones (1993), contrast active learning with passive learning by characterizing the former as something that involves activities other than mere listening. These activities place a larger emphasis on skill development, as well as the student's contribution to learning. Quite a lot can fit under this umbrella, including group discussion, role play, flipped classrooms, team-based learning, and of course, gamification. One of the fundamental ways that gamification differs from other forms of active learning is that it places an additional emphasis on competition. The object of 'winning' becoming a part of the learning process would initially seem to make gamification a superior motivator over other forms of active learning, and yet, there are educators who have taken issue with this aspect of gamification, with some arguing that this specifically is what makes it problematic (Toda et al., 2017). Indeed, students who are not motivated by competition and a desire to win may in fact become demotivated by the introduction of these factors to their learning environment. Anecdotally, it may be that gamification works well in neuroanatomy precisely because of the type of student that is drawn to this course (i.e., pre-med students with innately competitive tendencies). More research needs to be done to answer these questions. As of now, the literature seems to be dominated by case studies and meta-analyses which follow a pattern similar to my own (comparing a traditional lecture format course to one with added active learning elements). Future studies comparing student outcomes in active learning non-gamified, versus active learning gamified courses will be essential to answering this question in the long term. Still, the results of the present work with regard to student performance, and others which show clear changes in brain systems involved with learning during gamification (Howard-Jones et al., 2016) suggest that the potential benefits of gamification are clear.

Overall, these data add to the growing body of literature which supports gamification as an effective means of increasing student performance in the life sciences. Given that, until now, there have been relatively few studies looking at the impact of gamification on course performance in neuroscience classrooms specifically (Sandrone and Carlson, 2021), this underscores the need for more educators in our discipline to take up the charge. I intend to continue teaching the gamified version of Clinical Neuroanatomy with a focus on further increasing course content integration with BaZ. Future efforts will include attempting to build BaZ into an online version of the course, as well as formalizing the game rules and materials in a manner that can be used by other educators teaching neuroanatomy.

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Address correspondence to: Dr. Benjamin R. Fry, 219 Biobehavioral Health Building, University Park, PA 16802. Email: bbf5259@psu.edu