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Unlocking Anatomy: Gamified Problem Solving to Enhance Collaboration and Confidence with a Puzzle Box

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Abstract:

Background: Gamified "escape-room" style activities are increasingly used to promote engagement, collaboration, and applied problem-solving in engineering education. This study describes the implementation of a physical anatomy breakout box as a culminating laboratory experience in a lower-level 'Anatomy for Engineers' course to examine impacts on motivation.

Methods: Teams of 2–3 students entered a timed, narrative-driven scenario to unlock a series of anatomy-based puzzles to restore an organ perfusion machine before time expires. The activity ran across two semesters in a large R1 university setting ($n = 119$ post-activity survey responses; 46 in Spring '25, 73 in Fall '25). Measures included Likert-style items on engagement and collaboration, pre/post topic-specific confidence ratings (Very/Somewhat/Not comfortable), and an open-ended reflection analyzed for themes (Fall '25, $n = 71$).

Results: Most students agreed the activity promoted exploration of multiple solution paths (90%) and teamwork (88%); 73% reported that competition enhanced motivation, and 60% reported high absorption/flow. Pre/post confidence showed net positive change for 65% of students (76/117), net negative change for 15% (18/117), and no net change for 20% which suggests the experience both strengthened confidence for many and surfaced knowledge gaps for some. Thematic analysis of reflections highlighted high engagement/fun, favorable comparisons to traditional exams, collaboration/peer learning, application/integration of knowledge, and strategy use under time pressure.

Conclusions: A structured puzzle-box assessment can create a low-stakes, high-engagement environment that supports collaboration, applied reasoning, and confidence gains for many students while revealing specific areas needing review.

Introduction:

Gamified learning experiences have gained traction in engineering education for their ability to foster engagement, collaboration, and deeper understanding of complex topics in an immersive way. Breakout boxes, or other escape room like activities, have been shown to be an effective way to create engaged and active learning across disciplines [3], [4]. In engineering contexts, escape rooms have shown increases in participant's motivation and reported engagement across different audiences including faculty and undergraduates [5]. Digital escape rooms have also been shown to be effective tools for teaching anatomy [6], [7]. These type of activities have also helped to stimulate critical thinking, effective communication, divergent ideas, and other creative problem solving skills [3], which are essential to engineering. In prior work using a biomedical engineering laboratory escape room, students reported gains in teamwork, communication, and confidence while applying hands-on skills to authentic tasks [8],

[9]. This builds on the evidence that these game-based environments can deliver in both technical and professional skills.

Breakout boxes and escape rooms are inherently structured to facilitate team-based problem solving in a unique way relative to many other teaching techniques. They are typically designed with sequential puzzles and shared constraints that are intentionally crafted to be solved through collaboration [1]. Team-based problem solving is facilitated through the fact that people are asked to work together to solve a series of puzzles as a basis for these games. Students in education escape rooms report that they help practice and improve collaboration skills [2]. Escape rooms and breakout boxes are also effective at stimulating divergent thinking and problem-solving. By design, many puzzles require flexible reasoning, pattern recognition, and iterative testing, which contribute to the skill of divergent thinking. This ability to explore multiple pathways for a solution is a key skill for engineering.

The fact that escape rooms are typically done in groups allows them to be viewed through the social-constructivist framework which says that learning develops through social interactions and collaboration [10]. Success often relies on team input to progress and solve problems. Escape room like activities are used to promote teambuilding and support positive social interactions between people [11], [12]. One digital escape room used to teach anatomy and physiology to biomedical engineering students reported that 82% of students said that the activity helped create a sense of community in the class, highlighting the positive social impact [7]. Some escape rooms promote collaboration by utilizing puzzle components that require more than one person to physically interact with an object, but can also promote team work through other methods such as required collaboration due to complexity of the problems or the need for effective communication for efficiency when working against a time pressure [8], [9].

From a motivation perspective, escape rooms incorporate key self-determination theory design features: autonomy (multiple pathways and choices), competence (progress feedback and achievable challenges), and relatedness (team interdependence) similar to other gamification techniques [13], [14]. In a study of university student who participated in an educational escape room, the gamified experiences of creative thinking, feeling active, and feeling confident were related to intrinsic motivation toward knowledge, achievement, and stimulating experiences [14]. Other gamified educational experiences have shown a link between game-based learning and increased motivation and decreased learning anxiety [15]. Escape rooms can be positioned as safe spaces for learning through failure, emphasizing iterative play (test–fail–reflect–revise) that can mitigate high-stakes anxiety and normalize error as part of skill development, an important reframing for novice engineers. Additionally learning motivation is associated with a positive effect on increased academic performance [15].

This study investigates how one example of incorporating a gamified hands-on learning tool, a physical breakout box for engineering anatomy students, can enhance student motivation, reinforce content mastery, encourage collaboration, and increase motivation.

Materials and Methods:

Overview of Breakout Box and Curricular Context:

A custom-designed box, similar to an escape room in a box or “breakout box”, was implemented as a culminating activity to reinforce anatomical and physiological concepts in a lower-level Anatomy for Engineers course at The Ohio State University. The course where the breakout box is utilized is one out of a few options that students can choose from to meet a program requirement. The large majority of biomedical engineering students within the program at choose this course for their requirement. This course is open to non-majors and can be part of the biomedical engineering minor degree path. It is typically taken by sophomores, although first year and later students may take it. The course has a concurrent requirement of Physics 1 and no other biology or physiology course is a prerequisite.

The box was designed to promote collaborative problem-solving for students to work together in small groups of 2 or 3 people. The breakout box contained a series of interactive, physical puzzles that required students to apply knowledge acquired throughout the semester, including anatomical planes and directions, identification of major bones and muscles, and organ systems such as the digestive, urinary, respiratory, and central nervous systems. The timing of the breakout box activity is as the last laboratory experience of the semester, therefore serving as a culminating evaluation of learning topics from throughout the course.

Breakout Box Assembly and Design:

The breakout box was designed and assembled by one of the instructors of the course. Puzzles were created with easily obtained materials. Many puzzles were printed on standard paper, transparency paper, or with 3D printed components (Figure 1). Materials that were purchased include a locking storage file tote which contained all puzzles materials, various padlocks with different mechanisms, a small whiteboard, marker, eraser, a UV flashlight, and folders. Each box was assembled with ~$110 worth of materials, the locking storage box, making up about half of the cost. Padlocks were the next most costly material, at $12-$25 each.

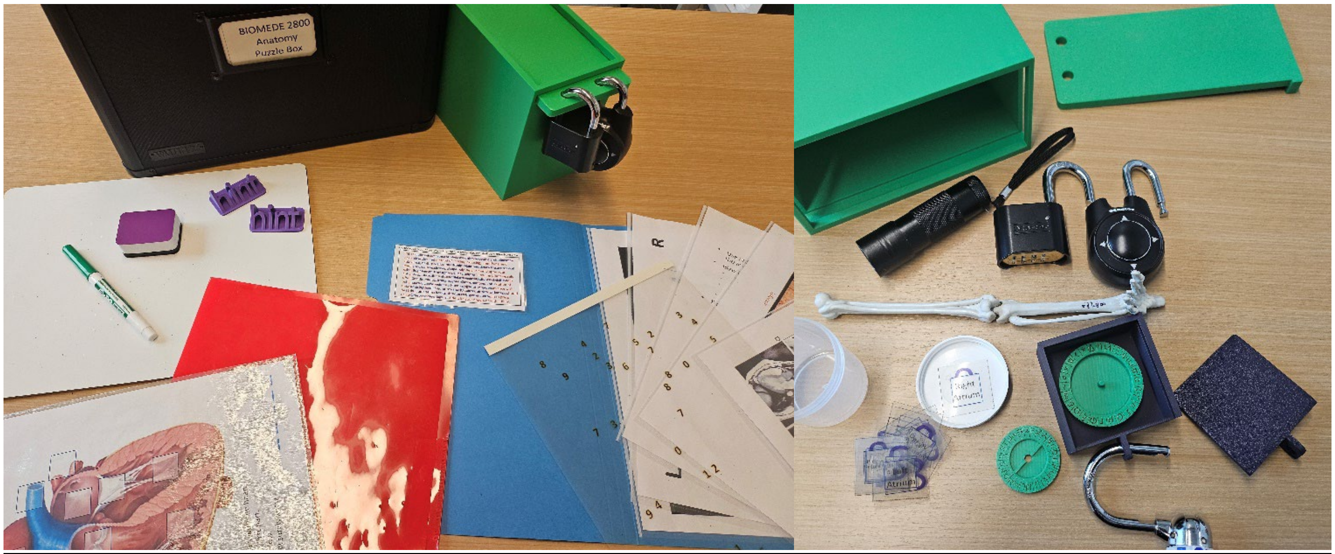

Figure 1*: Breakout box puzzles and components. Various locks, paper puzzles, 3D printed components, whiteboard, and other materials.*

Breakout Box Scenario and Setup

Upon entering the lab, up to ten small teams (of 2 or 3 students each) were presented with a clinical scenario: they must restore function to an organ perfusion machine within one hour before the organ becomes nonviable. A large screen projected a countdown timer and displayed a password hint encoded in a cipher, creating urgency and a shared focal point for all groups. Each team received a locked breakout box containing multiple sequential and concurrent puzzles. The overarching goal was to unlock the box, retrieve clues, and ultimately determine the password to 'save the organ,' creating engagement through a narratively high-stakes but functionally low-stakes, game-like scenario. The timer starts with 60 minutes counting down as soon as an instructor ends introducing the activity and special rules. The rules are that participants should not access the internet, each team gets 2 free hints, and asking questions about how a lock works doesn't count toward a hint usage. Another rule is that if a team guesses the wrong password, they must wait for another team to make a guess, this dissuades brute forcing the final game winning answer.

Puzzle Design and Cognitive Targets

The puzzle sequence integrates diverse anatomical concepts and spatial reasoning tasks to promote active recall and application. The initial challenge requires students to interpret a riddle and input the number of bones in an adult and a newborn, supported by hidden clues on the box exterior which prevents the need for pure memorization of factoids. Inside (Figure 1), students encounter puzzles utilizing medical imaging conventions: they must align transparent overlays with MRI slices, X-rays, and cadaver images to identify anatomical structures and extract numeric codes for combination locks. Another puzzle employs a directional lock, requiring interpretation of anatomical planes and positional terminology. Clues printed in blue ink were obscured by red text, revealed only when placed under a red transparent folder, introducing an element of discovery and reinforcing visual-spatial skills.

Advanced Puzzles and Final Cipher

Progressive locks open a 3D-printed compartment containing additional components (Figure 1, right): a limb bone inscribed with a part of the cipher key, a UV flashlight, and heart diagram labels. Students use overlays to correctly label cardiac structures, then trace blood flow under UV light to reveal glowing numbers for the next lock. Completing the heart-flow puzzle enables teams to finish the cipher and decode the password hint. The password hint is drawn from a bank of physiology questions, and the password itself is the correct answer to the selected question. To discourage brute-force guessing, password attempts were entered on a projected screen, with incorrect guesses triggering a delay until another team makes an attempt. Most winning groups complete the challenge within ~45 minutes or less, and optional new passwords allowed continued play for ranking purposes of the remaining groups. This multi-layered design requires collaboration, critical thinking, and integration of anatomy and physiology knowledge, aligning with experiential learning principles and gamification strategies to enhance motivation, confidence, and teamwork.

Before implementation with students in the course, the puzzles were refined through iterative testing with teaching assistants, faculty, and former students who had previously taken the course. For instance, one puzzle revealed a code after students labeled blood flow through the heart. In its original design, the code followed the numerical order in which the digits appeared on the page. However, during pilot testing, the designer observed that users consistently attempted the digits in the order of physiological blood flow instead. In response, both the puzzle and its accompanying clues were revised so that the correct code now aligns with the actual sequence of blood flow, improving clarity and conceptual depth of the physiological relevance of the puzzle.

Study participants and IRB:

This activity was implemented in a lower-level anatomy for engineers course which is a combination of a lecture and lab format. This course typically enrolls 45-100 undergraduates who are enrolled at The Ohio State University, a large R1 university. Most students are biomedical engineering students, but the course is open to other majors which may include majors such as pre-medicine, materials science engineering, computer science, and biological engineering. Participants were from two separate semesters with a total of 119 respondents (n=46 in Spring ’25 and n= 73 in Fall ’25 semester). This study (STUDY20250336) was determined exempt by the IRB at The Ohio State University. All participants were at least 18 years of age and provided informed consent.

Pre-and Post- confidence in anatomy and physiology topics:

Students were asked to rate their confidence ('Very Comfortable', 'Somewhat Comfortable', 'Not Comfortable') in various anatomy and physiology topics as part of their pre-lab assignment. This was completed before they did the breakout box. After the activity, students were asked to rate their comfort with each topic again. The change in comfort with each topic was noted. If a student marked the same comfort level, they had a net zero (0) change. If a student marked "Somewhat comfortable" for a particular topic in the pre-lab and "Very Comfortable" in the post-lab it was a +1 change. Likewise, if they changed from "Not comfortable" to "Somewhat comfortable. A negative change was marked for the reverse direction. The list of topics in the pre-lab served as a hint to the potential knowledge areas that would be tested in the breakout box. They included the topics listed in Table 1.

Table 1: Anatomy and physiology topics that appear in the pre-lab assignment and as puzzle components throughout the breakout box.

Anatomy & Physiology Topics
Anatomical planes (e.g., coronal, sagittal, frontal)
Anatomical directions (e.g., medial, superior, superficial, …)
Identification of major bones
Identification of major muscles
Relating medical images to human anatomy
Cardiac anatomy (chambers, valves, major blood vessels)
Blood vessel structure and function
Major endocrine organs and their function
Identification of digestive system organs and their function
Identification of urinary system organs and their function
Identification of respiratory system organs and their function
Identification of major components of the central nervous system

Open-ended Response Analysis:

Responses in the post-lab assignment were analyzed from the prompt of a short reflective essay. Students were asked to reflect on "What aspects of the puzzle box did you enjoy? How is this different from what you have done in other courses to test your knowledge? Is there anything that you would have done differently?". The responses from the Fall '25 semester (n= 71) were collated and analyzed with Microsoft Copilot to identify themes. The spring semester responses were not analyzed because the essay prompt question was updated. Salient themes were then manually identified by the author and the frequency of those themes were tabulated to count the number of occurrences those specific themes in responses. These results were cross-referenced with the results from Copilot to help reduce bias and provide consistency. Responses were coded into the following 8 themes: engagement fun, competition/gamification, teamwork/collaboration, application/integration of knowledge, low stakes/stress reduction, game strategy/problem solving, preparation/review of materials, confidence/self-efficacy.

Results and Discussion:

<u>Summary of perceptions</u>

A majority of participants (90%, 107/119) agreed that the activity required them to think of multiple solutions and explore various possibilities (Figure 2). This is related to the ability of breakout box activities to stimulate divergent thinking. In a different study that used a virtual escape room for anatomy education, researchers also observed that participants were encouraged to think about the material in a new way [6]. In addition, the activity helped the participants metacognitively to identify knowledge gaps [6].

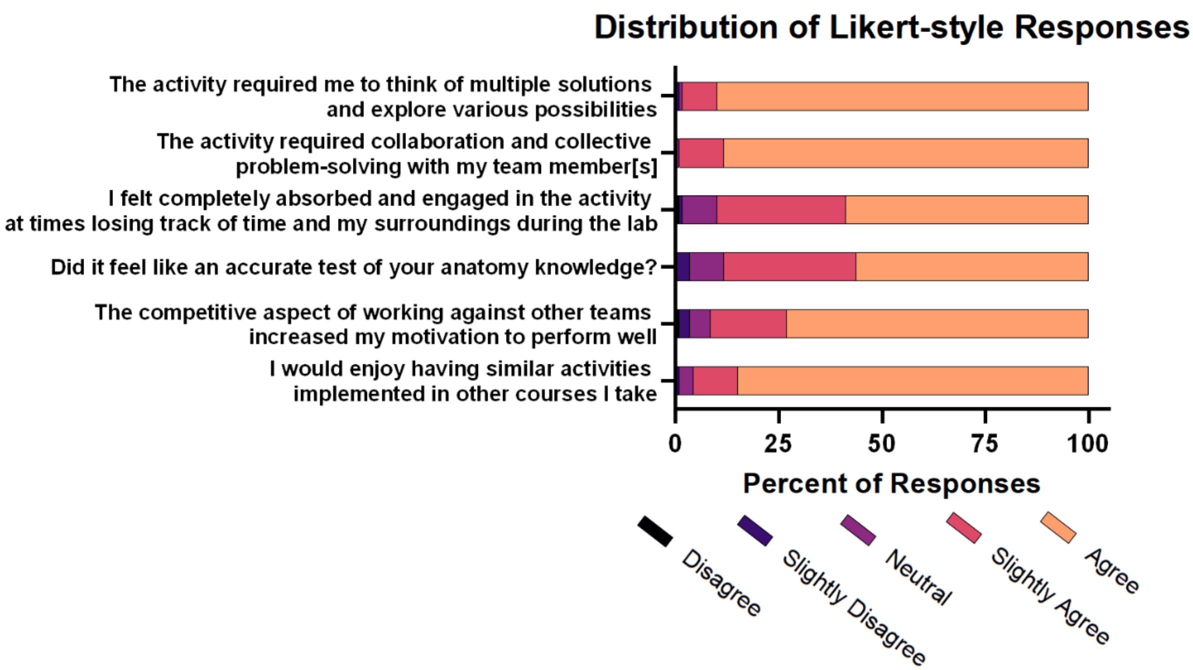

Figure 2: Student participant Likert-style responses to post-activity questions. Data show a distribution of 119 responses, from two semesters.

Similarly, students agreed that the activity promoted collaboration and collective problem solving with their teammates (88% selected agree, Figure 2). Students were in general agreement that they would like to see a similar activity in other courses that they take (Figure 2), which is consistent with the theme of enjoyment of the activity seen in open responses discussed below. The feeling of immersion and absorption in the activity was high for most respondents with 60% of students agreeing with the statement that they felt absorbed and engaged…at times losing track of time and their surroundings (Figure 2). This survey question was directed at the flow state, often associated with being immersed in a game that has the appropriate match of challenge with the players skill [16]. Flow can contribute motivation and has positive effects on learning [17]. Response rates showed that students felt that competition aspect of working against other teams contributed to their motivation (73% selected agree, Figure 2). Finally, the question related to whether the activity was an accurate test of their anatomy knowledge had the most diverse responses, with 56% of respondents selecting agree (Figure 2).

The majority of students showed an increase in Pre- to Post- confidence in anatomy and physiology topics:

Student responses (n=117) of their comfort levels with the topics listed in Table 1 showed overall increases in confidence for most students. 65% of respondents (76/117) had a net positive change in their responses. That is, students increased their rating of comfort level for 1 or more topics. Around 15% of participants (18/117) had a net negative change in their ratings, meaning they decreased their confidence in 1 or more topics. The remaining 20% had a net zero change, meaning they did not change their ratings, or they increased the same number of topics that they decreased.

Open-ended Responses indicate students were engaged, collaborative, and less stressed:

In open-ended responses, analyzed for themes, students consistently described the activity as fun, engaging, memorable, and creative. Many compared it favorably to other traditional lab checkouts or culminating activities in other courses. One student said, "*Its a completely different way to learn/test our knowledge, which was cool because it was the most engaged I had been with solving a problem this semester*." Another student said:

> "*I enjoyed how the puzzle box was interactive and felt like an escape room I'd pay to play. Although it assessed all the material we covered throughout the semester, it did not feel like an exam. It was nice to work with a team and my peers in a different manner than usual, doing truly collaborative work instead of just assigning different parts to different people. I enjoyed how this puzzle box combined material from both class and lab in a natural, more fun way.*"

According to theme coding, over 81% of respondents mentioned something like engagement or fun in their open-ended responses. This is consistent with instructor observations of active engagement of students throughout their time limit or until they fully solved the puzzle. On average, student groups that completed the puzzles spent about 44 minutes of their 1-hour time limit working on the puzzle box. There was an average of 16 ± 11 minutes of remaining times for groups that completed the box. The frequency of other themes beyond engagement/fun is reported in Table 2.

Table 2: Open-ended response themes, their frequency in responses, and example exerpts that link to those themes.

Theme	% of Responses	Example Quote Exerpt
engagement fun	81	*I enjoyed how the puzzle box was interactive and felt like an escape room I'd pay to play.*
application/integration of knowledge	80	*the puzzle box required me to merge concepts*
competition/gamification	57	*Working against other teams and against a clock motivated me to try my hardest.*
teamwork/collaboration	46	*Holes in my knowledge could be filled by my partner and vice versa.*
preparation/review of materials	43	*If I could go back and give myself advice...I would definitely tell myself to review the anatomical functions of organs in the brain*
game strategy/problem solving	29	*We should have used the hints early on instead of saving them.*
low stakes/stress reduction	21	*I think not having the stress of the testing environment helped bring out more knowledge than being panicked in an exam.*
confidence/self-efficacy	10	*It allowed me not to second guess myself and really show my knowledge.*

The difference between other traditional testing methods was also highlighted in many student responses. Students contrasted the breakout box with exams or quizzes, noting it demanded integration of anatomy knowledge, problem-solving, and reasoning under time pressure. One response said:

> *"This felt different from what I've done in other courses to test knowledge because it was more active and integrated. Rather than a quiz where you answer questions one by one, the puzzle box required me to merge concepts like anatomical directions, organ identification, and recall in real time. The competitive aspect also made me more focused and motivated to work efficiently."*

This assessment method emphasizes application and synthesis, not just recall, aligning with engineering-style thinking and problem-solving. About 80% (n=57) of respondents compared the puzzle box more favorably than traditional quizzes and exams, citing that it was more fun, engaging, less stressful, or generally better.

Related to comparing to exams, several students noted that it was a great way to test their knowledge without the anxiety of an exam. Students emphasized the stress difference versus a graded exam or quiz. They appreciated the 'try-and-iteratively-progress' experience of the puzzle box.

> "*I think adding some competition in the class made it environment fun and even similar to a final test for the anatomy class… I think not having the stress of the testing environment helped bring out more knowledge than being panicked in an exam.*"

Students also expanded on their enjoyment of competition and positive motivators of the puzzle box. Many students noted that the race against peers to compete was widely cited as energizing and focus-enhancing.

Their ability to work with other students was also equally important. Aspects of collaboration were apparent in many responses from students. Responses highlighted distributing tasks, combining strengths, and filling in gaps in knowledge for each other: "*My teammate came to some conclusions faster than me and vice versa. I think it really helped us think quicker on our feet."* The small groups of 2 or 3 students promoted peer instruction and social cohesion. One response said "*The puzzle box lab was a fun way to bond with team members… I enjoyed that we could pick our teams and the collective race as a class to get the password.".* This aligns with other work that showed that a over 80% of students reported a feeling of increased community in the classroom while complete a digital anatomy escape room [7].

Limitations & Future work:

While the anatomy breakout box demonstrated strong student engagement and positive perceptions related to collaboration, motivation, and confidence, several limitations should be considered when interpreting these findings. First, much of the evaluation relied on self-reported student reflections, which capture perceptions rather than objective measures of learning gains. Although these reflections provide valuable insight into metacognition, preparation strategies, and affective outcomes, they may be influenced by novelty effects or social desirability bias. Additionally, the activity was implemented within a single course context at one institution, which may limit broader generalizability. Finally, because the activity emphasized team-based problem solving, individual contributions and learning outcomes could not be disentangled, which may mask variation in individual preparation or mastery.

Future work could focus on strengthening the evidence base by incorporating mixed-methods and comparative designs. Planned studies could include pairing breakout box participation with pre/post measures of content knowledge, as well as examining longer-term retention relative to traditional assessments. An assessment such as this would allow interpretations beyond student perceptions and provide the ability to make conclusions about learning gains as a result of the breakout box as an intervention. Additional iterations could explore how explicit preparatory guidance (e.g., recommended study strategies or review prompts) influences performance, confidence, and equity of participation across teams. The flexibility of the breakout box format also enables future investigation into design variables such as puzzle sequencing, optional scaffolding, or role assignments, and how these choices impact collaboration and cognitive load.

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