One Health concepts were incorporated in a foodborne disease outbreak investigation with game features of data presented as visual and manipulative clues. Postsecondary pre-veterinary medicine and animal biosciences students and food science students \((n = 319)\) enrolled in an introductory animal and food sciences course over a 3-year period received a brief introduction to foodborne illness, an outbreak scenario, and investigative tasks to complete individually or in groups. Tasks addressed epidemiology, laboratory, environment, traceback, recall, and prevention concepts. Gamification of the exercise involved generation of a numerical code to unlock a combination lock as an indication of successful organization, compilation, and interpretation of data. Students presented investigation findings and responses to critical thought questions on their roles. Student surveys on engagement and self-perceived change in conceptual understanding indicated that nearly all expressed increased understanding of outbreak investigations, safe food production, and environmental water as a transmission vehicle. Volunteered learned concepts indicated enhanced appreciation for the complexity of food safety and interdisciplinary connections. Students enjoyed the exercise (92%) and cited the clues and group interaction among the most enjoyable features. Objective assessment of student conceptual learning with the subset of students who conducted the investigation individually \((n = 58)\) demonstrated significant increase in correct test responses \((49\% \text{ pretest}; 76\% \text{ posttest})\) after completion of the investigation for all questions combined and across all learning objectives. These data demonstrate the value of a foodborne disease investigation with escape room gamification features for engaging students in One Health concepts and exercising problem-solving, critical thinking, and skills for independent and collaborative work.

**KEYWORDS** food safety, investigation, One Health, education, microbiology, public health, escape room, problem-based learning, epidemiology, environment

**INTRODUCTION**

One Health acknowledges the interconnectedness of human, animal, and environmental health and is an interdisciplinary approach to addressing shared interests for wellbeing (1) (https://www.cdc.gov/onehealth/basics/index.html). The One Health approach is profoundly evident in the prevention and investigation of foodborne illness. Human impact from foodborne disease is significant, with an estimated annual burden of 48 million illnesses attributed to contaminated food in the United States (2) and consequent economic burden estimated at $15.5 billion due to loss of life, treatment, and lost productivity for survivors (3). The bacterial, viral, and parasitic disease agents most commonly associated with foodborne gastroenteritis are predominantly zoonotic and persist in environmental water and soil and on edible plants (4–6). The transmission of foodborne diseases and the professions centered on their prevention, control, and remediation provide a model for One Health instruction. An understanding of One Health concepts by future professionals of food science and related agriculture and public health disciplines is essential for societal wellbeing.

Foodborne illness outbreak investigations have been demonstrated to support instruction across the science curriculum for secondary and postsecondary students (7, 8). Their effectiveness was attributed in part to the case study format (7, 8), which is purported to support comprehension, critical thinking, and emotional connections when in context of a story (9–12). Gamification of educational content has also been reported to increase student engagement in subject content through interactive and playful features (13). Game-based education can take on digital and physical forms, including the presentation of data in the form of visual and physical (manipulatives) puzzles and clues which students interpret to solve a series of interconnected problems. An emerging game-based platform is based on the escape room model, in which a group
of participants work together to identify and interpret clues in order to escape from a confined space within a designated time (14) or determine codes to open a locked box (15). These formats have been regarded for engaging participants in content and exercising critical thinking, teamwork, communication, and resilience, as well as supporting multimodal learning styles (16, 17). This approach has been applied for education for a variety of disciplines (16–24), as well as in business training exercises (25), with positive impact on engagement, teamwork, communication, critical thinking, and making connections among concepts.

The activity presented herein combines case-based, problem-based, and gamification educational features in a novel mock foodborne illness outbreak investigation in which data are presented as visual, text, and manipulative-based puzzles or clues and formatted for individual or group investigation (Fig. 1 and 2). The outbreak scenario illustrates environmental transmission of foodborne zoonotic diseases and mitigation strategies centered on Shiga-toxigenic Escherichia coli with potential transmission from livestock to raw agricultural food commodities through contaminated environmental water. The scenario was selected to address One Health connections among animals, humans, plants, and the environment and to address natural resource limitations, such as water scarcity, that are pertinent to safe food production. The investigation purposefully did not implicate one commodity, region, or type of practice to minimize inappropriate assumptions about food safety risks. Phases of the investigation and related data clues address concepts in epidemiology, laboratory, traceback and product recall, environmental survey, and prevention of recurrence (Table 1). Through the investigation, students are introduced to interconnected careers in public health, food production, regulation, research, data management, and environmental monitoring in various institutional settings, including clinical care, public health agencies, regulatory agencies, the food industry, analytical laboratories, academia, and various research institutions. Individual and group formats expose students to the same type of data formatted as visual, text-based, or manipulative clues. For individual use, the students work through data of each phase of the investigation, followed by a class discussion. The group format provides for more gaming features and group interaction whereby groups of approximately five students each interpret data puzzles from one phase of the investigation to generate a 3-digit numeric code to unlock a preset combination lock based on the escape room model. Opening the lock unseals an envelope with a congratulatory note and a prompt for students to address critical thought questions regarding interconnectedness of investigative phases and related but unresolved challenges associated with safe food production. Groups communicate investigation findings and responses to critical thought questions to the class.

**Intended audience**

The investigation activity is appropriate for application in postsecondary and upper secondary courses related to food
FIG 2. Examples of data for investigation: (A) puzzles and clues as manipulatives, (B) example of one group’s tasks to complete to generate a 3-digit number corresponding to the lock code, and (C) example of text-based data set with placeholders to enter answer.
| Group | Investigative role | Tasks | Clue type | Concepts | Skill(s) | Critical thought topic(s) |
|-------|-------------------|-------|-----------|----------|----------|-------------------------|
| A     | Epidemiology      | Determine exposure date | Patient and control data disks | Disease surveillance | Data compilation | Patient symptom variability |
|       |                   | Determine common exposure | | Incubation period | | Exposure date relevance to investigation |
| B     | Laboratory        | Determine lab tests for clinical samples | Patient data disks | Pathogens and disease | | Recall measures if lab results cannot corroborate epidemiology data |
|       |                   | Determine time frame to results | Visual of lab protocols | Principles for pathogen detection | Data interpretation | |
|       |                   | Match clinical and food isolates | Jigsaw puzzle of PFGE© gel | Technologies for pathogen detection | | |
| C     | Traceback and recall | Interpret product bar code | Wheel puzzle of bar codes with decoder | Product labeling | Data organization | Traceability software and investigations |
|       |                   | Trace implicated product to source | Parking house source and distribution records | Food manufacturing | | |
|       |                   | Determine breadth of product distribution | | Traceback | Data interpretation | Actions to notify and protect public health |
| D     | Environmental     | Evaluate potential role of environmental conditions for contamination | Rainfall data disks and epidemic curve | Weather and climate impacts on water resources | Data organization | |
|       |                   | Evaluate production environment and practices on contamination risk | Jigsaw puzzle: topographical map and water sources | Water as a disease transmission vehicle | Data interpretation | |
|       |                   | Determine risk for contamination by irrigation method and commodity | Irrigation and commodity visuals | Good agricultural practices | | |
|       |                   | | | Food processing for risk reduction | | |

(Continued on next page)
| Group | Investigative role | Tasks | Clue type | Concepts | Skill(s) | Critical thought topic(s) |
|-------|-------------------|-------|-----------|----------|----------|--------------------------|
| E     | Prevention of recurrence | Determine microbiological risk of nontraditional water resources | Contamination data disk for water sources | Limited natural resources, Natural resource reclamation | Data compilation | Evidence and impact of human activity on natural resources |
|       |                    | Evaluate compliance with regulatory standards | Hidden graph and decoder | Technology for risk reduction, Indicator microorganisms | Graphical representation of data | |
|       |                    | Evaluate inactivation research data | | Regulatory compliance | | |
|       |                    | | | Research for advancement of science and problem solutions | Computation | |

<sup>a</sup>A shortened version of the same data sets and concepts are also formatted for students to complete investigation tasks individually.

<sup>b</sup>All group activities exercised collaboration and communication skills.

<sup>c</sup>PFGE, pulsed-field gel electrophoresis.
science, animal science, biology, public health, and One Health. The activity can be formatted for individual completion during class time, as a homework assignment, or as a group classroom activity. When formatted as a group investigation, completion of the activity in class is appropriate for class sizes of 18 to 30 students.

### Learning objectives

Upon completion of this problem-based, foodborne illness outbreak investigation conducted individually or collaboratively, students will be able to (i) characterize the impact of foodborne illness on public health, (ii) identify factors that contribute to the transmission of pathogens and evaluate strategies to minimize risk of disease transmission through food, (iii) identify stages of foodborne illness outbreak investigations and analyze and evaluate data utilized for resolution of outbreaks, and (iv) identify various professional roles and regulations associated with assurance of a safe food supply and their application for prevention and resolution of foodborne illness outbreaks.

### PROCEDURE

#### Materials

The materials needed to complete the investigation are described in Appendices 1 and 2. Appendix 1 is a handout for students to work through text-based data sets and is most suited for individual and independent work. These handouts can be laminated for students to record responses with an erasable marker to allow for cleaning and reuse between class sections or semesters. Appendix 2 provides handouts for students to work in groups and with instructions for the educator to create and present to students the data as manipulatives. The manipulatives can generally be created with paper, standard clips, plastic disks (optional alternative to paper), cellophane, and a magnifier, all of which were sourced from discount store chains and provided in envelopes by task (Fig. 2A features examples). Three-digit resettable combination locks can be sourced from retailers that distribute hardware, housewares, or travel supplies.

#### Student instructions

Student instructions are provided in Appendices 1 and 2. Appendix 1 is the self-contained student handout with all necessary background information and instructions included to work stepwise through the data individually and independently in class or as a homework activity. Appendix 2 provides the instructions for students to work through tasks as a group. Students should be provided a large envelope which contains the outbreak scenario, smaller envelopes with the group tasks, and an envelope sealed with the 3-digit combination lock inserted in the envelope closure through a small hole (Fig. 2B). Students complete the tasks within a group and collaborate to generate the 3-digit lock combination. Students then discuss and collectively respond to critical thought questions provided in the handout. When all groups have completed their tasks, students present their tasks and findings.

#### Faculty instructions

Appendices 1 and 2 provide the necessary content and instructions for preparation and administration of the activity, and Appendices 3 and 4 provide the accompanying instructor presentations for each activity format. These resources are available online at [https://www.udel.edu/academics/colleges/canr/departments/animal-and-food-sciences/affiliated-centers/conserve/outbreak-investigation/](https://www.udel.edu/academics/colleges/canr/departments/animal-and-food-sciences/affiliated-centers/conserve/outbreak-investigation/).

For students to complete the investigation individually within 40 min, instructors should prepare a set of handouts (Appendix 1) for each student. An accompanying instructor presentation is provided in Appendix 3 which includes slides to introduce the topic and activity and slides to guide the postactivity class discussion.

For group investigations with the data also presented as manipulatives, instructors should prepare Appendix 2. This guide includes the handouts and instructions for preparing the tasks and accompanying puzzles. Prior to class, the instructor will need to prepare envelopes for each of the five phases of the investigation to be completed by five groups of students (4 to 6 students per group). One large envelope will contain (i) the outbreak scenario, (ii) a worksheet to record their 3-digit code (which corresponds to the combination lock) generated by successful completion of tasks, (iii) critical thought discussion questions and guide for student presentation to the class, (iv)
smaller envelopes with the individual tasks and data, and (v) a smaller envelope sealed with the lock inserted through a hole punched through the seal. Groups can test the lock as many times as necessary in the allotted time. While it may be possible for students to randomly try numbers on the lock, students should be prompted to explain how each correct number is derived based on interpretation of evidence. Appendix 4 is the accompanying instructor presentation that includes slides to introduce the topic and activity and slides to guide the postactivity class discussion, during which students present their tasks and solutions to the class as well as the critical thought questions and their groups’ responses.

Suggestions for determining student learning

Foundational knowledge and application can be assessed by questions related to the learning objectives (Appendix 5). The investigation activity is further designed to exercise student recognition of patterns to organize and compile data sets, provide graphic representation of data, perform mathematical functions to aid interpretation of data sets, and draw conclusions from the data. The activity also exercises student communication within small groups and to the larger class body. Conceptual understanding and the ability to work with the data are demonstrated through the students’ ability to perform computations and draw appropriate conclusions regarding the likely outbreak source, recall needs, and risk identification and mitigation. These successes can be measured by student recordings on worksheets, successful generation of the code to open the lock, and class discussion at the conclusion of the investigation. Student learning can also be measured by written assessments for foundational information and ability to connect the investigative stages and data through response to critical thought questions that evaluate ability to apply knowledge.

Sample data

Students organized the provided data and performed computations and graphical representation of organized data. Students also discussed instructor-provided prompts related to each phase of the investigation and presented their ideas to the class. Representative student data are presented in Figure 3.

Safety issues

There are no safety issues with this lesson; the exercise does not involve laboratory work.

DISCUSSION

Field testing

The outbreak investigation activity was utilized by 319 students in an introductory animal and food sciences.
laboratory rotation course at the University of Delaware (UD) over three semesters spanning 3 years (Fig. 1). The same instructor taught each of the 16 different student sections of the course during the implementation period. The investigation was formatted as an individual activity (58 students) and as a group activity (261 students). Students were enrolled in pre-veterinary medicine and animal bioscience (91%), food science (8%), or other majors (<1%).

**Evidence of student learning**

Assessment protocols were submitted to the UD Institutional Review Board for Human Subjects Research and were deemed exempt from full IRB review under exemption category number 1 of the common rule. Students over 18 years of age were provided verbal and written description of their opportunity to participate in objective and subjective measures of learning, including voluntary and anonymous student surveys administered prior to and after completion of the investigation to measure conceptual understanding and perception of the educational experience. To maintain confidentiality, signed consent was not garnered; students were informed that their voluntary election to participate was considered consent. No personal identifying information was collected with responses, and data are reported in aggregate.

Both subjective and objective measures utilized in the evaluation of this exercise indicated positive impact on student engagement and learning. The students had limited prior exposure to the content, as indicated by their enrollment in the introductory course as well as self-characterization, with 93% reporting prior knowledge as "some" (52%) or "a little" (41%). Successful completion of the tasks relied on problem-solving skills and, in the case of group formatting, effective teamwork. At the conclusion of the exercise, students’ volunteered learning outcome themes demonstrated recognition of the overarching interconnectedness of One Health disciplines, concepts, and professional roles (Table 2). Student-volunteered responses...
| Response category                        | Representative response(s) to prompt “From this class exercise I learned...”                                                                 | No. of responses | Individual investigation (n =58) | Group investigation (n = 261) |
|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------------------------|-------------------------------|
| Investigative process, problem-solving | “...all of the procedures, time, and effort that goes into investigating an outbreak.”                                                         | 22              | 120                             |
|                                         | “...how many aspects influence the investigation of foodborne illness.”                                                                        |                 |                                 |
|                                         | “...that investigation takes a lot of time and parts to find the problems.”                                                                     |                 |                                 |
|                                         | “...there are many aspects to investigating an outbreak and they all connect to one another.”                                                  |                 |                                 |
|                                         | “...how to break down a problem.”                                                                                                            |                 |                                 |
| Food safety                             | “...how everything we do effects the quality and health of our food.”                                                                       | 20              | 30                              |
|                                         | “...how what humans do can impact food safety positively and negatively.”                                                                     |                 |                                 |
|                                         | “...how important it is to reduce foodborne illness transmission.”                                                                        |                 |                                 |
|                                         | “...the importance of regulating food production.”                                                                                           |                 |                                 |
| Water safety                            | “...how much different aspects of human activity actually affect water sources and crops.”                                                   | 8               | 65                              |
|                                         | “...human impact on water sources.”                                                                                                          |                 |                                 |
|                                         | “...the importance of controlling water quality.”                                                                                              |                 |                                 |
|                                         | “...foodborne illnesses and the role of water.”                                                                                                |                 |                                 |
| One Health connections                  | “...how everything is connected between the environment, people, and animals.”                                                                | 4               | 51                              |
|                                         | “...the connection between food safety and the environment.”                                                                                   |                 |                                 |
|                                         | “...the relationship of the components of One Health.”                                                                                         |                 |                                 |
|                                         | “...how illnesses can be transmitted through food and water.”                                                                                   |                 |                                 |
| Professional roles                      | “...how scientists protect society from foodborne illness.”                                                                                     | 1               | 7                               |
| Specific task                           | “...how barcodes are created.”                                                                                                                 | 1               | 12                              |

*Total responses by category exceeds number of student subjects because some students provided multiple responses.*
to the open-ended prompt regarding the most enjoyable aspect of the exercise focused predominantly on the puzzle/clue/escape room features and application of problem-solving skills in a real-life scenario for approximately 28% and 68% of students who completed the activity individually or in a group, respectively. For field testing, students who worked in groups used data clues presented as manipulatives, which may in part account for the difference in the volunteered responses and potential benefits of gamification for engaging students in the content. Among students who completed the investigation in groups, 23% volunteered that working as a team was the most enjoyable aspect of the investigation. Students who worked in groups also rated the interactive exercise more favorably as an enjoyable learning approach, indicating the value of collaboration for engaging students as well as exercising this important skill. Instructors observed active participation in the investigation among class members for both individual and group formatting and a high level of interaction among students who completed the investigation in groups.

In addition to engagement and self-perceived learning gains reported among all students, objective assessment outcomes with the subset of students (n = 58) who completed the investigation individually provide evidence for improvement in conceptual understanding for each of the learning objectives (Table 3). For all 15 questions combined (Appendix 5), the average percentage of correct responses increased significantly as determined by Student’s t-test (JMP Pro 15.1.0 Software, 2019) from approximately 49% prior to conducting the investigation activity to 76% after the activity. Significant improvement in

### Table 3

| Question no. | Learning objective (LO) and topic | Student correct responses (%) (n = 58) | Pretest | Posttest | Change* |
|--------------|----------------------------------|--------------------------------------|---------|----------|---------|
| 1            | LO1. Public health impact: estimated annual no. of foodborne illnesses |                                    | 6.9     | 94.8     | 87.9°   |
| 2            | LO1. Public health impact: illness symptoms and outcomes |                                    | 91.4    | 100.0    | 8.6     |
| 3            | LO2. Transmission factors: microbial persistence and replication in food and water matrices |                                    | 18.0    | 36.2     | 18.2    |
| 4            | LO2. Transmission factors: zoonotic disease agents |                                    | 94.8    | 100.0    | 6.9     |
| 5            | LO3. Investigative process, tools, and data: illness outbreak breadth and traceback |                                    | 84.5    | 91.4     | 6.9     |
| 6            | LO3. Investigative process, tools, and data: illness onset and epidemic curve |                                    | 67.2    | 84.5     | 17.2°   |
| 7            | LO3. Investigative process, tools, and data: illness source attribution |                                    | 31.0    | 86.2     | 55.2°   |
| 8            | LO3. Investigative process, tools, and data: illness outbreak traceback |                                    | 27.6    | 48.3     | 20.7°   |
| 9            | LO3. Investigative process, tools, and data: evaluation of environmental water |                                    | 6.9     | 29.3     | 22.4°   |
| 10           | LO3. Investigative process, tools, and data: laboratory strategies to connect samples |                                    | 56.9    | 82.8     | 25.9°   |
| 11           | LO4. Roles and regulations: regulation of water for food |                                    | 81.0    | 74.1     | –6.9    |
| 12           | LO2. Transmission factors: risk factors for environmental water safety for food |                                    | 94.8    | 94.8     | 0.0     |
| 13           | LO2. Transmission factors: bacteria persistence, transmission, and impact |                                    | 37.9    | 75.9     | 37.9°   |
| 14           | LO2/LO4. Transmission factors: risk factors for environmental water safety and food characteristics |                                    | 27.6    | 93.1     | 65.5°   |
| 15           | LO4. Roles and regulations: modern food regulations |                                    | 13.8    | 41.4     | 27.6°   |

*Significant difference (P < 0.05) between pretest and posttest percent student correct responses as determined by Fisher’s exact test (2-tailed) (JMP Pro 15.1.0 Software, 2019).
percent correct responses was observed for 9 of the 15 questions and across all learning objectives (Table 3). This assessment was conducted with the students who completed the investigation individually in field testing; however, the assessment resource (Appendix 5) could also be used with students who conduct the investigation collaboratively.

Possible modifications

While the investigation was implemented as either a visual and text-based individual activity or a more manipulatives-based group activity, individuals could also complete all phases of the investigation using the hands-on clues. This would require the instructor to either provide a sufficient number of manipulatives clue sets for all investigative phases for each student or offer stations of manipulatives clues through which students would rotate. This would provide for each student to use all of the hands-on clues for all phases of the investigation. The activity could also be modified for digital instruction via a learning management system through which students could access data visuals and question prompts and enter their answer codes. To accommodate different instructional schedules or student learning needs, the activity could also be completed over a series of class periods with potential instructional pause points after the introduction and/or after the group activity. The individual exercise format could also be completed as a homework assignment.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 8.1 MB.

ACKNOWLEDGMENTS

This material is based upon work supported in part by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-68007-25064. We declare no conflicts of interest.

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