Game-based learning in science: The use of an educational game in parasitology

Author: Christina Nykyforuk
Supervisors: Dr. Constance Finney and Dr. Mindi Summers

Table of Contents

Introduction

Parasitology is often viewed as a complex topic that is tricky for students to comprehend. Parasites have intricate lifecycles that are highly variable and difficult to represent (Menendez et al. 2020). Parasite lifecycles are often depicted using diagrams that are filled with highly technical terms and complicated life stages, making the concepts even less comprehensible (Raimondi 2016). Parasites are commonly viewed in a negative light, being associated with disease and as threats that need to be eradicated. Despite this, parasite education is critically important for creating an informed population that can recognize how parasites are diverse, impact their lives, and affect and interact with the world (Acka et al. 2010). Given that parasitology is a complex topic, this study aims to investigate how students' understanding and attitudes towards parasites change after playing an educational game.

Currently, there are relatively few studies investigating the perspectives and attitudes of students using game-based learning in undergraduate biology (Spiegel et al. 2009). Additionally, there is a lack of research regarding the impact of educational games on students' learning outcomes and knowledge attainment (Qian & Clark 2016). There is a clear need for more literature and studies that utilize standardized evaluation methods, such as pre and post-game assessments, to systematically analyze the impacts of educational games on students (Brown et al. 2018). In particular, studies using game-based learning in parasitology are scarce. As a result, we do not know the opinions of undergraduates in upper-level zoology courses regarding game-based learning in parasitology.

It is established that people enjoy playing games. Given the positive outcomes of game-based learning for teaching other complex topics in biology, we would like to investigate the impacts of an educational game in parasitology. There has yet to be a study focusing on the strategic development of an educational game for teaching parasitology to undergraduates in this context at the University of Calgary. The creation and implementation of a strategically designed educational game, *Parasite Patrol,* will be explored in two upper-level undergraduate courses at the University of Calgary, and students will be surveyed before and after playing the game.

We hope to gain insight into how game-based learning can impact students' understanding and attitudes towards parasites and their lifecycles. Is game-based learning capable of increasing students' understanding of concepts in parasitology? Can playing an educational game improve students' attitudes when learning about parasites? What are students' opinions of using an educational game to learn about parasitology? We are hopeful that game-based learning will positively impact student learning of this complex topic.

Games as learning tools

Active learning enhances the student experience by increasing engagement and participation in course material compared to traditional, less engaging methods, such as passive lectures (McGreevy & Church 2020). One technique for implementing active learning into education in order to enrich the learning experience is through the use of well-designed games. Due to their highly interactive nature, games are ideal active learning tools (Malone 1980). Games promote voluntary participation and engagement in course content, which is particularly advantageous for teaching complex topics (Perrotta et al. 2013).

The gaming industry is vast, as games can be applied to nearly any topic or discipline. Not only do games enhance many people's daily lives, but they also manage to maintain the devotion of billions of players worldwide every year, and the industry is still on the rise (Hamari & Keronen 2017). For example, the best-selling game in the world, *Minecraft*, entices over 126 million players every month (Clement 2021). Clearly, games can be very enjoyable and successful tools for obtaining people's interest. Therefore this makes games an attractive and promising educational device for improving students' experiences concerning complex course material, like parasitology. The use of games as an educational tool is a universal and ancient technique, dating back to 3500 B.C., and various game-based strategies have subsequently been utilized in a wide range of other settings (Anyanwu 2013).

There are multiple strategies for incorporating games into different learning contexts and settings (Figure 1). One of these strategies is through the use of gamification in teaching. Gamification is the process of applying video game elements to learning contexts, in order to promote motivation and engagement towards a subject matter (Fatta et al. 2019). Gamification does not involve the creation or use of complete games, rather it only focuses on certain game elements like points, badges, and leaderboards. Another game-based strategy that can be applied to learning contexts is the use of serious games. Serious games differ from gamification in that they have a primary learning goal built into a complete, fully-fledged game, and have educational purposes other than pure entertainment (Fatta et al. 2019). A division of serious games are known as educational games, which as a learning technique are referred to as game-based learning. Game-based learning utilizes a complete, fully-fledged game to teach learning outcomes through game-play, while simultaneously creating a fun, engaging, and enriching experience. An educational game aims to enhance knowledge through game-play and embedded educational content, and involves challenges that players must overcome in order to obtain a win-state (Qian & Clark 2016). Educational games can be a one-time activity in the classroom, or played multiple times throughout a course to supplement material taught in lectures (Fatta et al. 2019).
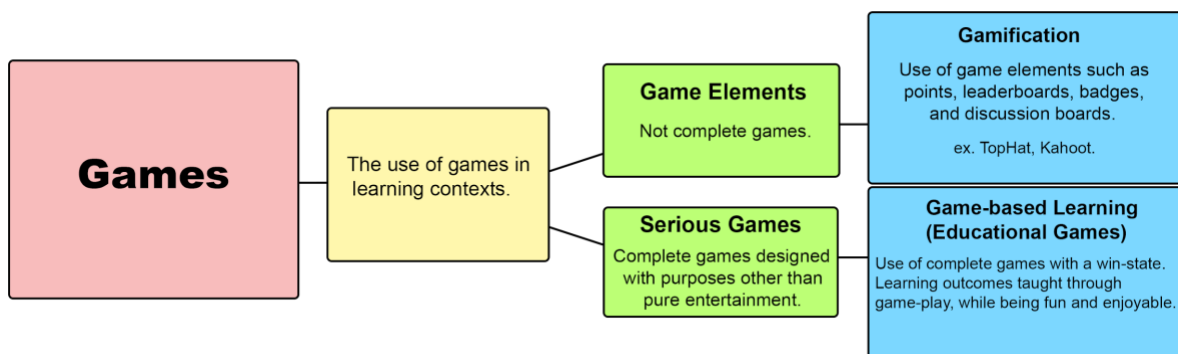
Figure 1. The position of educational games within the realm of games that are used in learning contexts (based on Fatta et al. 2019).

Educational games are diverse, having been applied to various disciplines such as biology, business, math, computer science, and psychology (Qian & Clark 2016). Educational games can take several forms including card games, role-playing games, board games, and video games. They may be digital or non-digital. Due to their intrinsically motivating nature, these games have been used in a variety of undergraduate settings to heighten student engagement, interest, and participation regarding complex topics in undergraduate biology. Some of these topics include entomology, animal diagnostic imaging, host defence, immunology, neurology, and genetics (Cosme et al. 2020; Pinhatti et al. 2019; Steinman & Blastos 2002; Raimondi 2016; Garcin et al. 2019; Annetta et al. 2009). These gaming

interventions have resulted in a combination of positive outcomes regarding student performance on assessments, knowledge retention, enjoyment, interest in the subject matter, and attitudes towards game-based learning as a teaching method. Therefore, in supplement to traditional teaching methods, well-designed games can be effective tools for enhancing student understanding, attitudes, and enjoyment towards complex topics (Liu & Chen 2013).

Game Design Criteria

Creating a game that is both engaging and educational requires the consultation of the theory and literature throughout the design process (Qian & Clark 2016). Well-designed educational games can incorporate a combination of compositional elements to increase player interest, including challenge, fantasy, curiosity and an overall attractive game design (Malone 1980). Challenge is working towards a clear goal with uncertain outcomes such as winning the game, and can be enhanced with randomness (Malone 1980). Fantasy is assuming the role of a character, which adds emotional appeal to the game to make it more interesting (Malone 1980). Fantasy also allows educational content to be embedded in an entertaining context, in order to strike a balance between fun and learning. Curiosity is the desire to learn something new and can be instigated by having rich visuals, surprising information, and content that is at an appropriate complexity level with minimized jargon (Malone 1980). Attractive design can include the effective use of visuals and colours to draw attention to important concepts (Dzulkifli & Mustafar, 2013).

Methods

A previous version of a parasite outreach game, *Pin the Parasite,* that was developed by the Host-Parasite Interactions group at the University of Calgary was revised. The literature was reviewed to determine important game design elements for enhancing the student learning experience, and changes were implemented to create an improved version of the game: *Parasite Patrol*.

Parasite Patrol was drawn digitally in Adobe Photoshop, and initially hosted online using Google Jamboard and Zoom Video Conferencing. After piloting a preliminary version of the game with the Host-Parasite Interactions group and receiving feedback from parasitologists and science communication experts, the final version was hosted using an online platform called Conceptboard instead of Google Jamboard.

Overview of *Parasite Patrol*

Parasite Patrol consists of several sections, including a control panel, game mission statement, host cards, gameboard, clue cards, and detective badges (Figure 2). The goal of the game is for students to role-play parasite detectives, who have been summoned to investigate one of three parasite-infected hosts with their investigation team: a human, cow, or dog host (Figure 3a-c). Each host is infected with five parasites. Players must find all of the parasite clues for their host in the form of a matching memory game with the clue cards. Using the information on the cards, they must piece together all five of the parasite lifecycles. The first team to correctly pin all of the parasite lifecycles onto their host wins the #1 parasite detective badge.
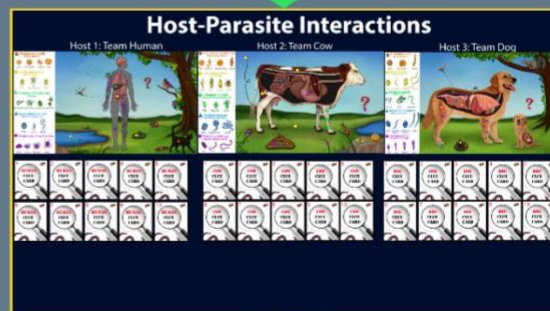
a) Game controls.

b) Game mission statement.

c) Host cards.

d) Gameboard with clue cards.

e) 1st, 2nd, and 3rd place parasite detective badges.

Figure 2. The different sections of *Parasite Patrol*, including **(a)** the game controls, **(b)** mission statement, **(c)** host cards, **(d)** gameboard with clue cards, **(e)** and parasite badges.

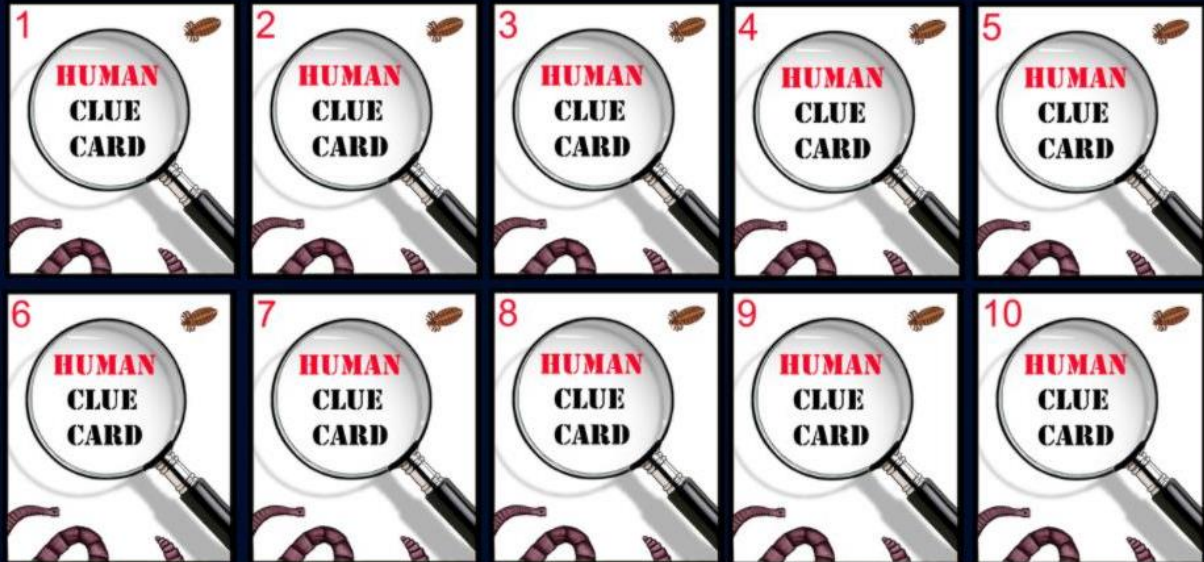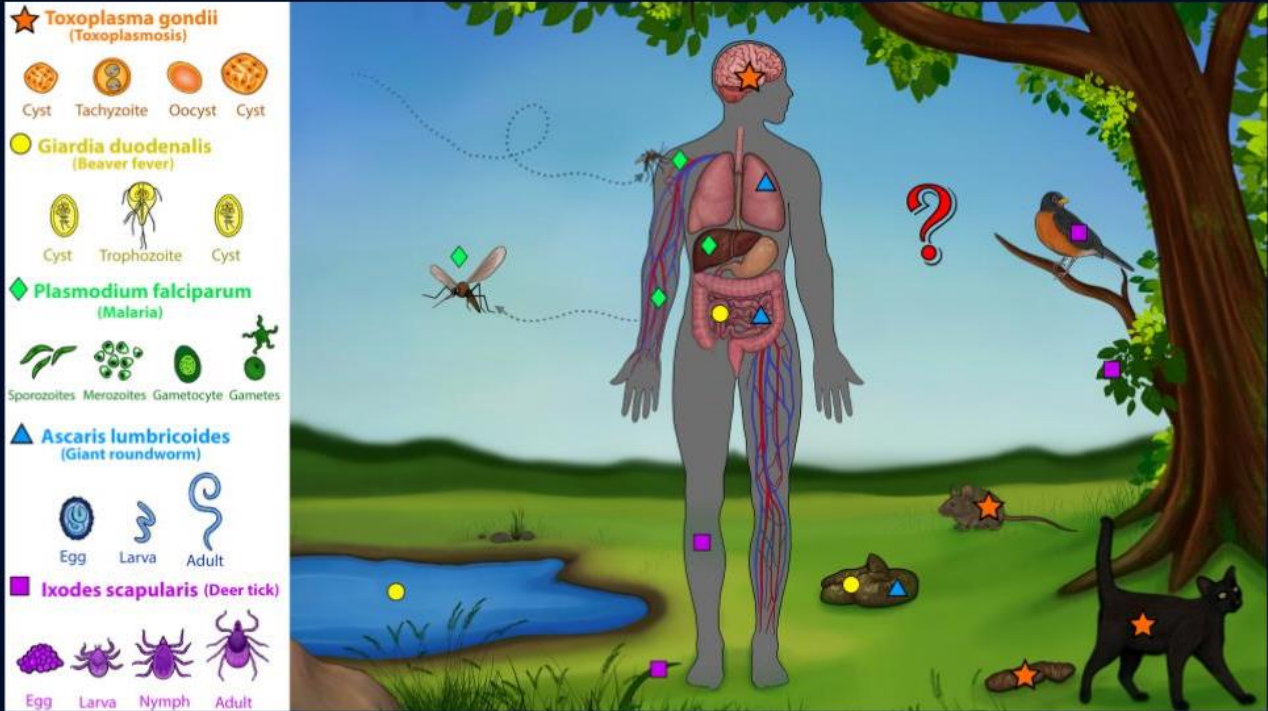**Figure 3a.** The human host in *Parasite Patrol,* infected with five parasites: *Toxoplasma gondii, Giardia duodenalis, Plasmodium falciparum, Ascaris lumbricoides,* and *Ixodes scapularis.*
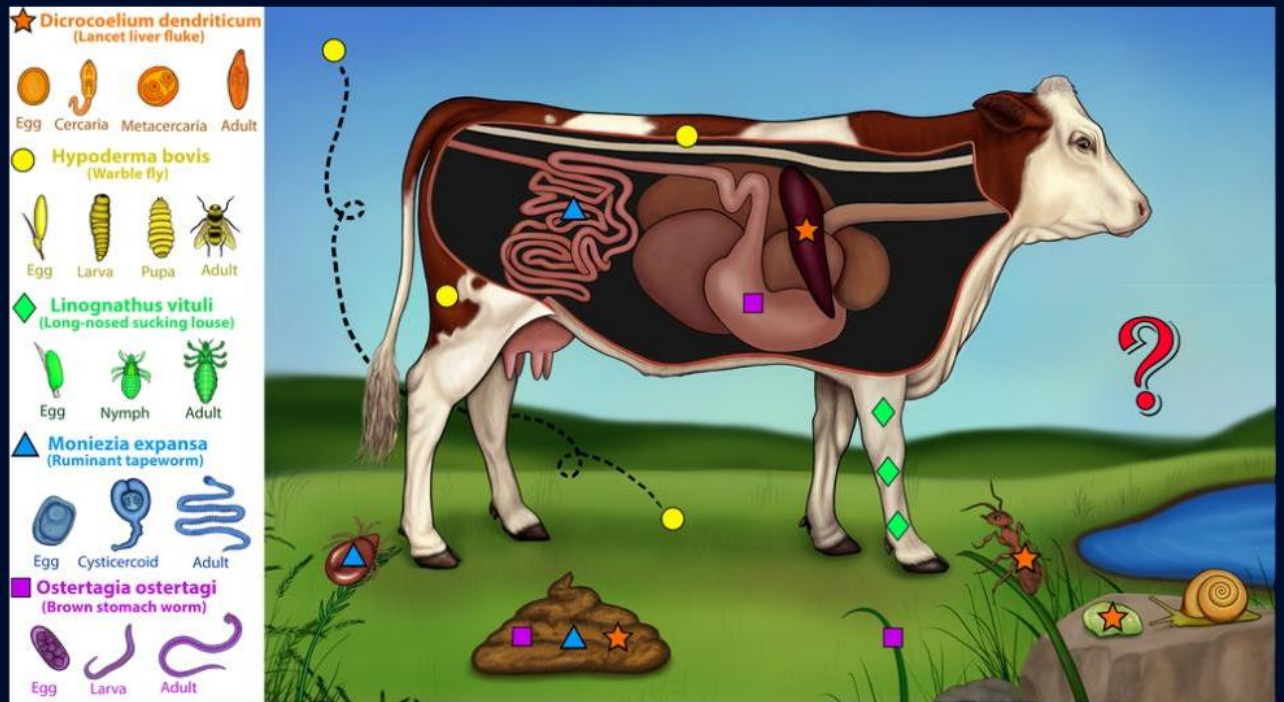
Figure 3b. The cow host in *Parasite Patrol,* infected with five parasites: *Dicrocoelium dendriticum, Hypoderma bovis, Linognathus vituli, Moniezia expansa,* and *Ostertagia ostertagi.*

Figure 3c. The dog host in *Parasite Patrol,* infected with five parasites: *Echinococcus multilocularis, Toxocara canis, Dirofilaria immitis, Ancylostoma caninum,* and *Demodex canis.*

How to Play

      Parasite Patrol can accommodate a range of players. However, the ideal set-up is six players, with students divided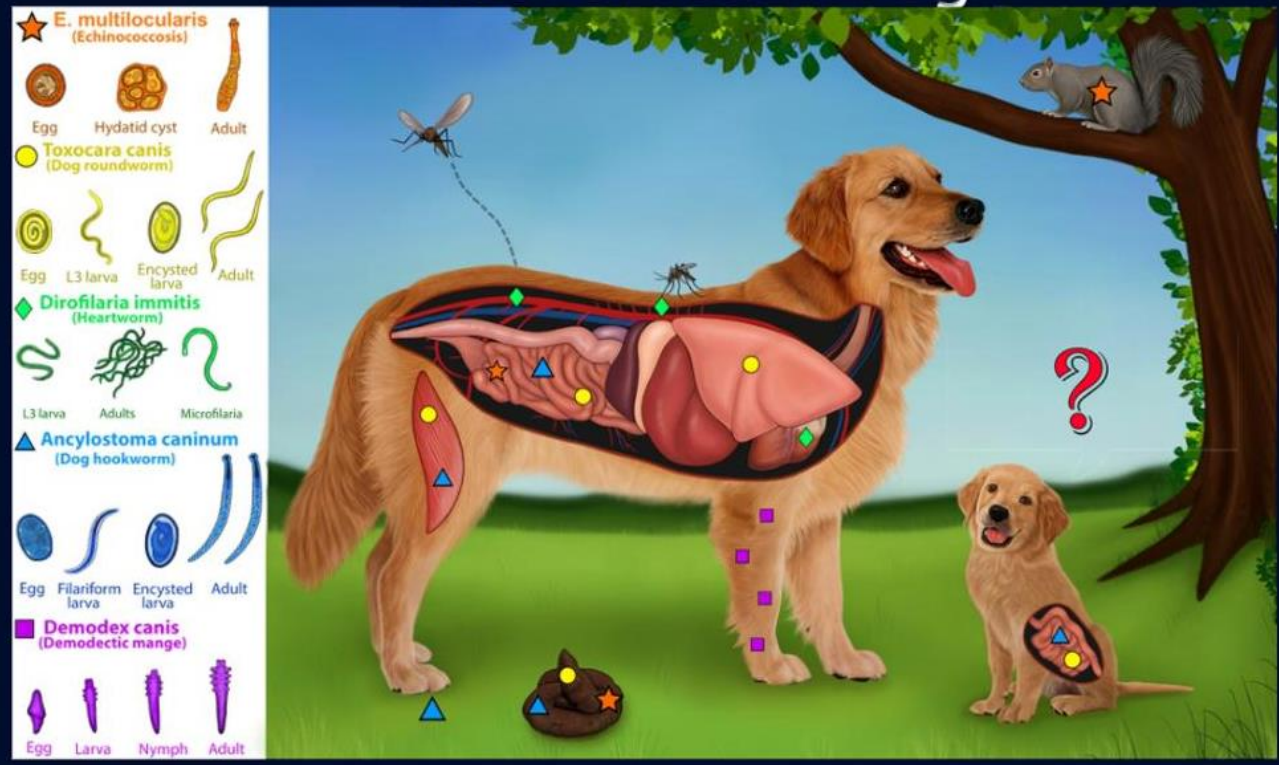 into three teams of two. Once students are divided into three teams, the game starts by having each team flip over one host card (Figure 4). The host card that each team flips over reveals the host that they are assigned to investigate during the game (human, cow, or dog host). After establishing which host each team will be investigating, team human goes first, followed by team cow and team dog. To begin, team human must flip over two of their human clue cards, with the goal of finding the matching cards. Each clue card contains information about the parasite species infecting that host (Figure 5). If a match is not found, the students must flip the two cards back over and pass the turn to the next host's team, team cow. However, if they do find a match, students read the information on the matching clue cards out loud. Using these clues, the players must "pin" the parasite life stages onto the human host by dragging the parasite pieces onto the correct locations (Figure 6). The turn is then passed to the next team, and the same process continues. While playing, each team has the opportunity to find one super clue hidden among their clue cards, signified by a red question mark, and reveal it on the gameboard (Figure 6). Super clues contain additional pieces of information about parasites and their lifecycles. All three teams must finish finding their matching clue cards and correctly pinning all five parasite lifecycles onto their host. The team that is the first to complete this mission wins the #1 parasite detective badge.

Figure 4. **(a)** The host cards before being flipped over. **(b)** The host cards after being flipped over. The card that each team flips over is the host they are assigned to investigate during the game.

a) Clue cards.
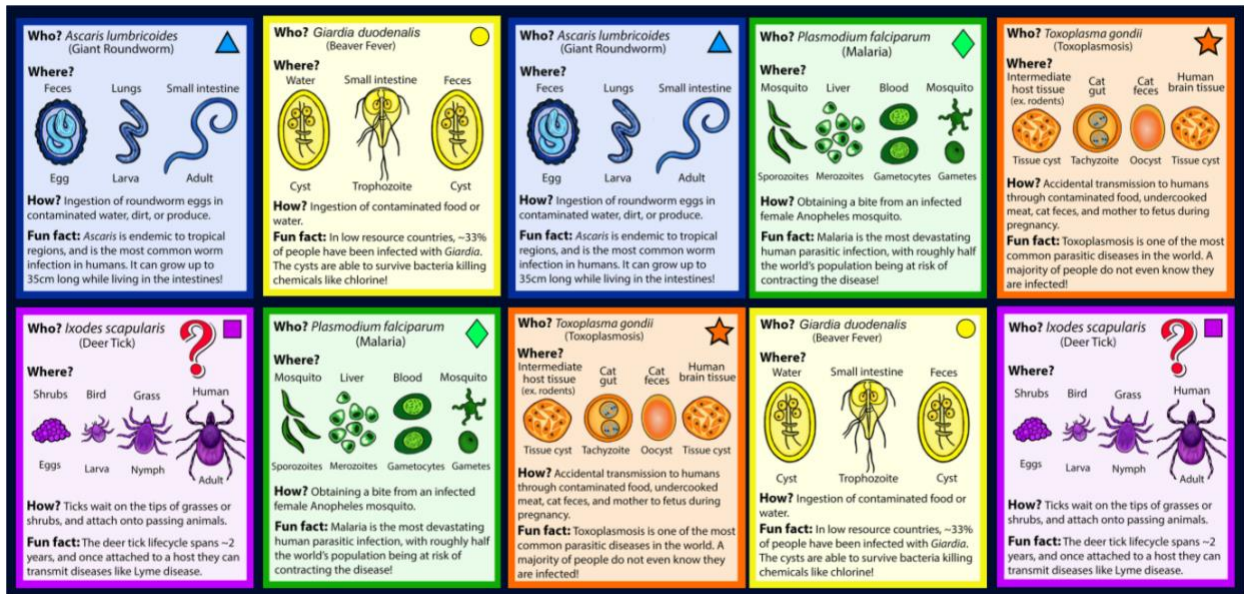
b) Close-up of clue card.
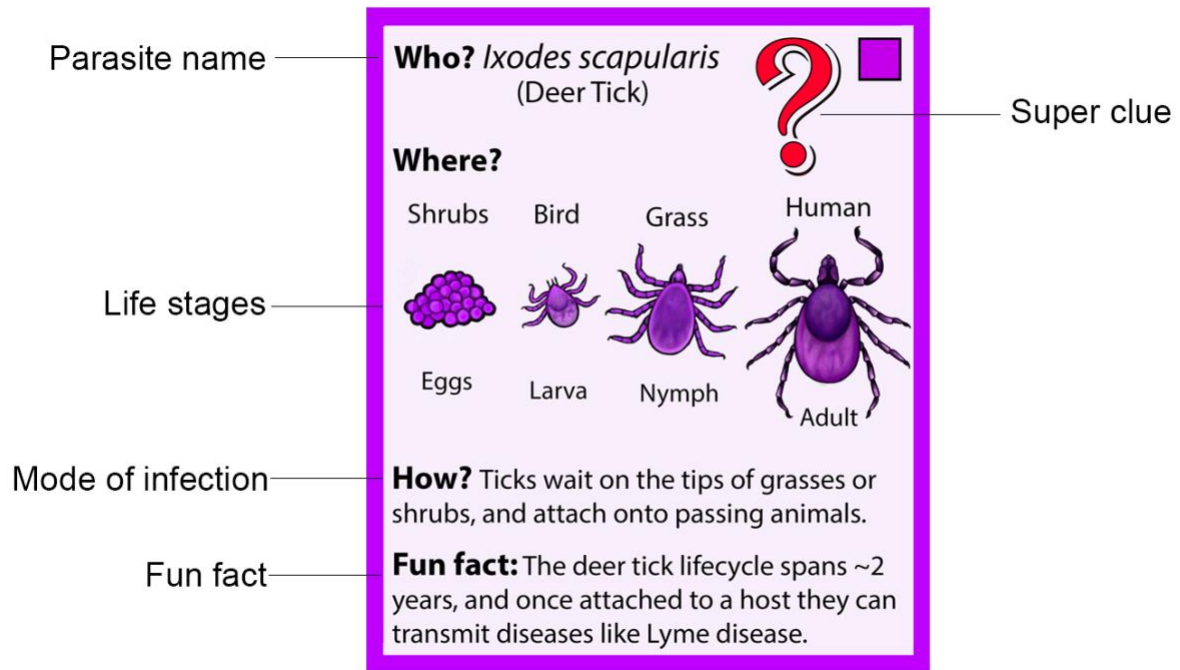
Figure 5. (a) All of the clue cards for the human host after being flipped over. **(b)** Close-up of the *Ixodes scapularis* clue card, showing the information that is provided for each parasite including the name, life stages, mode of infection, and a fun fact. This card also contains a super clue.

Figure 6. The human host, where all of the matching clue cards have been found, the parasite life stages have been pinned onto their correct locations, and the super clue has been uncovered.

Design Elements

     Parasite Patrol was strategically designed in order to create an immersive learning experience. The game includes a combination of compositional elements with the aim of increasing player engagement and understanding of the material. Based on the Malone (1980) heuristics for educational game design, *Parasite Patrol* incorporates challenge, fantasy, and curiosity elements into the game design (Table 1).

Table 1. Malone (1980) criteria for designing educational games, including challenge, fantasy, and curiosity, and their implementation into *Parasite Patrol*.

Design Element (Malone 1980)	Why?	How?
Challenge	Presenting players with challenges to overcome in the form of clear and attainable goals can increase intrinsic motivation to participate in an activity, and make learning concepts more enjoyable (Malone 1980).	Challenge is included in the form of a clear goal with an uncertain outcome, such as being the first team to win and obtain the #1 parasite detective badge. This challenge is enhanced with randomness by having a matching memory card aspect to the game. Students are tasked with finding the matching pairs of clue cards for their host, which contain information about their host's parasites. When students find a match, they read the parasite information on the cards and are challenged with using the clues to correctly pin the parasite life stages onto their host.
Fantasy	Fantasy is incorporated as a design element to help stimulate the students, reinforce the educational material, and strike a balance between fun and learning. The utilization of even minimal fantasy elements has been shown to greatly increase the motivation of students during educational activities, making the learning process more enjoyable and interesting (Parker & Lepper 1992).	Fantasy is embedded in the form of a role-playing element, whereby students act as parasite detectives who are summoned to investigate several parasite-infected hosts. As detectives, students must find and use the parasite clues to piece together the various lifecycles for their host. Additionally, the game ends with each team winning either a 1st, 2nd, or 3rd place detective badge, further enhancing this fantasy component. The visual design of the game and game pieces also supplements the fantasy element, including the use of parasite crime scene tape, detective badges, and clue cards organized in a criminal record type format (Figure 5).
Curiosity	Curiosity increases players' desire to learn something new and "fill in" the gaps in their pre-existing knowledge (Malone 1980).	Cognitive curiosity is promoted through the inclusion of surprising and interesting information, taking the form of fun facts on the clue cards and super clues on the game board. The parasite species included in the game were selected to showcase a diverse range of lifestyles, aiming to make the content more interesting and increase participants' desire to learn something new. To foster a desire of filling in the gaps in the players pre-existing knowledge, the game encompasses

		both familiar and unfamiliar parasites, with some species that are local and relevant to the province of Alberta. The lifecycles are simplified in order to avoid discouraging or deterring students from engaging with the activity. Sensory curiosity is enhanced through having rich visuals and colours, in order to draw attention to important concepts and further enhance the fantasy element of the game.

A card game component is included as part of *Parasite Patrol*, since card games are particularly useful for enhancing student learning (Su et al. 2014). Card games foster collaboration among teammates, yet competition against opponents. Cards also enable the seamless integration of educational content into the game. Players willingly read the educational content on the cards as they play and progress towards winning the game. Therefore *Parasite Patrol* includes a matching memory card game with the clue cards. Inspired by Spiegel et al. (2009), the clue cards are used to encourage students to voluntarily explore the educational content while playing the game, with each set of matching cards acting as a challenge. The clue cards contain information about the parasites, which students must learn in order to correctly pin the parasite lifecycles onto their host and win the game. This information includes the names of the parasites (common and scientific), life stages, methods of infection, and a fun fact (Figure 5).

Three hosts were chosen to be the main focus of the game: a human, cow, and dog. The hosts were selected due to their relevance, ability to showcase parasite diversity, and impacts on human and animal health. When representing lifecycles, perceptual richness with colour and details is beneficial, particularly if the details are relevant (Menendez et al. 2020). Therefore when drawing the human, cow, and dog hosts, details in the visuals were emphasized in the most relevant areas. These areas include the definitive and intermediate hosts, target organs, and aspects of the environment that were pertinent to the parasite lifecycles. As recommended by Menendez et al. (2020), excess background details were avoided and kept relatively simple, in order to avoid detracting from the lifecycles and hindering student learning.

The creation and use of visuals and colours was a significant portion of the game design. The use of colours and colour coding in the game, such as on the clue cards, parasites, and hosts, was inspired by Cosme et al (2020). This allows players to visualize the lifecycles for each parasite, and to easily identify the connections between the game components like the parasites, the parasite locations on the host, and the clue cards. The colour schemes for each parasite were specifically chosen to be contrasting and stand out among the background. Aside from colour, corresponding shapes were also utilized to connect the parasites, parasite locations on the hosts, and clue cards, in order to accommodate colour blind individuals (Figure 6).

Implementation in the classroom

To assess the effectiveness of *Parasite Patrol* in the classroom, the game was played by undergraduate students in two upper-level zoology courses at the University of Calgary. These include An Introduction to Invertebrate Zoology course (ZOOL 401), and a Principles in Parasitism course (ZOOL 581). The gaming intervention was a one-time activity, which took place during the weekly lab session. Instruction was conducted remotely through Zoom

Video Conferencing. Prior to participating, all students were made aware of the ethics and their right to provide or not provide consent towards the use of their data.

ZOOL 401

Students in An Introduction to Invertebrate Zoology (ZOOL 401) had been introduced to the basics of parasitology. A total of 112 students participated, comprising six lab sections. The game was one of several activities completed during their weekly lab, which also included the reading of a parasite storybook, *Nick the Tick,* and an optional book club activity. A detailed breakdown of the activities completed is available in Table 2. In lab sessions 1, 3, and 6, students were assigned to play *Parasite Patrol* as their first laboratory activity (Table 2). In lab sessions 2, 4, and 5, students completed *Nick the Tick* as their first activity (Table 2).

Each lab session was divided into multiple groups of students. Before playing *Parasite Patrol*, a brief introduction was given to familiarize students with the rules and how to play. The game instructions were also provided in a written format on the students' laboratory exercise sheets for that week. Prior to starting the game, students completed a pre-game survey regarding their parasite knowledge, attitudes towards parasites, and attitudes towards educational games. After completion of the pre-survey, students were sent into their Zoom breakout rooms with their groups to play the game. Moderators were available to enter breakout rooms when necessary, to answer students' questions and to ensure that the activities were running smoothly. After playing, students completed a post-game survey before moving on to the next activity. The post-game survey was the same as the pre-game survey, but contained additional questions that were specific to their experience playing *Parasite patrol.* A detailed outline of the time that each activity took is available in Table 2.

To help the students solidify their knowledge, they were initially instructed to record how each of the parasite species they encountered in *Parasite Patrol* differed from one another, and to draw the lifecycle for the parasite that they were the least familiar with before playing the game. Additionally, students were also asked to take some time to reflect upon parasite diversity, parasite lifecycles, changes in their views towards parasites, their experience playing the game, and to be prepared to discuss these thoughts with a teaching assistant and their fellow group members. However, since the game-play of *Parasite Patrol* required more time than anticipated, the students were no longer required to complete these additional activities.

ZOOL 581

Students in Principles in Parasitism (ZOOL 581) had been learning about parasites and their lifecycles throughout the semester, and thus had a more in-depth knowledge of parasitology. A total of 23 undergraduate students in one lab session participated in playing the game. Students were divided into groups as evenly as possible, and half of the lab was assigned to play *Parasite Patrol* as their first laboratory activity. The other half of the lab was assigned to read *Nick the Tick* first. After completion of their first assigned activity, the groups swapped activities.

A brief introduction to the game was given by the professor and teaching assistants, and the students were provided with an instructional video that outlined how to play the game (https://www.youtube.com/watch?v=-J1Md4Q198s feature=youtu.be). Before sending students into their Zoom breakout rooms, they completed a pre-survey regarding their

parasite knowledge, attitudes towards parasites, and attitudes towards educational games. Moderators were available to monitor the game-play and to answer any questions. After playing the game, students completed a post-survey before moving on to the next activity. The post-survey was the same as the pre-game survey, but contained additional questions regarding their experience playing *Parasite Patrol*.

Table 2. Time-table for the laboratory activities performed by students in ZOOL 401 (n=112) across six laboratory sessions. A breakdown of the laboratory activities is provided, as well as the time (minutes) it took to complete each activity.

ZOOL 401 Lab Session	Activity Description	Time
Lab session 1: -game first, n=19 -23rd February, 2021 -9:00am-11:50am	-Introduction to the lab. -Pre-survey. -Description of *Parasite Patrol* and demonstration. -Play *Parasite Patrol*. -Game post-survey. -Half of the lab reads *Nick the tick* first, other half participates in Activity 3 (book club) -Introduction to *Nick the tick*. -Read book. -Book post-survey. -Groups swap: Book club group now reads *Nick the tick*. -Introduction to *Nick the tick*. -Read book. -Book post-survey.	~8 minutes ~10 minutes ~10 minutes ~35 minutes ~12 minutes ~4 minutes ~20 minutes ~13 minutes ~1 minute ~22 minutes ~8 minutes
Lab session 2: -book first, n=21 -23rd February, 2021 -12:00pm-2:50pm	-Introduction to the lab and pre-survey. -Introduction to *Nick the tick*. -Read book. -Book post-survey. -Half of the lab plays *Parasite Patrol* first, other half participates in Activity 3 (book club) -Description of *Parasite Patrol* and demonstration. -Play *Parasite Patrol*. -Game post-survey. -Groups swap: Book club group now plays *Parasite Patrol*. -Description of *Parasite Patrol* and demonstration. -Play *Parasite Patrol*. -Game post-survey.	~11 minutes ~2 minutes ~30 minutes ~10 minutes ~8 minutes ~52 minutes ~10 minutes ~7 minutes ~25 minutes ~8 minutes
Lab session 3: -game first, n=20 -23rd February, 2021 3:00pm-5:50pm	-Introduction to the lab and pre-survey. -Description of *Parasite Patrol* and demonstration. -Play *Parasite Patrol*. -Game post-survey. -Half of the lab reads *Nick the tick* first, other half participates in Activity 3 (book club) -Introduction to *Nick the tick*. -Read book. -Book post-survey. -Groups swap: Book club group now reads *Nick the tick*. -Introduction to *Nick the tick*. -Read book. -Book post-survey.	~14 minutes ~8 minutes ~33 minutes ~9 minutes ~2 minutes ~43 minutes ~14 minutes ~2 minutes ~41 minutes ~10 minutes
Lab session 4: -book first, n=24 -25th February, 2021 -9:00am-11:50am	-Introduction to the lab and pre-survey. -Introduction to *Nick the tick*. -Read book. -Book post-survey.	~10 minutes ~2 minutes ~32 minutes ~10 minutes

	-Half of the lab plays *Parasite Patrol* first, other half participates in Activity 3 (book club)	
	-Description of *Parasite Patrol* and demonstration.	~7 minutes
	-Play *Parasite Patrol*.	~37 minutes
	-Game post-survey.	~10 minutes
	-Groups swap: Book club group now plays *Parasite Patrol*.	
	-Description of *Parasite Patrol* and demonstration.	~8 minutes
	-Play *Parasite Patrol*.	~25 minutes
	-Game post-survey.	~10 minutes
Lab session 5: -book first, n=21 -25th February, 2021 -12:00pm-2:50pm	-Introduction to the lab and pre-survey.	~15 minutes
	-Introduction to *Nick the tick*.	~2 minutes
	-Read book.	~29 minutes
	-Book post-survey.	~14 minutes
	-Half of the lab plays *Parasite Patrol* first, other half participates in Activity 3 (book club)	
	-Description of *Parasite Patrol* and demonstration.	~7 minutes
	-Play *Parasite Patrol*.	~35 minutes
	-Game post-survey.	~12 minutes
	-Groups swap: Book club group now plays *Parasite Patrol*.	
	-Description of *Parasite Patrol* and demonstration.	~7 minutes
	-Play *Parasite Patrol*.	~33 minutes
	-Game post-survey.	~9 minutes
Lab session 6: -game first, n=7 -25th February, 2021 -3:00pm-5:50pm	-Introduction to the lab and pre-survey.	~15 minutes
	-Description of *Parasite Patrol* and demonstration.	~9 minutes
	-Play *Parasite Patrol*.	~25 minutes
	-Game post-survey.	~10 minutes
	-Introduction to *Nick the tick*.	~4 minutes
	-Read book.	~31 minutes
	-Book post-survey.	~10 minutes

Evaluation of the Game

     Parasite Patrol was used to investigate the impact of game-based learning on students' understanding of basic parasitology concepts, attitudes towards parasites, and attitudes towards educational games. To test the effectiveness of *Parasite Patrol*, a pre-survey and post-survey experimental design was utilized, as recommended by Brown et al (2018). The surveys were created and distributed electronically using Google Forms. The survey consisted of several sections with open and closed questions. The first section of the survey focused on assessing students' knowledge and attitudes of parasites and their lifecycles. The second section of the survey aimed to capture students' attitudes towards *Parasite Patrol* and educational games. After survey responses were de-identified, changes between the pre-survey and post-survey were analyzed and descriptive statistics were performed. All of the data that was analyzed was obtained with the express consent of the participants. 96 students in ZOOL 401 and 18 students in ZOOL 581 consented to the use of their data for this study.

     Data from students who completed *Parasite Patrol* as their first laboratory activity (ZOOL 401 n=43, ZOOL 581 n=10) was used for survey questions where the prior completion of *Nick the Tick* before playing the game would confound their responses. Combined data from students who completed *Parasite Patrol* or *Nick the Tick* as their first laboratory activity (ZOOL 401 n=96, ZOOL 581 n=18) was used for survey questions where the prior completion of other laboratory activities would not confound their responses.

Results

Student Context

Students in the course An Introduction to Invertebrate Zoology (ZOOL 401) had been studying invertebrates throughout the semester. As part of studying invertebrate diversity and ecology, students received a brief introduction to parasites and their lifecycles. Students in the course Principles in Parasitism (ZOOL 581) had been specifically studying parasitology throughout the semester, including a diverse range of parasites and their lifecycles, and therefore had a more in-depth knowledge of parasitology.

Students in ZOOL 401 and ZOOL 581 were asked several pre-survey questions regarding their prior experience with educational games.

ZOOL 401

In ZOOL 401 (n=96), 93.7% of students (n=90) indicated that they had played an educational game before. When students were asked to identify the settings in which they had played educational games, a majority of students had played games in a school setting, including kindergarten (n=44), middle school (n=53), junior high (n=71), high school (n=82), and university (n=72). Fewer students had played educational games outside of school (n=37) and at work (n=16). Students were also asked to identify the types of games they had previously played. A majority of the students had experience with gamification in the form of TopHat (n=93), Kahoot (n=77), and game-based learning in the form of Jeopardy (n=72). Fewer students had experience playing role-playing games (n=35), science card games (n=19), science board games (n=15), scientific video games (n=15), and other (n=4).

ZOOL 581

In ZOOL 581 (n=18), 94.4% of students (n=17) indicated that they had played an educational game before. When students were asked to identify the settings in which they had played educational games, a majority of students had played games in a school setting, including kindergarten (n=14), middle school (n=14), junior high (n=17), high school (n=18), and university (n=15). Fewer students had played educational games outside of school (n=9) and at work (n=4). Students were also asked to identify the types of games they had previously played. A majority of the students had experience with gamification in the form of TopHat (n=18), Kahoot (n=18), and game-based learning in the form of Jeopardy (n=16). Fewer students had experience playing role-playing games (n=6), science card games (n=5), science board games (n=5), scientific video games (n=4), and other (n=4).

Parasite Knowledge

Students responded to questions on the pre-survey and post-survey that assessed their knowledge and understanding of parasites and their lifecycles. First, students were prompted to name as many parasites as possible, to see if their knowledge increased after playing *Parasite Patrol.*

Q1. Name as many parasites as you can (in ~30 seconds).

ZOOL 401 (Figure 7a and 7b)

After playing *Parasite Patrol*, the average number of parasites listed by ZOOL 401 (n=43) students increased by 1.4 parasites, going from 3.8 on the pre-survey to 5.2 on the post-survey. Overall, students were also able to name more parasite species that were specific to *Parasite Patrol* after playing the game. The percentage of parasites named by students that were specific to *Parasite Patrol* increased by 33.5%, going from 10.5% on the pre-survey to 44% on the post-survey.

ZOOL 581 (Figure 7c and 7d)

After playing *Parasite Patrol*, the average number of parasites listed by ZOOL 581 (n=10) students decreased by 0.3 parasites, going from 6.0 on the pre-survey to 5.7 on the post-survey. Overall, students were able to name more parasite species that were specific to *Parasite Patrol* after playing the game. The percentage of parasites named by students that were specific to *Parasite Patrol* increased by 24.1%, going from 25% on the pre-survey to 49.1% on the post-survey.
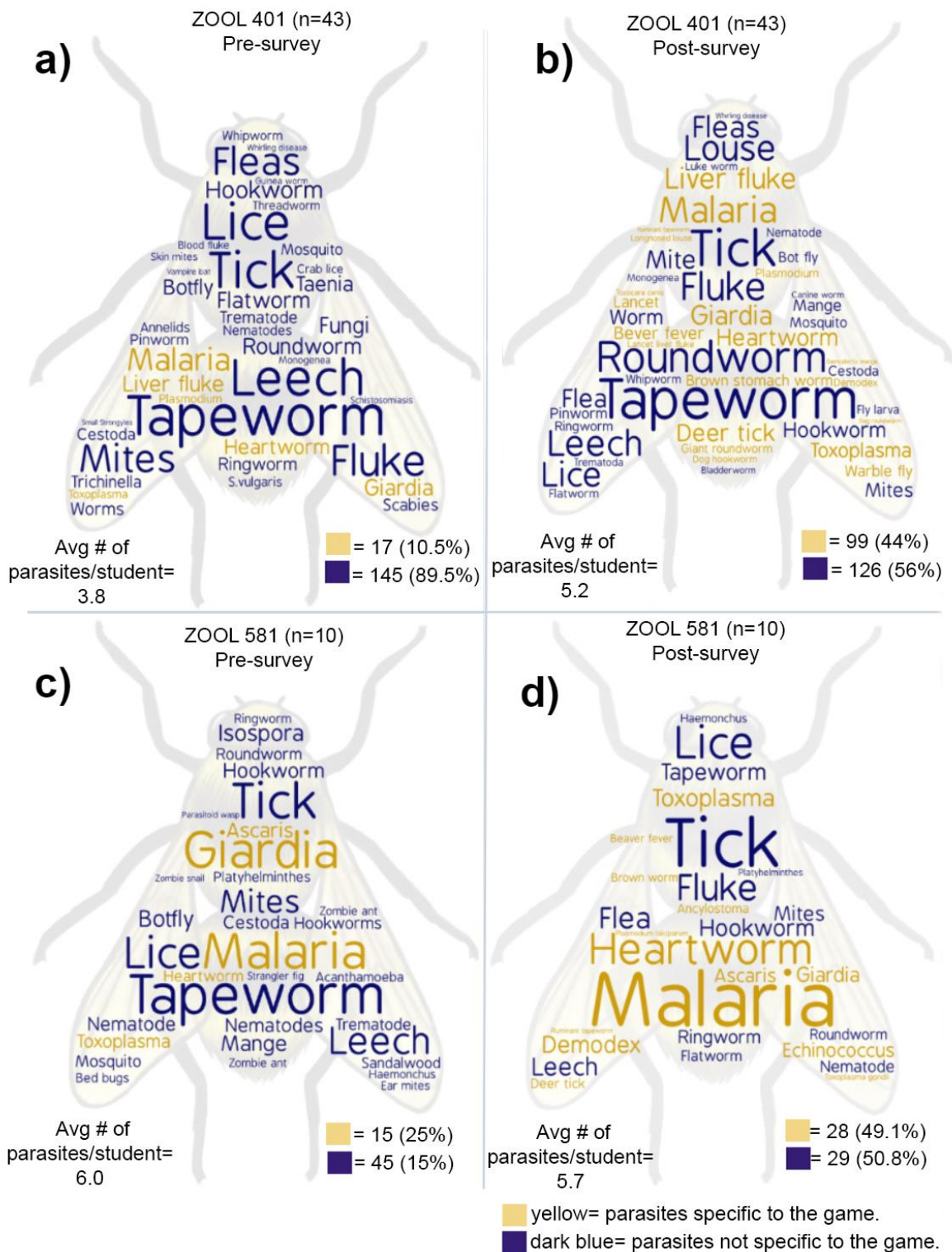
Figure 7. Wordles created using students survey responses when asked to name as many parasites as possible in ~30 seconds. Dark blue words indicate parasite species that were not specific to the game. Yellow words indicate parasites that were specific to the game. The size of the words represents the frequency of the responses. **(a)** Pre-survey responses for ZOOL 401 (n=43). **(b)** Post-survey responses for ZOOL 401 (n=43). **(c)** Pre-survey responses for ZOOL 581 (n=10). **(d)** Post-survey responses for ZOOL 581 (n=10).

Students were also presented with a list of the 15 parasite species included in *Parasite Patrol*, and given an example description of a parasite lifecycle. Using a five-point Likert scale (strongly agree to strongly disagree), students were asked to identify the parasite lifecycles that they could accurately describe before and after playing the game. Strongly agree and agree responses were considered "agreement".

Q2. I am able to accurately and completely describe the lifecycle for the following parasites (strongly agree to strongly disagree):

ZOOL 401 (Table 3)

In ZOOl 401 (n=43), more students agreed that they were able to accurately describe the lifecycles for all 15 of the parasite species after playing *Parasite Patrol*. Students' pre-survey knowledge was lower, with agreement ranging from 0% to 34.9%. Students' post-survey knowledge was higher, with agreement ranging from 30.2% to 69.8%. The lifecycles with the highest percentage of agreement after playing the game were *Plasmodium falciparum* (Malaria) at 65.1% and *Ixodes scapularis* (Deer tick) at 69.8%. The lifecycles that had the greatest increase in agreement were *Ancylostoma caninum* (Dog hookworm) and *Ascaris lumbricoides* (Giant roundworm), which both had a percentage increase of 46.5%. The lifecycle with the lowest percentage of agreement after playing the game was *Echinococcus multilocularis* (Echinococcosis) at 30.2%. The lifecycle that had the smallest increase in agreement was *Moniezia expansa* (Ruminant tapeworm), which had a percentage increase of 20.9%.

ZOOL 581 (Table 3)

In ZOOl 581 (n=10), more students agreed that they were able to accurately describe the lifecycles for 13 of the parasite species after playing *Parasite Patrol*. Students' pre-survey knowledge was lower, with agreement ranging from 30% to 70%. Students' post-survey knowledge was higher, with agreement ranging from 40% to 80%. The lifecycle with the highest percentage of agreement after playing the game was *Plasmodium falciparum* (Malaria) at 80%. The lifecycles that had the greatest increase in agreement were *Giardia duodenalis* (Beaver fever), *Ostertagia ostertagi* (Brown stomach worm), and *Demodex canis* (Demodex mange), which all had a percentage increase of 60%. The lifecycle with the lowest percentage of agreement after playing the game was *Dicrocoelium dendriticum* (Lancet liver fluke) at 40%. The lifecycles that had the smallest increase in agreement were *Echinococcus multilocularis* (Echinococcosis) and *Dicrocoelium dendriticum* (Lancet liver fluke), which had no percentage increase.

Table 3. Percentages of agreement for ZOOL 401 (n=43) and ZOOL 581 (n=10) students when asked to indicate the parasite lifecycles they could accurately describe before (pre %) and after (post %) playing *Parasite Patrol*. Students responded using a five-point Likert scale (strongly agree to strongly disagree), where strongly agree and agree responses were considered "agreement". The percentages are colour coded according to the level of agreement, where bright red= 0%-49.9%, light red= 50%-59.9%, orange= 60%-69.9%, yellow= 70%-79.9%, light green= 80%-89.9%, and bright green= 90%-100%.

	ZOOL 401 (n=43)					ZOOL 581 (n=10)				
Parasite species in *Parasite Patrol*	Pre (%)	Count	Post (%)	Count	% increase	Pre (%)	Count	Post (%)	Count	% increase
Dirofilaria immitis (Heartworm)	9.3	4	48.8	21	39.5	30	3	50	5	20
Moniezia expansa (Ruminant tapeworm)	34.9	15	55.8	24	20.9	50	5	60	6	10

Ancylostoma caninum (Dog hookworm)	11.6	5	58.1	25	46.5	60	6	70	7	10
Echinococcus multilocularis (Echinococcosis)	0.0	0	30.2	13	30.2	70	7	70	7	0
Dicrocoelium dendriticum (Lancet liver fluke)	34.9	15	58.1	25	23.2	40	4	40	4	0
Toxoplasma gondii (Toxoplasmosis)	2.3	1	37.2	16	34.9	30	3	70	7	40
Giardia (Beaver fever)	11.6	5	46.5	20	34.9	10	1	70	7	60
Hypoderma bovis (Warble fly)	11.6	5	51.2	22	39.6	10	1	50	5	40
Ostertagia ostertagi (Brown stomach worm)	11.6	5	44.2	19	32.6	10	1	70	7	60
Plasmodium falciparum (Malaria)	27.9	12	65.1	28	37.2	60	6	80	8	20
Toxocara canis (Canine roundworm)	14.0	6	55.8	24	41.8	40	4	70	7	30
Ascaris lumbricoides (Giant roundworm)	9.3	4	55.8	24	46.5	40	4	50	5	10
Ixodes scapularis (Deer tick)	34.9	15	69.8	30	34.9	40	4	70	7	30
Demodex canis (Demodex mange)	14.0	6	46.5	20	32.5	10	1	70	7	60
Linognathus vituli (Long-nosed sucking louse)	16.3	7	44.2	19	27.9	10	1	50	5	40

Students were given six knowledge-based parasite questions on the pre and post-game surveys, to test their understanding of concepts covered in *Parasite Patrol* (Figure 8a & 8b). Question numbers 4, 6, 7, 8, and 9 were specific to content covered in *Parasite Patrol*. Question 5 was specific to the content covered in *Nick the Tick*.

ZOOL 401 (Figure 8a)

In ZOOL 401 (n=43), there was an increase in the percentage of correct responses for all of the questions specific to *Parasite Patrol* after playing the game (questions 4, 6, 7, 8, 9). The largest percentage increase in correct responses was for question 4, where students were given a list of parasites from *Parasite Patrol* and asked to select the host that they infect. The percentage of correct responses for question 4 increased by 32.6%, from 2.3% on the pre-survey to 32.9% on the post survey, with a normalized gain of 0.33. There was a decrease in the percentage of correct responses for question 5, which was specific to *Nick the Tick,* and asked students to match different tick drawings to their correct life stages. The percentage of correct responses for question 5 decreased by 4.7%, from 90.7% on the pre-survey to 86% on the post-survey, with a normalized gain of -0.5. The complete data for these knowledge-based questions can be found in Supplementary Materials Table A1.

ZOOL 401 (n=43)

■ % Correct Pre   ■ % Correct Post

| Normalized gain: | 0.33 | -0.50 | 0.19 | 0.12 | 0.25 | 0.26 |
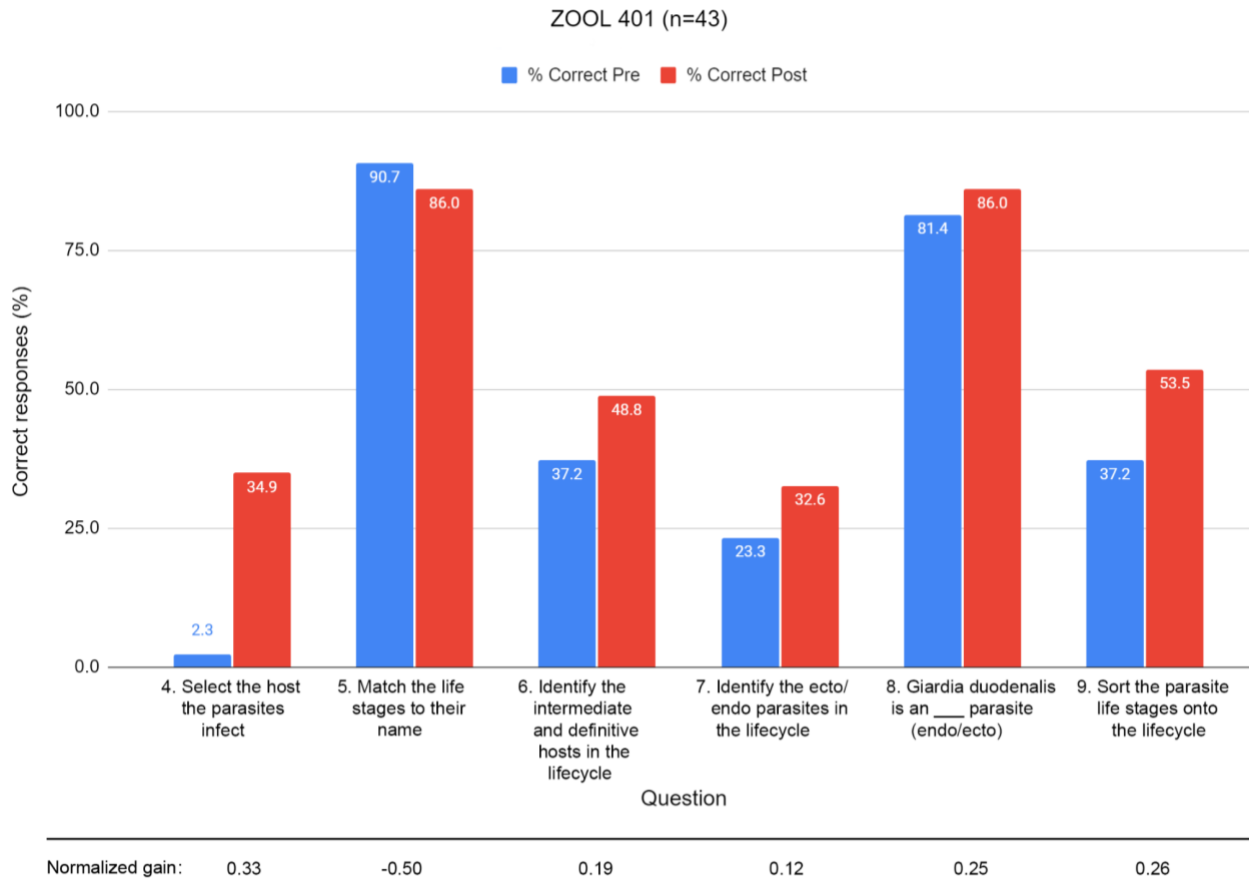
Figure 8a. Percentage of correct responses and normalized gain for ZOOL 401 (n=43) students when asked knowledge-based parasite questions before and after playing *Parasite Patrol*. Blue bars represent pre-survey responses, and red bars represent post-survey responses. Questions 4, 6, 7, 8, 9 were specific to content explored in *Parasite Patrol.* Question 5 was specific to content covered in *Nick the Tick*. Data used to create this figure can be found in Supplementary Materials Table A1.

ZOOL 581 (Figure 8b)

In ZOOL 581 (n=10), there was an increase in the percentage of correct responses for all of the questions after playing *Parasite Patrol* (questions 4-9). The largest percentage increase in correct responses was for question 4, where students were given a list of parasites from *Parasite Patrol* and asked to select the host that they infect. The percentage of correct responses for question 4 increased by 50%, from 0% on the pre-survey to 50% on the post survey, with a normalized gain of 0.50. There was no change in the percentage of correct responses for question 8, where students were asked to indicate whether *Giardia duodenalis* was an ectoparasite or endoparasite. The percentage of students that got question 8 correct on the pre-survey and post-survey remained the same at 90%, with a normalized gain of 0. The complete data for these knowledge-based questions can be found in Supplementary Materials Table A1.
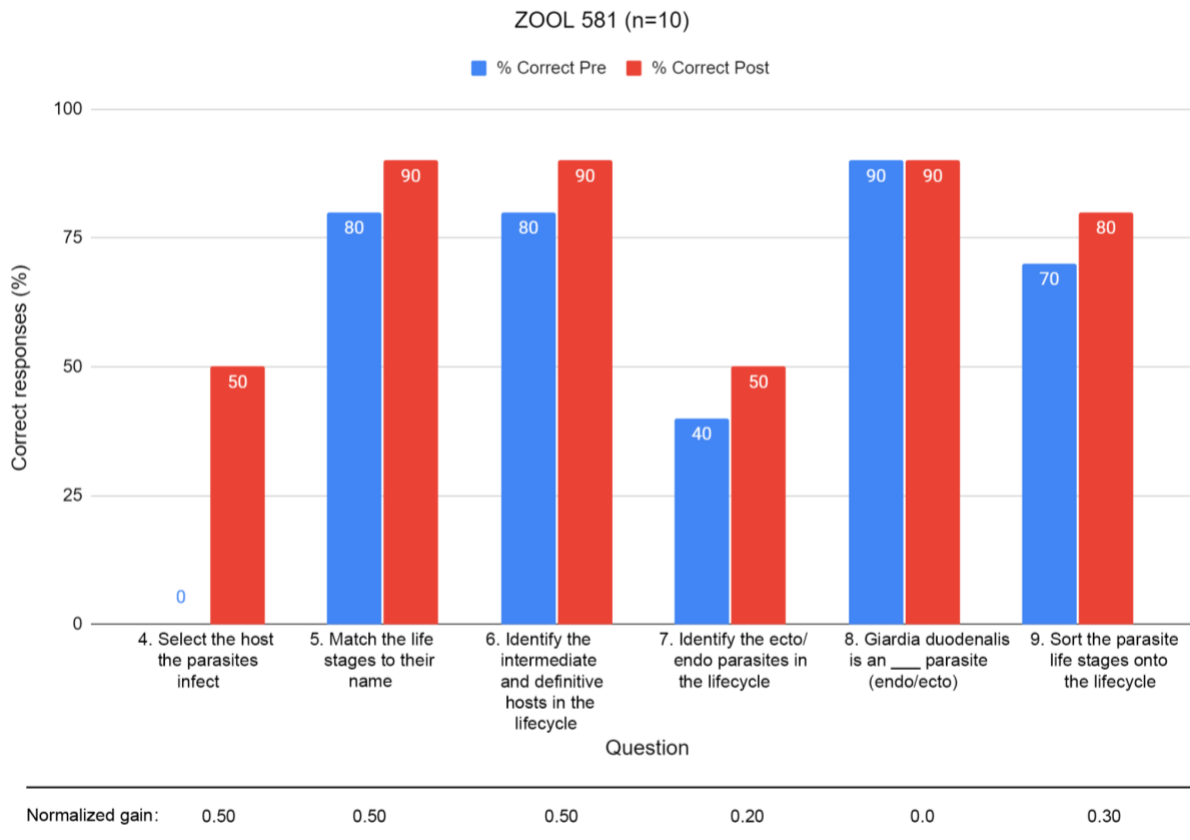
Figure 8b. Percentage of correct responses and normalized gain for ZOOL 581 (n=10) students when asked knowledge-based parasite questions before and after playing *Parasite Patrol.* Blue bars represent pre-survey responses, and red bars represent post-survey responses. Questions 4, 6-9 were specific to content explored in *Parasite Patrol.* Question 5 was specific to content covered in *Nick the Tick.* Data used to create this figure can be found in Supplementary Materials Table A1.

Attitudes towards parasites

Students responded to questions on the pre-survey and post-survey that assessed their attitudes towards parasites. To begin, they were asked to name the first words that came to mind when they thought about parasites.

1. What are the first words that come to mind when you think of parasites? (1-5 words).

ZOOL 401 (Figure 9a and 9b)

Before playing *Parasite Patrol,* students in ZOOL 401 (n=43) frequently used negative words such as "gross", "diseases", "bad" and "harmful" to describe parasites. After playing *Parasite Patrol*, students still used words like "gross", but also used more positive words such as "cool", "diverse", and "interesting". Overall the percentage of words with negative connotations used by students to describe parasites decreased after playing *Parasite Patrol.* The percentage of positive words used by students increased by 7.1%, from 5.3% on the pre-survey to 12.4% on the post-survey. The percentage of neutral words increased by 15.7%, from 38% on the pre-survey to 53.7% on the post-survey. The percentage of negative words decreased by 22.8%, from 56.7% on the pre-survey to 33.9% on the post-survey.

ZOOL 581 (Figure 9c and 9d)

Before playing *Parasite Patrol,* students in ZOOL 581 (n=10) frequently used negative words to describe parasites such as "disease", "gross", "alien" and "danger". After playing *Parasite Patrol*, students used more neutral words such as "larvae", "eggs", "host, and "worm". Overall the percentage of words with negative connotations used by students to describe parasites decreased after playing *Parasite Patrol*. The percentage of positive words used by students did not change, and remained at 2.1% on the pre-survey and post-survey. The percentage of neutral words increased by 39.9%, from 45.8% on the pre-survey to 85.7% on the post-survey. The percentage of negative words decreased by 39.9%, from 52.1% on the pre-survey to 12.2% on the post-survey.
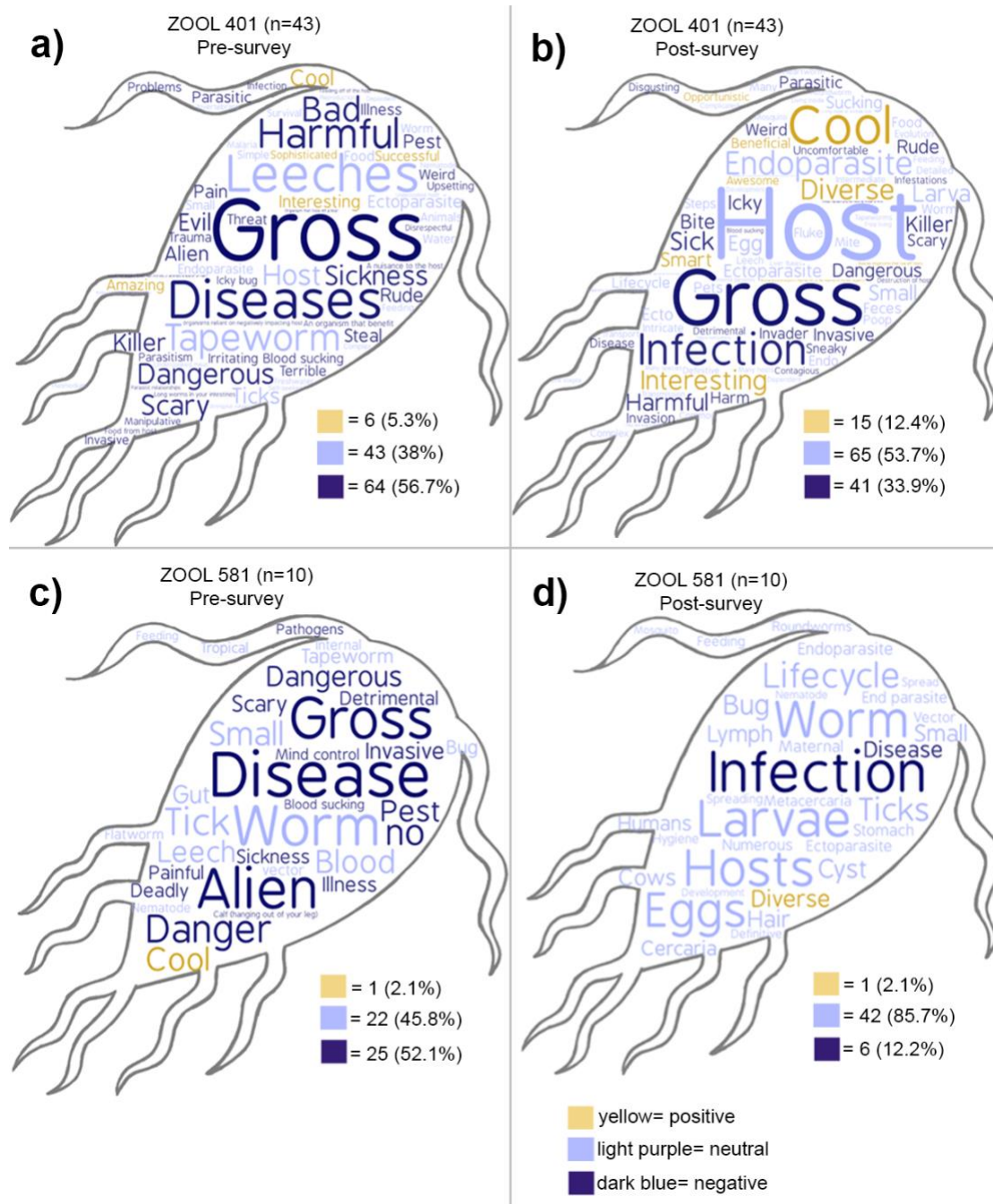
Figure 9. Wordles created using students survey responses when asked to list the first words that come to mind when they think about parasites. Dark blue indicates words with negative connotations. Light purple indicates words with neutral connotations. Yellow indicates words with positive

connotations. The size of the words represents the frequency. **(a)** Pre-survey responses for ZOOL 401 (n=43). **(b)** Post-survey responses for ZOOL 401 (n=43). **(c)** Pre-survey responses for ZOOL 581 (n=10). **(d)** Post-survey responses for ZOOL 581 (n=10).

Students were also asked to respond to positively and negatively worded statements regarding their attitudes towards parasites using a five-point Likert scale (strongly agree to strongly disagree) before and after playing *Parasite Patrol.*

ZOOL 401 (Table 4)

The percentage of ZOOL 401 (n=43) students' agreement for the positively worded statements generally remained very high across the pre-survey and post-survey. There were small decreases in students' agreement towards the statements "I want to learn more about parasites", "Parasites have important impacts on our pets", and "Parasites have important impacts on the agricultural industry", ranging from 1-4 fewer students after playing *Parasite Patrol*. There were small increases in students' agreement towards the statements "I want to share what I know about parasites with others", and "Learning about parasite lifecycles is interesting", ranging from 1-4 more students after playing the game.

The percentage of students' agreement for the negatively worded statements was generally low. After playing the game, there was a decrease in students' agreement when asked if "Learning about parasite lifecycles is intimidating". There was a large increase in agreement for the statement "I am afraid of parasites", with a percentage increase of 39.6% after playing *Parasite Patrol*.

ZOOL 581 (Table 4)

The percentages of ZOOL 581 (n=10) students' agreement for the positively worded statements remained very high across the pre-survey and post-survey. After playing *Parasite Patrol* there was a small increase in agreement of 1 student towards the statement "I want to share what I know about parasites with others". The other positively worded statements had no change in agreement and maintained a 90%-100% agreement across the pre-survey and post-survey.

The percentage of students' agreement for the negatively worded statements did not increase. There was a large decrease in students' agreement towards the statement "learning about parasite life cycles is intimidating", with a percentage decrease of 30% after playing the game. There was no change in agreement towards the statement "I am afraid of parasites".

Table 4. Percentage of agreement from students in ZOOL 401 (n=43) and ZOOL 581 (n=10) for positively and negatively worded statements regarding their attitudes towards parasites before and after playing *Parasite Patrol*. Students responded on a five-point Likert scale (strongly agree to strongly disagree), where strongly agree and agree responses were considered "agreement". Asterisks (*) indicate negatively worded statements. The percentages are colour coded according to the level of agreement, where bright red= 0%-49.9%, light red= 50%-59.9%, orange= 60%-69.9%, yellow= 70%-79.9%, light green= 80%-89.9%, and bright green= 90%-100%.

	ZOOL 401 (n=43)				ZOOL 581 (n=10)			
Questions	Pre (%)	Count	Post (%)	Count	Pre (%)	Count	Post (%)	Count
I want to learn more about parasites.	86.0	37	76.7	33	100	10	100	10
I want to share what I know about parasites with others.	65.1	28	74.4	32	70	7	80	8

Parasites have important impacts on our pets.	95.3	41	93.0	40	100	10	100	10
Parasites have important impacts on the agricultural industry.	97.7	42	95.3	41	100	10	100	10
Parasites are relevant to Albertans.	95.3	41	95.3	41	100	10	100	10
Learning about parasite lifecycles is interesting.	83.7	36	86.0	37	90	9	90	9
*I am afraid of parasites.	48.8	21	88.4	38	60	6	60	6
*Learning about parasite lifecycles is intimidating.	34.9	15	27.9	12	90	9	60	6

Attitudes towards educational games

Students responded to questions that pertained to their experience playing *Parasite Patrol,* and attitudes towards using educational games as a learning tool. First, students were asked to describe *Parasite Patrol* using one word after playing the game.

Q1. Write one word to describe this activity:

ZOOL 401 (Figure 10a)
In ZOOL 401 (n=96), a majority of the words students used to describe the game were positive. The most popular word used to describe *Parasite Patrol* was "fun". Other predominant words used to describe the game included "engaging", "interactive", and "educational".

ZOOL 581 (Figure 10b)
In ZOOL 581 (n=18), all of the words students used to describe the game were positive. The most popular word used to describe *Parasite Patrol* was "fun". Other predominant words used to describe the game included "engaging", "interactive", and "educational".
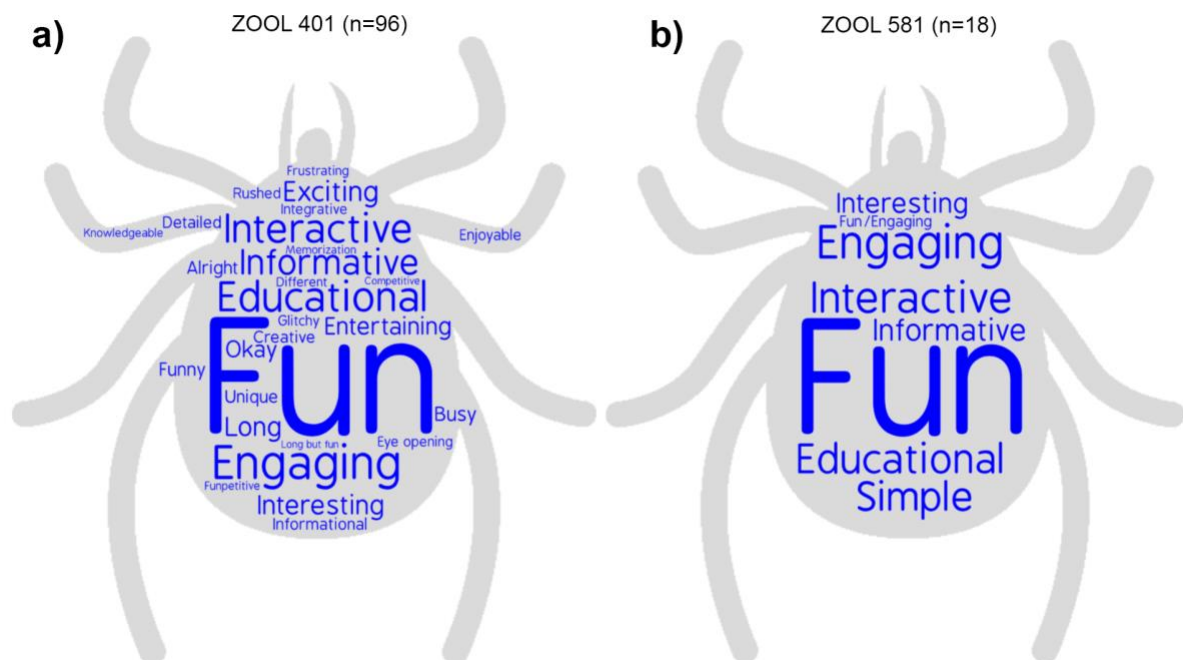
Figure 10. Wordles showing students responses when asked to describe *Parasite Patrol* using one word after playing the game. The size of the words indicates the frequency. **(a)** ZOOL 401 (n=96) post-survey responses. **(b)** ZOOL 581 (n=18) post-survey responses.

Students were asked two questions regarding whether they found *Parasite Patrol* helpful for their understanding of concepts in parasitology. Students responded using a five-point Likert scale (strongly agree to strongly disagree), where strongly agree and agree statements were considered "agreement". Students justified their response with a short open-ended response.

Q2. Do you think that Parasite Patrol helped you understand concepts in parasitology better?
Q3. Regarding your answer to the last question, please briefly explain why or why not.

ZOOL 401

In ZOOL 401 (n=96), 88.5% of students agreed that the game was helpful to their learning. When asked to provide comments as to why, students left comments such as: "This game helped me understand the concepts because it was interactive and because I was actually playing the game I retained the information better than if someone was just telling me the concepts", and "I have a better general understanding of the parasites out in the world and how their lifecycles work". The 11.5% of students that did not agree *Parasite Patrol* was helpful to their learning left comments such as "I think it would have if we weren't rushing through it. It completely defeats the fun of having a game in the first place. Would have been awesome if we had more time" and "You learn more about one host parasites more than the others but need to take extra time to retain other host's parasites". A full list of the comments provided by students is available in Supplementary Materials Table A2.

ZOOL 581

In ZOOL 581 (n=18), 83.3% of students agreed that the game was helpful to their learning. When asked to provide comments as to why, students left positive comments such as: "The fun facts were engaging, the emphasis on all the different hosts being in the environment as shown by the images was great! It was engaging to build the lifecycle yourself and the hint of competition was engaging! The fun facts were a great idea", and "It was an interactive way of learning about parasite lifecycles and diversity, and the requirement to match cards kept it fun and game-like while providing a good pace to introducing new information". The 16.7% of students that did not agree left comments such as "It was fun, but I do not like online board games. I think it would be better to have it in person (post-covid world) as I felt a bit rushed reading the cards" and "This is good for someone with very little background knowledge. Not me personally". A full list of the comments provided by students is available in Supplementary Materials Table A2.

Students were also given positively and negatively worded statements regarding educational games, and asked to respond on a five-point Likert scale (strongly agree to strongly disagree) before and after playing *Parasite Patrol*. Strongly agree and agree responses were considered for the positively worded statements, and strongly disagree and disagree responses were considered for the negatively worded statements.

ZOOL 401 (Table 5)

In ZOOL 401 (n=96), the percentage of students' agreement for the positively worded statements was generally high, with slight variations. There was a small decrease in

agreement towards the statement "I find educational games motivating" of 1% (n=1) after playing *Parasite Patrol*. There was no change in agreement towards the statement "I enjoy playing games about science", with a maintenance of 90.6% agreement across the pre-survey and post-survey. There were small increases in agreement for the statements "Playing a game makes learning about science more interesting", "I would like games to be included in more of my classes", and "Playing a game is useful to my learning". The largest increase in agreement was for the statement "I often ask questions when playing games about science" of 19.8% (n=19).

   For the negatively worded statements, disagreement decreased towards the statement "I will only play a game if an assignment requires me to" by 5.2% (n=5) after playing the game. Disagreement increased towards the statements "I feel anxious, nervous, or fearful when I am asked to play games about science/parasites", and "Playing games as an undergraduate is a waste of time" by 6.2% (n=6).

ZOOL 581 (Table 5)

   In ZOOL 581 (n=18), the percentage of students' agreement for the positively worded statements was generally high, with slight variations. There was a small decrease in agreement towards the statement "Playing a game is useful to my learning" of 5.5% (n=1) after playing *Parasite Patrol*. There was no change in agreement towards the statement "Playing a game makes learning about science more interesting", as agreement remained at 100%. There were small increases in agreement for the statements "I enjoy playing games about science", "I would like games to be included in more of my classes", "I often ask when playing games about science", and "I find educational games motivating".

   For the negatively worded statements, disagreement decreased towards the statement "Playing games as an undergraduate is a waste of time" by 11.1% (n=2). Disagreement remained the same for the statement "I will only play a game if an assignment requires me to" at 44.4%. Disagreement increased towards the statement "I feel anxious, nervous, or fearful when I am asked to play games about science/parasites" by 16.7% (n=3).

Table 5. Pre-survey and post-survey responses from students in ZOOL 401 (n=96) and ZOOL 581 (n=18) when asked attitudinal questions regarding educational games. Students responded on a five-point Likert scale (strongly agree to strongly disagree). Strongly agree and agree responses were considered for the positively worded statements. Strongly disagree and disagree responses were considered for the negatively worded statements. Asterisks (*) indicate negatively worded statements. Percentages are colour coded according to the level of agreement/disagreement, where bright red= 0%-49.9%, light red= 50%-59.9%, orange= 60%-69.9%, yellow= 70%-79.9%, light green= 80%-89.9%, and bright green= 90%-100%.

ZOOL 401 (n=96)									
Positively worded statements	Pre (%)	Count	Post (%)	Count	Negatively worded statements	Pre (%)	Count	Post (%)	Count
I enjoy playing games about science.	90.6	87	90.6	87	*I feel anxious, nervous, or fearful when I am asked to play games about science/parasites	50	48	77.1	74
Playing a game makes learning about science more interesting.	86.5	83	93.8	90	*I will only play a game if an assignment requires me to.	45.8	44	40.6	39
I would like games to be included in more of my classes.	71.9	69	78.1	75	*Playing games as an undergraduate is a waste of time.	76	73	82.2	79
I often ask questions when playing games about science.	38.5	37	58.3	56					
Playing a game is useful to my learning.	84.4	81	86.5	83					

	Pre (%)	Count	Post (%)	Count		Pre (%)	Count	Post (%)	Count
I find educational games motivating.	81.2	78	80.2	77					
ZOOL 581 (n=18)									
Positively worded statements	Pre (%)	Count	Post (%)	Count	Negatively worded statements	Pre (%)	Count	Post (%)	Count
I enjoy playing games about science.	94.4	17	100.0	18	*I feel anxious, nervous, or fearful when I am asked to play games about science/parasites	50.0	9	66.7	12
Playing a game makes learning about science more interesting.	100.0	18	100.0	18	*I will only play a game if an assignment requires me to.	44.4	8	44.4	8
I would like games to be included in more of my classes.	72.2	13	83.3	15	*Playing games as an undergraduate is a waste of time.	88.9	16	77.8	14
I often ask questions when playing games about science.	38.9	7	44.4	8					
Playing a game is useful to my learning.	83.3	15	77.8	14					
I find educational games motivating.	61.1	11	72.2	13					

After playing the *Parasite Patrol,* students were also asked to select the game components that were important to their learning and enjoyment of the game from a list of elements including challenge, fantasy, curiosity, the colours, the visuals/graphics, and the cards.

Q4. Which of the following components did you find important to your learning and/or enjoyment of the game?

ZOOL 401 (Table 6)

While all of the components were identified to be important, ZOOL 401 (n=96) students found the visuals/graphics to be the most important component of *Parasite Patrol*, with 79.2% indicating that it was important for their learning and enjoyment of the game. Students found the fantasy element of the game to be the least important component of *Parasite Patrol,* with 13.5% indicating that it was important for their learning and enjoyment of the game.

ZOOL 581 (Table 6)

While all of the components were identified to be important, ZOOL 581 (n=18) students found the visuals and graphics to be the most important component of *Parasite Patrol*, with 83.3% indicating that it was important for their learning and enjoyment of the game. Students found the fantasy element of the game to be the least important component of *Parasite Patrol,* with 11.1% indicating that it was important for their learning and enjoyment of the game.

Table 6. Percentage of students in ZOOL 401 (n=96) and ZOOL 581 (n=18) that found the game components helpful to their learning and enjoyment of the game on the post-survey. Percentages are colour coded, where bright red= 0%-49.9%, light red= 50%-59.9%, orange= 60%-69.9%, yellow= 70%-79.9%, light green= 80%-89.9%, and bright green= 90%-100%.

	ZOOL 401 (n=96)		ZOOL 581 (n=18)	
Game Component	Count	Percentage	Count	Percentage
Visuals/Graphics	76	79.2	15	83.3

Curiosity	70	72.9	14	77.8
Challenge	62	64.6	14	77.8
The Cards	52	54.2	9	50
The Colours	51	53.1	7	38.9
Fantasy	13	13.5	2	11.1

Students were asked to comment on their favourite parts of *Parasite Patrol* after playing the game, by providing a short answer open-ended response.

Q5. My favourite parts of Parasite Patrol are:

ZOOL 401 (Table 7)

ZOOL 401 (n=96) students' comments regarding their favourite parts of the game were grouped into seven categories. The parts of *Parasite Patrol* that students most commonly described as being their favourite were the "visuals" and "pinning the parasites", with comments such as "The cool diagrams of the human, cow, and dog" and "I really liked putting the parasites on the different parts of the organisms. It helped me form a better understanding of where each stage of the lifecycle occurs". All of the students' comments can be found in Supplementary Materials Table A3.

Table 7. ZOOL 401 (n=96) students favourite parts of *Parasite Patrol,* when asked to comment on their favourite parts of the game. Their responses were grouped into seven categories, and a representative quote is provided for each of these categories. Data used to create this chart is found in Supplementary Materials A3.

ZOOL 401 (n=96)		
Favourite part	Representative comments	Count
1. Visuals	"The cool diagrams of the human, cow, and dog."	25
2. Interactiveness: a) Pinning the parasites	"I really liked putting the parasites on the different parts of the organisms. It helped me form a better understanding of where each stage of the lifecycle occurs."	21
3. Interactiveness b) Clue Cards	"The memory challenge aspect."	20
4. Interactiveness c) Teamwork	"working together with a teammate and having to discuss course material."	20
5. Game content/information	"Learning which parasites infect which hosts."	20
6. Competition	"The competitive aspect makes it fun and engaging."	12
7. Fun	"was fun to have a different experience to the norm."	6

ZOOL 581 (Table 8)

ZOOL 581 (n=18) students' comments regarding their favourite parts of the game were grouped into five categories. The parts of *Parasite Patrol* that students most commonly described as being their favourite were "pinning the parasites" and the "clue cards", with comments such as ""Being able to match the stages of the parasite life cycle to the diagrams" and "Finding the matching cards". A full list of the students' comments is provided in Supplementary Materials A4.

Table 8. ZOOL 581 (n=18) students favourite parts of *Parasite Patrol,* when asked to comment on their favourite parts of the game. Their responses were grouped into five categories, and a representative quote is provided for each of these categories. Data used to create this chart is found in Supplementary Materials A4.

ZOOL 581 (n=18)		
Favourite part	Representative comments	Count
1. Interactiveness: a) Pinning the parasites	"Being able to match the stages of the parasite life cycle to the diagrams."	10
2. Interactiveness b) Clue Cards	"Finding the matching cards."	5
3. Visuals	"the colours, and graphics."	4
4. Competition	"I'm competitive so it was fun to win."	1
5. Game content	"Lots of information."	1

After playing the game, students were also asked to provide comments regarding ideas they had to improve *Parasite Patrol*.

Q5. Ideas I have to improve Parasite Patrol for the future are:

ZOOL 401 (Table 9)

ZOOL 401 (n=96) students' comments regarding *Parasite Patrol* improvements were grouped into ten categories. The most common improvement suggested by students was to change the game platform, with comments such as "Make it a board game!!". A full list of the students recommended improvements is provided in Supplementary Materials Table A5.

Table 9. Improvements suggested by ZOOL 401 (n=96) students after playing *Parasite Patrol*. The improvements were grouped into 10 categories, and a representative comment is provided for each category. Data used to create this chart is found in Supplementary Materials Table A5.

ZOOL 401 (n=96)		
Improvements	Representative comments	Count
1. Game platform	"Make it a board game!"	31

2. None	"None. Since I'm colourblind I found the use of shapes very helpful to distinguish colours; thank you for including that!"	26
3. More time	"There needs to be more time to enjoy playing the game, it was way too rushed."	11
4. Game mechanics	"Maybe have a way to have another turn of matching, or like finding the superclue lets you pick again. Bc other wise team human will likely win because they get to first."	11
5. Game content	"Maybe giving too many clues on where the phase of the lifecycle may make it a little easy. To challenge players, maybe you could add riddles or subtle hints so one may investigate and further engage to figure out the correct answer."	6
6. Visuals	"Maybe less shapes on the graphics as things got really messy near the end."	6
7. Game length	"The game was long as it included lots of chance moments, like waiting to come across a matching pair of cards, so it took a lot longer to get started. Since each card contained lots of information it was also challenging enough to get through it in a timely fashion."	3
8. Team formation	"Get people to make teams before starting the game. Some people were confused about what teams they were in."	2
9. Competition	"More incentive for competition."	2
10. Game instructions	"Adding to the control description that you can change what your cursor does"	1

ZOOL 581 (Table 10)

ZOOL 581 (n=18) students' comments regarding *Parasite Patrol* improvements were grouped into seven categories. The most common improvement suggested by students was to change the game mechanics and the game platform, with comments such as ""Knowledge wise it is interesting, a component to motivate you to find it would be a great addition like an extra turn or getting to peek at an extra card. Some sort of twist revolving around the superclue" and "Possibly the way it was presented: it was difficult to do on zoom when we couldn't talk to our team (especially for trying to choose cards!), would have been easier to do in person, but with that not possible I am really not sure how it could have been better adapted for online!". A full list of the students recommended improvements is provided in Supplementary Materials Table A6.

Table 10. Improvements suggested by ZOOL 581 (n=18) students after playing *Parasite Patrol*. The improvements were grouped into seven categories, and a representative comment is provided for each category. Data used to create this chart is found in Supplementary Materials Table A6.

ZOOL 581 (n=18)	

Improvements	Representative comments	Count
1. Game mechanics	"Knowledge wise it is interesting, a component to motivate you to find it would be a great addition like an extra turn or getting to peek at an extra card. Some sort of twist revolving around the superclue."	11
2. Game platform	"Possibly the way it was presented: it was difficult to do on zoom when we couldn't talk to our team (especially for trying to choose cards!), would have been easier to do in person, but with that not possible I am really not sure how it could have been better adapted for online!"	5
3. Game instructions	"The question mark was a bit confusing."	4
4. Game content	"adding more parasites if possible."	3
5. None	"None, sorry. The images and colours were all fantastic, the pace of the game was really good, and it managed to be fun and definitely a game while also being educational."	2
6. Visuals	"Maybe not having the locations for the parasites coded onto the animal would make students use their application skills a little bit more as they try to find the locations by themselves."	1
7. Game environment	"maybe less monitoring by the TA, it got more fun once we felt we could freely talk to the other classmates without the TA instructing us what to do for every part of the game"	1

Discussion

Parasitology is an important subject matter that is highly complex. This complexity creates challenges with student comprehension and engagement. The predominant modes of instruction for teaching complex scientific topics in the classroom are currently traditional methods, such as passive lectures and rote memorization (Pinhatti et al. 2019). However, interactive techniques like game-based learning have helped increase students' conceptual knowledge of complex biological subjects in a variety of settings, making students more

interested and excited to learn using a fun and interactive format (Selvi & Cosan. 2018). The ways in which game-based learning can impact undergraduate students' knowledge and attitudes towards parasites at the University of Calgary remain unclear. The creation, implementation, and systematic assessment of an educational game will provide insight into how game-based learning interventions may improve students' understanding and attitudes towards complex biological topics, and capture their opinions regarding games as learning tools.

In this study, we investigated the effectiveness of an educational game called *Parasite Patrol* in two upper-level zoology courses: An Introduction to Invertebrate Zoology (ZOOL 401) and Principles in Parasitism (ZOOL 581). The game was strategically designed using the essential elements outlined by Malone (1980) to create an effective and engaging learning tool. Through the utilization of a pre and post-game survey design, we assessed the impact of playing *Parasite Patrol* on undergraduate students' knowledge of parasitology, attitudes towards parasites, and attitudes towards educational games. We identified that students in both courses had an improved performance on parasite knowledge questions after playing the game, more positive attitudes towards parasites, and enjoyed using the game as a learning tool.

Parasite knowledge

Parasite Patrol successfully increased both ZOOL 401 and ZOOL 581 students' conceptual knowledge and understanding of parasites and their lifecycles. This is highlighted by the students' ability to name a greater number of parasite species that were specific to *Parasite Patrol* after playing the game. The participants' capacity to recall more specific parasites indicates that, through exposure to a diverse range of species, the game was able to help students expand their knowledge regarding parasites. The number of parasites named by students in ZOOl 401 increased after playing the game, showing that students with limited background knowledge in parasitology were able to learn about parasites through an educational game. Interestingly, the number of parasites named by ZOOL 581 students did not increase after playing the game. The lack of any increase may be due to the fact that these students already had a high baseline level of knowledge for a diversity of parasites, and therefore had less room to expand this knowledge. When comparing the post-survey responses to the pre-survey responses for both classes, we saw large increases in the students' ability to accurately describe the lifecycles of the 15 parasite species included in the game. This increase suggests that by exploring complex parasite lifecycles through the use of an interactive and engaging format like game-play, students are able to obtain conceptual knowledge and a better understanding of how parasite lifecycles work. In the end, students in these two courses performed better on application-based questions that stemmed from parasitology content covered in *Parasite Patrol*. Intriguingly, students in ZOOl 401 performed worse on the question that related to educational content not covered in the game, but covered in the storybook *Nick the Tick*. This signifies that *Parasite Patrol* was a factor in improving student's performance for the questions that related to the concepts covered in the game. The finding that an educational game can increase students' knowledge of parasitology is consistent with other studies that have employed game-based learning in the classroom. Previous research has found that students' acquisition of knowledge and performance on assessments for complex biological topics increased after playing educational games (Spiegel et al. 2008; Steinman & Blastos, 2002; Garcin et al. 2019). This is consistent with the findings surrounding the implementation of *Parasite Patrol* for teaching undergraduates parasitology, and suggests that strategically designed educational games can be used to

increase students' understanding and performance regarding difficult biological subject matters.

Attitudes towards parasites

The game-based learning intervention also improved students' attitudes towards parasites and parasitology after playing the game. This impact is exemplified by students in both classes using fewer words with negative connotations to describe parasites after playing *Parasite Patrol*. Students using fewer negative words suggests that the educational game altered students' attitudes towards parasites in a positive way, allowing them to recognize how parasites are diverse and interesting. The educational game also resulted in students from both courses expressing an increased desire to share what they know about parasites with others, and feeling less intimidated when learning about their lifecycles. Thus *Parasite Patrol* improved students' attitudes towards parasitology, because they felt inspired to inform others about parasites using what they had learned by playing the game. It also shows how game-based learning made a complex biological topic less daunting, so that students perceived learning about parasite lifecycles to be less intimidating. This result is consistent with existing research, showing the effectiveness of an educational card game for reducing jargon, complex images, and student intimidation for topics in undergraduate biology (Pinhatti et al. 2019). Interestingly, more students in ZOOL 401 were afraid of parasites after playing *Parasite Patrol.* This should not necessarily be viewed as a negative outcome, as it could signify that the students become better educated on parasite transmission, infection, disease, and more aware of how parasites impact humans, pets, and livestock. It may show that students became more cognizant of parasites and their impacts on the world, however, future studies would be needed to obtain more insight into this result.

Attitudes towards educational games

This study also revealed that students had positive attitudes towards *Parasite Patrol* and the use of educational games as a learning tool in the classroom. Students in both ZOOL 401 and ZOOL 581 described the game using predominantly positive words such as "fun", "engaging", "exciting", "interesting", and "interactive". This description characterizes *Parasite Patrol* as an engaging, fun and positive experience for students, and suggests that educational games can be used to increase students' enjoyment while learning. This positive experience is consistent with other game-based learning interventions in the classroom, where students also found educational games to be fun, engaging, and interesting compared to passive teaching methods (Selvi & Cosan. 2018; Pinhatti et al. 2019). However, this positive view of the educational game contradicts with one study by Raimondi (2016), where students described the game-based learning experience to be "frustrating". This surprisingly negative view could be due to the game being too difficult for students, resulting in players failing to complete the game and feeling frustrated (Raimondi 2016). Additionally, students in both courses expressed that they enjoy educational games as a learning tool. This amusement was shown by students agreeing that they enjoy playing games about science, that games make learning about science more interesting, that they often ask questions while playing games about science, and that they would like games to be included in more of their classes. The students enjoyed game-based learning and found it useful enough that they would like more educational games to be implemented into their other university courses. After playing *Parasite Patrol* students in both classes felt much less anxious and fearful when asked to play games about science and parasites. This reduced fear suggests that since students enjoyed their experience playing *Parasite Patrol,* they also became more open to the idea of playing

educational games to learn complex scientific concepts. More ZOOL 401 students also found educational games motivating after playing *Parasite Patrol*. This increase in motivation for ZOOL 401 students is consistent with existing research showing that students find educational games motivating (Brown et al. 2018; Barata et al. 2013; Selvi & Cosan 2018). Interestingly, less ZOOL 581 indicated that they found games motivating. The decrease in motivation for ZOOL 581 students after playing *Parasite Patrol* could suggest that students with a high level of parasite knowledge need a more difficult or challenging game to feel motivated. Nevertheless, both courses indicated that they found *Parasite Patrol* helpful to their learning. This shows that regardless of the players' existing knowledge, an educational game can be helpful for communicating complex scientific concepts to a variety of people from different backgrounds.

Game design elements

The most impactful elements of *Parasite Patrol* for the students' learning and enjoyment were the game's visuals, followed by the curiosity element and the challenge element. Interestingly, students found the fantasy element to be the least helpful to their learning. This contradicts previous theories, which claim fantasy should be one of the most important elements for an educational game, among challenge and curiosity (Malone 1980). This surprising finding could be due to the type of the fantasy used in *Parasite Patrol,* which was extrinsic in nature. Extrinsic fantasies are when the fantasy depends on the skill or information being learned, but not vice versa (Malone 1980). In this case, playing a parasite detective and obtaining the #1 detective badge depends on the students' ability to find the matching clue cards, and correctly pin their parasites onto the hosts. Perhaps having an intrinsic fantasy where the skill also depends on the fantasy would make this element more helpful for the students' learning (Malone 1980). Not only did students in both classes find the visuals and graphics to be the most useful to their learning and enjoyment, but they also found this element to be one of their favourite components, along with the interactiveness of the game. Therefore, carefully designed visuals with the strategic use of colours and shapes can be important for making a game that is both enjoyable and effective at relaying complex information. These outcomes could be helpful for subsequent game-based learning interventions, and act as guidelines for the design of future educational games.

Study limitations

The design of the current study is subject to limitations. The first limitation is the relatively small sample size for both courses in the study, with n=96 students participating in ZOOL 401 and n=18 students in ZOOL 581. Hence, the results may not be completely representative of the larger population, which might help explain some of the unexpected results. The second limitation is in the pre and post-game surveys. The reliability of the survey responses depends on the respondents' willingness to provide accurate and honest answers, and may also be subject to respondent fatigue given that the students filled out multiple surveys during their laboratory session. Completion of the pre-survey may also have sensitized students to the questions and influenced their post-survey responses. In the future, the survey questions could be randomized to help reduce this possibility. A third limitation is the influence of confounding variables. The completion of other laboratory activities before playing *Parasite Patrol*, such as *Nick the Tick*, could have confounded the students' responses. We tried to control for this on a question-by-question basis, analyzing either combined or separated data from students who played the game first or did not play the game first.

Future Directions

Given that *Parasite Patrol* helped improve students' parasite knowledge, attitudes towards parasites, and attitudes towards educational games, future efforts should be made to continue to investigate this promising field of research. It would be interesting to compare this study to the semester-long use of an educational game as a supplementary tool for traditional lectures. We could measure the long-term effects of game-based learning on students' retention of knowledge similar to Selvi & Cosan (2018), and assess the games' effects on students' overall course performance as in Garcin et al. (2019). We could also carry out a similar study to the one we performed, but include more students and a larger sample size. This study specifically concerned upper-level students in an undergraduate zoology setting at the University of Calgary, but it would be interesting to carry out a research project on participants of different educational levels, such as first-year biology students or the general public. These future implementations would allow us to test how an educational game like *Parasite Patrol* impacts people with a more limited knowledge of parasites and biological concepts. We could also study the use of games for other difficult subject matters, to see if we get similar impacts on students' learning and attitudes towards other complex subjects.

A physical version of Parasite Patrol could be created according to the improvements recommended by the ZOOL 401 and ZOOL 581 students. The mechanics of the game could be altered, as students requested that a bonus be added for players who find a pair of matching clue cards, such as a point system or the chance to peek at an extra card. We could also add more parasite species and hosts to the game, to expose players to more types of parasites. This research project could act as a guideline for future projects concerning the creation of engaging educational games, as well as the implementation and evaluation of game-based learning in the classroom.

In summary, it is clear that *Parasite Patrol* was an effective learning tool for teaching parasitology to both ZOOL 401 and ZOOL 581 students at the University of Calgary. The game improved students' knowledge of parasites, attitudes towards parasites, and provided insight into their attitudes towards *Parasite Patrol* and the use of educational games in the classroom. Using Parasite Patrol, students can get a more effective, interesting, and enjoyable learning experience, so game-based learning may be a valuable educational tool and supplement to future courses.

Supplementary Materials

Table A1. Percentages, counts, and normalized gains for correct responses on knowledge-based questions for ZOOL 401 (n=43) and ZOOL 581 (n=10) students before and after playing *Parasite Patrol.* The percentages are colour coded according to the level of correct responses, where bright red= 0%-49.9%, light red= 50-59.9%, orange= 60%-69.9%, yellow= 70%-79.9%, light green= 80%-89.9%, and bright green= 90%-100%.

Question	ZOOL 401 (n=43)					ZOOL 581 (n=10)				
	% Correct Pre	Count	% Correct Post	Count	Normalized gain	% Correct Pre	Count	% Correct Post	Count	Normalized gain
4. Select the host that the following parasites infect (if you are unsure, please select unknown):	2.3	1	34.9	15	0.33	0	0	50	5	0.5
5. Match the following figures (a, b, c and d) with their respective life stages.	90.7	39	86.0	37	-0.50	80	8	90	9	0.5
6 In the following lifecycle, identify the intermediate and definitive host (if you are unsure, please select unknown):	37.2	16	48.8	21	0.19	80	8	90	9	0.5
7. In the following lifecycle, select which letters (A-D) demonstrate an ectoparasite or an endoparasite (If you are unsure, please select unknown):	23.3	10	32.6	14	0.12	40	4	50	5	0.2
8.Giardia duodenalis is an _____ (endoparasite/ectoparasite).	81.4	35	86.0	37	0.25	90	9	90	9	0.0
9. Please sort the following parasite life stages onto the lifecycle (if you are unsure, please select unknown):	37.2	16	53.5	23	0.26	70	7	80	8	0.3

Table A2. Comments from students in ZOOL 401 (n=96) and ZOOL 581 (n=18) when asked if they found *Parasite Patrol* helpful to their learning. Comments were grouped into either positive or negative responses, with counts.

ZOOL 401 (n=96)		Count
	"prompts discussion amongst peer.", "Visualisation was helpful.", "I think the interactive activity helped us to visualize and understand them better. Working with team members also helped as well.", "helps to discuss more with classmates.", "Helped me visualize key aspects of the life cycles of parasitic species.", "The game made us read information regarding the parasites and their life cycles.", "It was a useful tool to visualize the diversity that exists among parasites.", "We didn't make it all the way through the game in the time allowed but the parts we did were educational.", "I think a little more time was needed then we got to fully understand more.", "It made it easier to visualize life cycles.", "It didn't overwhelm us with information as a textbook might.", "The diagram helped me understand where the parasites are located in each life stage.", "it was a fun way to learn.", "Having a visual diagram to place the parasite in helped establish connections between the concepts being taught and reality.", "It helped me understand about the parasite patrol visually and I loved it.", "I loved the colours and interacting with the game, it seemed more hands on than just reading.", "The game was focused on helping us learn about parasites in a way that was simple and did not overwhelm with excessive information.", "Because it helped me to visualize how parasite lifecycles more generally.", "it allowed me to see where the stages occurred in a diagram and I got to place them on the lifecycle diagram so I understood it better.", "it was well organized and went more in about which parasite was in which host and their lifecycle.", "by being able to see how the parasites work.", "Was interesting, harder to play on a screen but worked very well otherwise.", "It was interactive so it made you more inclined to learn..", "I am more familiar with a variety of parasites and I learned about parasites I was not previously aware of.", "It visualized the life cycles and made it fun and engaging to learn.", "Helped understand the diversity of parasites.", "The game provided information on a large number of parasites organized by host.", "Having multiple parasites together in one image and actually having to move them into place was helpful.", "reading information about the parasites and then using that knowledge to put the life stages in the right places helped cement the information.", "It was good to see the lifecycles of all the parasites in the body of the host. It helped me learn.", "All the cards were really informative, the pinning was also interactive.", "This was a very informative visual way to understand the lifecycle of parasites.", "helped learn many life cycles in a fun and interactive way.", "It was a break from the normal activities and there was no pressure.", "It felt like a competitive game not like a learning lab which was nice.", "Very detailed, the cards were informative.", "This game helped me understand the concepts because it was interactive and because i was actually playing the game i retained the information better than if someone was just telling me the concepts.", "It was memorable and informative.", "Good for comparing parasite lifecycles.", "Having to place the parasites ourselves was helpful.", "It was a fun way to learn information about different parasites.", "It helped me visualize where each parasite is found and where the life cycles take place, but it was long and had quite a bit of info covered.", "I already knew most of the information, but if I hadn't it definitely would have!", "It helped because I was interacting with it and could therefore remember what I did better than just reading a textbook.", "Yes as it accurately outlined the life cycles of different parasites.", "I found it helped me understand the concepts better because it was more hands on and allowed me to apply some of the concepts I was learning.", "I think the competitiveness that came in the game formal helped me want to learn more and more about the lifecycles as fast as possible!", "It was a fun and entertaining way to learn more about parasites, especially with the fun facts included in.", "I think that it was really interesting to see how different parasites can get into the systems of these mammals.",	
Positive responses	"reading out all the facts and seeing where each of the lifecycle stages belonged	79

<table>
<tr><td></td><td>on the host really helped visualize the information easily.", "I think it was helpful pinning each different lifecycle on the corresponding environment/host.", "it was different and will likely stick with me.", "Yes it did because you see a range of parasites with their different hosts.", "It clearly described all the parts of the lifecycles and made it fun by adding some competition.", "It had a lot of information that helped apply the knowledge needed.", "sometimes its hard to decide where the lifecycles take place for different parasites, so this was a more interactive way to be able to place where they belong.", "Its a very informative game that covers a lot of parasites for several types of hosts.", "The presentation was memorable and encouraged teamwork.", "I have a better general understanding of the parasites out in the world and how their lifecycles work.", "It gave in depth information and wonderful visuals too.", "The competitive nature of the game drove me to learn the information more clearly than if it was not a game.", "The game had a lot of great info and it was fun to play with others! The only reason I didn't put strongly agree is just because I didn't get much time to finish the game with my group, so I did not get to full absorb everything, but I know I would if I were playing on my own time - awesome job!", "the visual is really helpful.", "The cards were concise but informative. The interactive quality was well suited to my learning style.", "it was a much more fun and relaxed learning environment.", "visualizing the stages and hosts helped solidify my learning rather than just reading about it.", "I think it was a fun and competitive way to get the players engaged and this in turn caused everyone to actually focus and learn so they could win the game!", "It has the information in a concise way. It was also fun!", "This was an engaging activity with good visuals. I think it did a great job representing the different lifecycles of the parasites.", "The simple matching concept is like repetition so it helps with memorization of facts and the turns and competition made it more engaging.", "lost of information, fun, well paced.", "Helped to incorporate parasites into a matching memory game.", "Exposure to the different kinds of parasites.", "Gave a fun and insightful way of developing invertebrate biology knowledge.", "Yes, but the game was lagging a little and we ran out of time.", "I think it help me to use my knowledge.", "Had visuals and all the information.", "I did find the game a very interesting way to learn about the concepts, but there definitely is a lot of information still and will require some repetition to remember.","I think this is more useful to me than the story and wish I had more than 25 minutes to do it.",</td><td></td></tr>
<tr><td>Negative responses</td><td>"There was just a lot of information to remember in such a short time.", "I think a little more time was needed then we got to fully understand more.", "If given more time we definitely would have been able to learn a lot more.", "no time to actually take in the info, also when one person is doing all of the work for the whole game, i don't feel like i'm learning anything. if we had a longer time to play, i think i would be able to learn, but this was too short.", "I think it would have if we werent rushing through it. It completely defeats the fun of having a game in the first place. Would have been awesome if we had more time.", "There was a lot of information so some of it was immediately lost, especially the information given by other teams.", "we spent more time trying to figure out the controls and pin things on the proper places and messing with our computers and wifi etc. than actually learning
there way too many steps so we felt we had to rush and couldn't learn as much.", " I don't think that flipping and matching cards aided in my learning.", "Was too long so had to rush and couldn't learn.", "It just took so long that I was rushing to get it done rather than learn.", "Unfortunately the game was very glitchy for all parties, so the majority of the time was spent just trying to make it work properly and finish on time.", "I just finished reading Parasite Rex so a lot of the information was still fresh in my mind from the book, there wasn't as much left for me to learn from the game.", "I would perhaps have different information on the two cards to build the lifecycle.", "I really only explored parasites in cows so im missing info about other hosts.", "sometimes couldn't focus on the information given provided because focused on winning.", "There wasn't enough time to take notes on all parasites but I did learn about the ones I took notes on.", "I do think it helped but we didn't get to spend too much time on the activity so i think more time with the game would be even more beneficial.", "You learn more about one host parasites more than the others but need to take extra time to retain other host's parasites.", "It is a lot of information at once and for someone</td><td>20</td></tr>
</table>

	like me with a disability its hard to learn a lot in one sitting like this. But it was still fun.", "We were in a bit of a time crunch and there was a lot of material to get through so we didn't get to all of it.".	
ZOOL 581 (n=18)		Count
Positive responses	"collaboration and talking to others about their knowledge helped people build on each other's preexisting knowledge.", "The fun facts were engaging, the emphasis on all the different hosts being in the environment as shown by the images was great! It was engaging to build the lifecycle yourself and the hint of competition was engaging! The fun facts were a great idea.", "Having to think through the lifecycles was good and having a visual alongside an action to match it was really good.", "gave detailed descriptions of parasites and where they live.", "It had a lot of detail and was engaging, which helped us understand main concepts.", "Pinning the stages on the diagrams did help a lot with understanding certain lifecycle stages for sure.", "It was an easy game to follow and simplified lifecycles.", "Having an interactive component to learning makes it easier to absorb and remember.", "It was interactive which I think allows students to grasp information more and have it sink in.", "Interactive learning helps with memory.", "I think I learn better at my own pace so it would almost be good to have access to it post-class to review it on our own time, but the information is good and it's great for visual learners with the drag and drop and colour coding.", "I think the information was really helpful and well condensed.", "It was an interactive way of learning about parasite lifecycles and diversity, and the requirement to match cards kept it fun and game-like while providing a good pace to introducing new information.", "Great tool to visual and show many parasite interactions.".	14
Negative responses	"The game had the potential to help me understand concepts through the visuals and simplified information, however, it was also easy to go on autopilot mode because all the locations and answers were already provided so there wasn't much of a need to think.", "This is good for someone with very little background knowledge. Not me personally.", "some technical difficulties online. Also reliant on the teams reading their cards out loud. Would probably be great for younger students like elementary school.", "It was fun, but I do not like online board games. I think it would be better to have it in person (post-covid world) as I felt a bit rushed reading the cards.".	4

Table A3. Comments from ZOOL 401 (n=96) students when asked to describe their favourite parts of *Parasite Patrol.* Students' responses fell into seven categories, and the quotes and counts for each category are provided.

ZOOL 401 (combined n=96)		
Favourite Part	Comments	Counts
1. Visuals	"The cool diagrams of the human, cow and dog.", "The visuals...", "...drawings...", "The graphics.", "...the visuals.", "I enjoyed how you could exactly see where the different life stages were on the diagram...", "The visuals/drawings/locations.", "The visuals.", "The visuals and graphics.", "The illustrations...", "...the design of the game. I think it was super creative!", "The graphics....", "Graphics.", "the graphics were nice.", "...the board with the areas that the lifecycles are present in.", "I like seeing everything all together.", "I liked that everything was colour-coded, which made it easier to understand what was going on.", "The visuals, and how it relates to the game.", "The visuals depicting the lifecycles.", "...the visuals!", "The colour coding of the cards and the visual diagrams.", "Inclusive interactions.", "Drawing the life cycle.", "The different cards...", "The cards...",	25

2. Interactiveness : a) Pinning the parasites	"...getting to drag the life stages.", "Putting the different parts of the parasite lifecycle on the pictures.", "The pinning of the different stages.", "The placing the parasite to see where it is.", "Correctly pinning the parasites onto the host.", "...labelling.", "Matching the lifecycle part to the image.", "Identifying the Life cycle.", "Moving the stage to the correct parts of the human.", "The organization of it and being able to drage the parasites to their location.", "you had to locate them which improved my understanding.", "Placing the parasites where they belong.", "I liked placing the different parts of the parasite's lifecycle.", "...I enjoyed dragging each stage onto the diagram.", "Needing to actually label the different parts helped me visualize the lifecycle.", "I really liked putting the parasites on the different parts of the organisms. It helped me form a better understanding of where each stage of the lifecycle occurs.", "Placing the images of parasites on the different body parts. This created a memorable visual that sticks with me.", "...the dragging...", "placing the life stages on the organisms.", "Pinning the corresponding life cycle stages to the correct location on the illustration.", "Placing the parasites on the organism was fun and interactive.",	21
3. Interactiveness b) Clue Cards	"the card matching of the info sheet.", "correct card matching...:", "Matching the cards together.", "The matching...", "trying to remember the cards that were already flipped.", "...getting guesses correct.", "...the game concept (matching cards).", "memory matching game...", "the memory/matching portion.", "trying to match the cards together so beat the other teams.", "the matching scheme.", "The matching.", "The memory challenge aspect.", "Reading clues.", "flipping the cards was fun.", "flipping the cards over.", "reading the information cards were also very interesting as well.", "reading out the lifecycle...", "The interactive card flipping...", "flip the card.",	20
4. Interactiveness c) Teamwork	"The group interaction.","team work.", "teamwork.", "The interactiveness.", "interaction.", "being able to engage with the game.", "playing with classmates,", "it being interactive...", "The interactiveness.", "the interactive nature.", "the teamwork aspects.", "How interactive the game was..." , "The interactive parts of the lifecycle...", "Panicking with my team mate, great team building exercise.", "Interacting with peers.", "The interactiveness required.", "working as a team.", "it was engaging.", "working together with a teammate and having to discuss course material.", "the interactivity of the game and that it didn't take too long.",	20
5. Game content/information	"...fun facts.",. "...fun facts!", "Learning more about parasites!!!", "learning about diversity in parasites.", "Learning more about parasites.", "Learning which parasites infect which hosts.", "The way information is presented simply.", "...information...", "The information on the cards telling me about the parasite lifecycles.", "the game.", "...the large amount of information.", "...all of the details that were put into the game.", "Using teams with different hosts.", "its simple, not too many rules.", "fun facts.", "the cards that were flipped over with information.", "...parasite fact cards.", "...The cards were also very informative and helped teach the concepts well.", "The cards as they do not have too much information...", "The cards and the facts on them.".	20
6. Competition	"Competing to win the detective badge, and we won!!", "...competition.", "Beating the opposing team...", "the fact that there was a winner.", "The competition! ", "The competition aspect against the other teams.", "...the competition.", "Competing with my friends.", "the competitive aspect makes it fun and engaging.", "The friendly competition.", "The general idea that you are competing against others, adds an elements to the enjoyment.", "working towards a goal.",	12
7. Fun	"that its actually a fun card game.", "...was fun to have a different experience to the norm.", "...fun..", "...having fun.", "having a fun interactive lab in an online environment.", "The fun interactive portions...",	6

Table A4. Comments from ZOOL 581 (n=18) students when asked to describe their favourite parts of *Parasite Patrol.* Students' responses fell into five categories, and the quotes and counts for each category are provided.

ZOOL 581 (n=18)		
Favourite part	Comments	Counts
1. Interactiveness: a) Pinning the parasites	"the game and figuring out the lifecycle and placing it in the picture.", "I liked how the components fit together and how you could build the lifecycles yourself! That interaction with the game pieces beyond reading is very helpful and from a teaching perspective I could see this being a lot of fun with kids.", "pinning different life cycle stages onto the hosts.", "Being able to match the stages of the parasite life cycle to the diagrams.", "...pinning the life cycle stages.", "...physically matching areas...", "drag and drop stages on diagram.", "The interactiveness.", "The interactive aspect.", , "The interactive component...".	10

2. Interactiveness b) Clue Cards	"Reading the cards...", "Reading everyone's cards.", "finding matching cards.", "Finding the matching cards.", "Matching the cards and trying to win."	5
3. Visuals	"The graphics.", "the colours, and graphics.", "when you get to visually see the lifecycle.", "-great graphics and design!"	4
4. Competition	"I'm competitive so it was fun to win."	1
5. Game content	"Lots of information."	1

Table A5. ZOOL 401 (n=96) students recommended improvements for *Parasite Patrol* after playing the game. Their responses fell into ten categories, and the quotes and counts for each category are provided.

ZOOL 401 (n=96)		
Improvements	Representative comments	Count
1. Game platform	"Make it a board game!", "Sometimes the interface was tricky to navigate but I think that was just because I hadn't used it before.", "A more non-computer friendly interface.", "improvement to the platform.", "Maybe UI updates.", "Making the controls easier for macs.", "easier controls would be better.", "Potentially making the cards easier to read without zooming.", "Game noises?", "A more user friendly platform.", "controls were confusing to use.", "A couple group members were confused about the controls could be more cohesive.", "Different website with less glitches.", "would be better in person because there was a lot of talking over and technical difficulties. but overall great game!", "Someway to control the turns of different people so team's turns do not overlap.", "the game was a little glitchy and slow to load but that's unforeseen.", "It was really good, but the clicking/deleting was difficult.", "Make controls a little less complicated!", "Easier ways to interact (just in terms of the tech).", "I don't know if this is possible but maybe have a program with a faster reaction time to the inputs.", "I know it's not really possible, but the place where it was done was a bit laggy.", "Fix the glitches to make it run more smoothly.", "it was hard to control. I could not flip the cards or drag them. it kept zooming out randomly.", "maybe work on the game, it took awhile to be able to click and flip things.", "perhaps not as many people on the platform at once because it was a bit glitchy but that's alright!", "Make it easier to use, the gameplay was difficult and we had issues where we couldn't undo deleting the cards which took away from the actual game play.", "The system used to play the game on could at times be a bit non-user friendly (controls were slow, etc.) but I totally recognize that with virtual learning it can be difficult and I think you did great!", "It can make some improvement for flip back thing.", "some difficulties with running the game.", "Maybe make easier controls. The cards wouldn't flip for anyone in our room except one, to they had to control everything.", "Overall it was a good game. Some of the game play could have been made easier though.".	31
2. None	"None. Since I'm colourblind I found the use of shapes very helpful to distinguish colours; thank you for including that!", "It was a great experience. I don't think it needs any changing.", "It was great.", "nothing comes to mind.", "NA.", "None! I thought it was great!", "None that could come into mind.", "The game is good as is.", "I'm not sure.", "None! It was really nice.", "Nothing, once we got the hang of how to control the game with worked very well with no issues.", "None.", "Sorry, I can't think of any.", "N/A.", "NA.", "n/a", "n/a", "N/A", "None! It was great and very fun.", "I think it was good as is! Very well done :) ", "None! Very good game.", "The game is pretty great as is! Very informative.", "no ideas.", "website structure.", "I thought the game was well executed and I really enjoyed the visuals.", "as said above!".	26

3. More time	"There needs to be more time to enjoy playing the game, it was way too rushed.", "More time to properly play the game.", "just a little more time.", "longer time for playing.", "more time to get around to all the parasites would've been nice.", "Give us more time! We didn't have time to thoroughly finish and go through everything in the game.", "None for the game itself, I would have liked more time.", "Give more time to play.", "more time.", "maybe a little more time to play so it doesn't feel rushed at there is time to talk about it.", "This activity needs more than 25 minutes and I think that the cards could provide more information about the life cycle.".	11
4. Game mechanics	"not have so many steps. i.e. flipping over the cards. just have clues or something that we have to match the parasite to the parts on the host body.", "Maybe find a way to make it less reliant on luck. Maybe combine a small trivia question part with a section that improves on existing knowledge with additional information.", "If someone is up for a challenge maybe they can choose time limit mode so the game is more fast paced and winning requires knowledge.", "Maybe some more activities requiring that you place the larvae, adult etc. in the order of the lifecycle.", "Maybe have a way to have another turn of matching, or like finding the superclue lets you pick again. Bc other wise team human will likely win because they get to first.", "would suggest that a single team has to pick cards from every host to enhance the learning of all of the host parasites rather than be limited to a single host. It might make the game slightly more complicated, however.", "I don't think the randomness element aided in my memory- if anything it made me focus less on each parasite by focusing so much on why colour was where.", "maybe for returning players, have a bigger deck of cards to choose from to create more of a challenge and for more parasites to read about.", "Maybe have it so that whoever finds the question marks gains points in descending order.", "The only drawback is that its a little more based on luck and guessing for the matching. This made it fun but maybe if you can recall info about the lifecycle or something you get bonus points? That would be fun!", "music in the background, maybe a timer to make it more challenging,".	11
5. Game content	"providing a little more information about more fun facts about parasites if possible.", "Maybe giving too many clues on where the phase of the lifecycle may make it a little easy. To challenge players, maybe you could add riddles or subtle hints so one may investigate and further engage to figure out the correct answer.", "maybe put sideeffects of parasiteon card to make it something that could be identified in reality.", "...perhaps more parasite and host animals.", "Make it half as many parasites.", "I would suggest adding a little information on how the host is effected by the parasite, like what does toxoplasmosis do to the human brain, how does heartworm affect dogs, thing like that.".	6
6. Visuals	"lifecycle organization.", "Larger font size.", "I thought it was a pretty good game, some of the locations on the diagram were a little confusing at times but all in all it was very good.", "Maybe if the cards themselves were a bit bigger for more room, not too much to critique.", "Run a bit better, maybe more spread out information?", "Maybe less shapes on the graphics as things got really messy near the end.".	6
7. Game length	"The game was long as it included lots of chance moments, like waiting to come across a matching pair of cards, so it took a lot longer to get started. Since each card contained lots of information it was also challenging enough to get through it in a timely fashion.", "The game can be shortened a little bit. It felt really long at times.", "Much sorter, no card matching,".	3
8. Team formation	"Get people to make teams before starting the game. Some people were confused about what teams they were in."	2
9. Competition	"More incentive for competition.", "Something that adds some more competition to win rather than just chance.".	2
10. Game instructions	"Adding to the control description that you can change what your cursor does.".	1

Table A6. ZOOL 581 (n=18) students recommended improvements for *Parasite Patrol* after playing the game. Their responses fell into seven categories, and the quotes and counts for each category are provided.

ZOOL 581 (n=18)	

Improvements	Representative comments	Count
1. Game mechanics	"if the three teams played at the same time it would be more of a competition.", "more cohesive competition needed perhaps, want it to be more of a game where winning is incentivized.", "Finding a way to randomize which team goes first or try and eliminate the advantage the human team has by going first.", "Knowledge wise it is interesting, a component to motivate you to find it would be a great addition like an extra turn or getting to peek at an extra card. Some sort of twist revolving around the superclue.", "Also, some bonus for finding the superclue would be great.", "Find a way to balance the disadvantage of going last for Team Dog.", "balance out the first-turn advantage.", "Find a way to break a tie. Team cow finished the same round as us but it was only because they get to go before us.", "Can we get a "solve this puzzle" option like wheel of fortune haha.", "Have a function to sort teams and something that tells you which team you are on (if it will be kept as an online game).", "Make it so the team has to come to a mutual agreement before cards can be flipped (i.e. every single team member must click the card before flipping is enabled)."	11
2. Game platform	"Possibly the way it was presented: it was difficult to do on zoom when we couldn't talk to our team (especially for trying to choose cards!), would have been easier to do in person, but with that not possible I am really not sure how it could have been better adapted for online!", "would be fun to have an actual board game as I got caught up in the controls.", "Some of the control were a little glitchy.", "be able to zoom out more on the console...", "the platform is difficult to use when zooming in and out..."	5
3. Game instructions	"I would move the last slide (game instructions) to the very beginning, right after the game controls. It got a bit lost at the bottom of the game. Other than that, it was very well done!", "Move instructions to the top", "It would also be helpful to move the instructions to the beginning of the game instead of at the end of it.", "The question mark was a bit confusing."	4
4. Game content	"adding more parasites if possible.", "...for university level it was simple. would be great for elementary students.", "There is a lot going on I'll admit but considering I've only played this one time maybe playing it multiple times will help me get used to it more. I think having more cards to match would bring a bigger challenge but for those who have already played it, it will make it more fun."	3
5. None	"N/A.", "None, sorry. The images and colours were all fantastic, the pace of the game was really good, and it managed to be fun and definitely a game while also being educational."	2
6. Visuals	"Maybe not having the locations for the parasites coded onto the animal would make students use their application skills a little bit more as they try to find the locations by themselves."	1
7. Game environment	"maybe less monitoring by the TA, it got more fun once we felt we could freely talk to the other classmates without the TA instructing us what to do for every part of the game"	1

References

Acka CA, Raso G, N'Goran EK, Tschannen AB, Bogoch II, Séraphin E, Tanner M, Obrist B, Utzinger J. 2010. Parasitic worms: Knowledge, attitudes, and practices in western côte d'ivoire with implications for integrated control. *PLoS Negl Trop Dis,* 4, 1–14.

Annetta, L.A., Minogue, J., Holmes, S.Y., Cheng, M. 2009. Investigating the Impact of Video Games on High School Students' Engagement and Learning About Genetics. *Computers & Education,* 53, 74-85.

Anyanwu EG. 2014. Anatomy adventure: A board game for enhancing understanding of anatomy. *Anat Sci Educ,* 7, 153–160.

Barata G, Gama S, Jorge J, Goncalves D. 2013. Engaging engineering students with gamification. 2013. In: *5th Int Conf Games Virtual Worlds Serious Appl VS-GAMES 2013.* Lisbon, Portugal.

Brown, C.L., Comunale, M., Wigdahl, B., Urdaneta-Hartmann, S. 2018. Current Climate for Digital Game-Based Learning of Science in Further Education and Higher Education. *FEMS Microbiology Letters*, 365, 1-10.

Clement, J. 2021. *Number of monthly active players of Minecraft worldwide as of May 2020.* https://www.statista.com/statistics/680139/minecraft-active-players-worldwide/#:~:text=How%20many%20people%20play%20Minecraft,items%20within%20their%20new%20world (accessed February 2021).

Cosme Junior, L., Turchen, L.M., Guedes, R. 2020. Insect World: Game-Based Learning as a Strategy for Teaching Entomology. *The American Biology Teacher*, 82, 210-215.

Dzulkifli MA, Mustafar MF. 2013. The influence of colour on memory performance: a review. *Malays J Med Sci* 20, 3-9.

Fatta, H., Maksom, Z., Zakaria, M.H. 2019. Game-Based Learning and Gamification: Searching for Definitions. *International Journal of Simulation: Systems,* 19, 41.1-41.5.

Garcin, B., Mariani, L.L., Meneret, A., Mongin M., Delorme, C., Cormier, F., Renaud, M-C., Roze, E., Degos, B. 2019. The "Neurological Hat Game": A Fun Way to Learn the Neurological Semiology. *Rev Neurol,* 175, 528-533.

Hamari J, Keronen L. 2017. Why do people play games? A meta-analysis. *International Journal of Information Management,* 37, 125-14.

Liu EZF, Chen P-K. 2013. The Effect of Game-Based Learning on Students' Learning Performance in Science Learning – A Case of "Conveyance Go." *Procedia - Soc Behav Sci,* 103, 1044-1051.

Malone TW. 1980. What makes things fun to learn? heuristics for designing instructional computer games, p. 162–169. In: *Proceedings of the 3rd ACM SIGSMALL Symposium and the 1st SIGPC Symposium.* Palo Alto, California.

McGreevy KM, Church FC. 2020. Active Learning: Subtypes, Intra-Exam Comparison, and Student Survey in Undergraduate Biology Course. *Education Sciences,* 10, 1-15.

Menendez D, Mathiaparanam ON, Liu D, Seitz V, Alibali MW, Rosengren KS. 2020. Representing Variability: The Case of Life Cycle Diagrams. *CBE Life Sci Educ*, 19, 1-15.

Parker LE, Lepper MR. 1992. Effects of Fantasy Contexts on Children's Learning and Motivation: Making Learning More Fun. *J Pers Soc Psychol,* 62, 625–633.

Perrotta C, Featherstone G, Aston H, Houghton E. 2013. *Game-based Learning: Latest Evidence and Future Directions*. Slough: National Foundation for Educational Research. 1-40p.

Pinhatti, K., Amaro de Lima, M., Cirimbelli, C.F., Ercolin, A.C.M., Disselli, T., Hage, M.C.F.N.S. 2019. Board Game Improves the Learning Process in Small Animal Diagnostic Imaging. *Adv Physiol Educ,* 43, 66-68.

Qian M, Clark KR. 2016. Game-based Learning and 21st century skills: A review of recent research. *Computers in Human Behaviour,* 63, 50-58.

Raimondi, SL. 2016. ImmuneQuest: Assessment of a Video Game as a Supplement to an Undergraduate Immunology Course. *Journal of Microbiology & Biology Education,* 17, 237-245.

Selvi, M., Cosan, A.O. 2018. The effect of using Educational Games in Teaching Kingdoms of Living Things. *Universal Journal of Educational Research,* 6, 2019-2028.

Spiegel, C.N., Alves, G.G., Cardona, T., Leandra, M.C.M., Mauricio R.M.L., Tania, C.A, Andrea H. (2009). Discovering the Cell: An Educational Game About Cell and Molecular Biology. *Journal of Biological Education*, 43, 27-36.

Steinman, R.A., Blastos, M.T. 2002. A Trading-card Game for Teaching About Host Defence. *Med Educ,* 36, 1201-1208.

Su, T., Cheng, M., Lin, S. 2014. Investigating the Effectiveness of an Educational card Game for Learning how Human Immunology is Regulated. *CBE Life Sciences Education,* 13, 504-515.