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Jigsaw method improves learning and retention for observation-based undergraduate biology laboratory activities

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ABSTRACT

Complementing biology lecture courses with laboratory sections is nearly universal at undergraduate institutions, yet many topics in biology do not easily lend themselves to experiment-based laboratory activities. Topics such as comparative anatomy, evolution and systematics are often taught as passive, observation-based laboratories. In this experiment, we modified and tested the efficacy of a team-based learning approach called the 'Jigsaw' method in 14 sections of an undergraduate Vertebrate Biology laboratory course at Iowa State University. Specifically, we implemented the modified Jigsaw method in seven lab sections and taught seven lab sections in the traditional lecture and observation style, comparing mean quiz score between the experimental and control sections after accounting for variation due to instructor and year. We revealed significantly higher average quiz scores for students in the experimental sections as compared to the control sections. Herein, we describe the details of our modified Jigsaw implementation that can be applied to other such biology laboratory courses. Thus, we provide further support for the use of team-based learning approaches such as the Jigsaw method and specifically show that undergraduate biology laboratory courses can be improved by implementing such activities in lieu of a clear experimental approach to laboratory courses.

KEYWORDS

Jigsaw; biology laboratory; quasi-experimental; undergraduate

Introduction

Collaborative and active learning teaching methods have been implemented in classes of all subject matter in order to promote deeper and more meaningful learning (e.g. Ebert-May, CA, and Allred 1997; Paulson 1999; Johnson, Johnson, and Smith 1998). The benefits of these teaching approaches have been demonstrated thoroughly such that the question is no longer whether or not collaborative or active learning is beneficial, but rather when, and under what circumstances is it most beneficial (Nokes-Malach, Richey, and Gadgil 2015). To answer this, continued quantification of learning outcomes for different styles of collaborative and active learning are necessary. In this experiment, we expand this important area of research to an understudied aspect of biological instruction: observation-based laboratory courses.

Active learning in biology is certainly not a new concept. For the vast majority of biology undergraduate courses, active participation in learning is achieved by experiment-based laboratories. However, many topics in biology do not easily lend themselves to experiments that fit the temporal and budgetary limitations of the laboratory setting, and for those units, experiment-based learning is often replaced with observation-based laboratories. For example, comparative anatomy and

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macroevolutionary theory are frequently taught with lectures and observation-based laboratories, potentially allowing students to disengage from in-class learning. To counter this disengagement, instructors may incorporate worksheets or guides to help students participate in learning the material more deeply, but these activities can be frustrating to some (Griffin 2004) and can lead students to focus solely on topics covered by the worksheet at the expense of learning broadly (Harrison 1967). To encourage a more holistic understanding of the material, we developed and tested a method of active, collaborative learning for broad use in observation-based biology laboratory courses.

The approach tested herein is a modified implementation of the 'Jigsaw' method, a well-studied team-based learning (TBL) approach proven to be useful in several biology lecture topics such as systems biology (Kumar 2005), invertebrate taxonomy (Sezek 2013) and cell-biology (Dori, Yeroslavski, and Laxarowitz 1995). The Jigsaw method is a unique, two-phased activity that fosters cooperation and interdependence between students (Aronson et al. 1978; Hennessy and Evans 2006; Doymus 2007), which promotes positive feelings towards school (Blaney et al. 1977), the course in which the Jigsaw method is implemented (Eilks 2005; Sahin, 2010; Ural et al. 2017), and classmates (Phillips 1956; Phillips and D'Amico 1956; Cooper and Kerns 2006). The first phase of the Jigsaw method separates the students into 'Expert Groups', whereby each group is assigned a different portion of the class material to learn and master. As an Expert Group, the students are tasked with understanding their topic deeply enough to be able to teach others about their material in the second Jigsaw phase, in which students are reassigned into new 'Learning Groups'. Each Learning Group is made up of one member from each Expert Group. This way, each Learning Group has an Expert from each portion of the class material. During phase two, each member of the new Learning Group takes a turn teaching their new group members about the material they mastered as part of phase one.

In this study, we tested the efficacy of the modified Jigsaw method in 14 sections of a Vertebrate Biology Laboratory, a 300-level (i.e. upper-division) course at Iowa State University in Ames, Iowa across two years (2016 and 2017). Laboratory class topics include taxonomy, comparative anatomy and macroevolutionary patterns of vertebrates. Traditionally, this course is taught with a 50-minute lecture followed by either an observational period or a dissection period, depending on the week's material. For each laboratory class, the students are given a worksheet designed to encourage the students to explore the displayed specimens thoroughly, which students completed before leaving. In the experimental sections, the modified Jigsaw method was implemented after the same 50-minute lecture was given. Six quizzes covering taxonomy, comparative anatomy and evolutionary biology were given to students throughout the semester, which were used as the measures of learning and retention in this experiment.

Methods

Participants: Data were collected from Iowa State University undergraduate students enrolled in Vertebrate Biology (BIOL 365) in 2016 and 2017. Fourteen sections were taught by six instructors, and sections were randomly assigned as experimental (n = 7) or control (n = 7) such that each instructor taught one of each design when possible (Table 1). Because participation in this experiment was voluntary for instructors, this paired design was not always possible, such that one instructor taught two control sections (instructor D). To achieve an equal number of sections in each group, one instructor was assigned two experimental sections (instructor C). We also randomised order of teaching such that some instructors taught the experimental section as their first section of the week, while others taught the experimental section as their second section. All students were informed of their participation before the course began and were given a written opportunity to be excluded from the study. IRB certifications were obtained for all authors and instructor participants implementing the Jigsaw Treatments.

Control Treatments: Each week, students attended a two-hour lab section that began with a 50-minute lecture and followed with either specimen dissections or specimen observations. For specimen observations, instructors placed various preserved specimens throughout the classroom organised by

Table 1. Section data, including the total number of quizzes taken (n), instructor ID, treatment, year, and mean quiz score. Randomisation of treatment assignment was according to instructor willingness and prioritised balancing the order of which treatment was taught first to mitigate instructional differences between novice and practised lectures (2 jigsaw sections taught as the first section, 3 taught second, 2 taught as a sole section for the year from instructor C).

Section	n	Instructor	Treatment	Year	Mean Quiz Score
1	161	A	Jigsaw	2016	78.4
2	148	A	Control	2016	82.7
3	167	B	Jigsaw	2016	76.8
4	131	B	Jigsaw	2017	56.1
5	144	B	Control	2016	71.9
6	130	B	Control	2017	56.2
7	168	C	Jigsaw	2016	80.9
8	124	C	Jigsaw	2017	61.5
9	132	D	Control	2017	59.8
10	123	D	Control	2017	53.0
11	136	E	Jigsaw	2017	56.2
12	131	E	Control	2017	54.1
13	141	F	Jigsaw	2017	62.8
14	135	F	Control	2017	61.1

Order. After the instructor's lecture, students were encouraged to look at all specimens to visualise the concepts and patterns discussed during the lecture. Students were given a short worksheet to complete, after which they were free to leave or remain to ask questions or study more thoroughly. For dissection weeks, each section was broken into six groups, and each group was given a distinct specimen to dissect while focusing on a specific body system across all taxa. The specimens for any one week spanned the breadth of vertebrate clades, including rats, rabbits, mink, frogs, snakes, turtles, lizards, fishes, sharks and others. After dissections, students were encouraged to explore other groups' specimens and complete a worksheet covering all specimens, but no further interaction was required.

Jigsaw Treatments: Sections in the experimental group experienced the same weekly class lecture with the added structure of the Jigsaw activity following the lecture. As per the first stage of the Jigsaw method, students were broken into six 'Expert Groups' and assigned either a portion of the observational specimens to examine or a single specimen for dissection (same specimen selection as control groups). After the students had become comfortable with their Expert material, groups were reshuffled into four new 'Learning Groups' with one student from each of the Expert Groups. The new Learning Groups then rotated around the classroom, visiting the preserved or dissected specimen(s) designated to each Expert topic. At each station, the Learning Group's resident Expert would teach the other members of their group the important components of their topic before moving onto the next station.

Data Collection and Analysis: All students were given six in-class quizzes throughout the semester, each written and graded by the instructor. The same quizzes were given to both sections of each instructor. Quiz scores were collated and analysed with personal identifiers removed, and scores were calculated as percentages. Scores of zero were given to students who missed class on the day of the quiz and were excluded from this study. Scores above 100 resulted from extra credit questions available on some quizzes. We analysed our data with a mixed effects ANOVA with the RRPP package (Collyer and Adams 2019, 2018) in R v.3.6.0 (R Core Team 2019). As some instructors only taught for one of the two years and quizzes were written by individual instructors, our model quantified the differences in experimental and control quiz scores while accounting for variation due to instructor and year. From this ANOVA, we extracted empirically derived Z-scores as a measure of effect size for each independent variable.

Results

We collected data from 411 students of the Vertebrate Biology laboratory course, ranging from sophomore to senior level. Across the two-year duration of this study, we quantified scores from

1,971 quizzes (1028 Jigsaw, 943 Control; Table 1). On average, students in the experimental Jigsaw sections scored 5.336 percentage points higher than the Control sections on quizzes ($Jigsaw_{Mean}$ = 68.597%, $Control_{Mean}$ = 63.261%; Figure 1). Results from the ANOVA demonstrated a substantial effect of treatment on average quiz score after accounting for instructor and year ($Z_{Treatment}$ = 2.3924, $p_{Treatment}$ = 0.001; Table 2).

Discussion

We tested the efficacy of the Jigsaw method in improving learning and retention in students of an upper-level undergraduate biology course. Such classes are traditionally taught in a morepassive manner, leaving room for pedagogical improvement in these settings. Using a quasi-experimental approach and robust statistical analyses, we demonstrated a substantial improvement in average quiz score for students involved in the Jigsaw teaching method (Table 2 and Figure 1) across two years and several instructors. Thus, our study contributes to the growing literature that demonstrates when and under what circumstances active learning methods are most impactful.

Although our findings support the general trend of improved learning and retention when the Jigsaw method was implemented, this was not observed universally across instructors. In particular, instructor A demonstrated the opposite effect of lower average quiz scores in the Jigsaw section

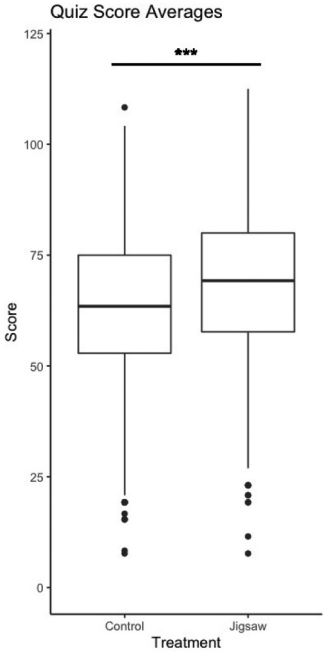


Figure 1. Average quiz scores between control and Jigsaw sections. Quiz scores were significantly higher in the Jigsaw sections (Z = 2.3924, p = 0.001), averaging 5.336 percentage points higher.

Table 2. ANOVA table from the mixed-effects model. Results for the treatment effect of Jigsaw vs Control are bolded, and the large Z-score indicates a substantial effect size of the Jigsaw teaching method.

	df	SS	MS	F	Z	P
Treatment	1	14,003	0.02169	63.286	2.3924	0.001
Instructor	5	122,600	0.18990	110.815	7.1610	0.001
Year	1	74,648	0.11563	337.364	3.3044	0.001
Residuals	1963	434,350	0.67278			
Total	1970	645,601				

(Table 1). This may be due to several factors, not least of which is the dependence of Jigsaw effectiveness on instructor experience in implementing and facilitating the necessary classroom procedures (Webb 2009). Indeed, instructor A had not previously taught the course in which this experiment was conducted, and this lack of experience could explain the less effective implementation of the Jigsaw method. Thus, our results emphasise the importance of proper training and preparation for instructors implementing the Jigsaw method.

Originally developed by Aronson et al. (1978) to foster a feeling of community between students of different races in newly integrated schools, the Jigsaw method has also been shown to improve in-class learning and retention (e.g. Mattingly and VanSickle 1991). Since its inception, it has been utilised in many settings, yet quantitative studies have revealed a variety of outcomes regarding the effectiveness of the Jigsaw method in different learning environments. For instance, Tarhan et al. (2013) found that the implementation of a Jigsaw learning group yielded better acquisition of physical and chemical concepts in sixth-grade public school students, while Slish (2005) found no significant improvement in test scores when the Jigsaw method was implemented in a Non-Majors Introductory Biology lecture course. Our study is the first to quantify the efficacy of the Jigsaw method for biology laboratory topics traditionally taught using observation and dissection, showing conclusively that learning and retention in these laboratory courses can be improved through the Jigsaw method. Thus, we broaden the understanding of when the Jigsaw method is most effective.

Many biology laboratory courses are experiment-based and thus already involve active learning. However, many topics in biology do not lend themselves to the type of experiment-based Jigsaw method utilised in these papers, and labs covering topics like comparative anatomy, evolution, or vertebrate biology are still traditionally taught in passive learning environments, encouraging students to explore specimens on display without much direction or incentive. These results show the utility of the Jigsaw method across many non-experimental laboratory lessons. For subjects that lend themselves to an observational study, the Jigsaw method can help engage students in collaborative and active learning, leading to higher performance and deeper understanding of the topics at hand.

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Author contributions

EKB, DCA and MSR conceived of the project. EKB and MSR implemented the experimental intervention and collected the data. EKB analyzed the data and wrote the manuscript with input from both DCA and MSR.

All authors gave final approval for publication and agree to be held accountable for the work performed therein.

Disclosure statement

No potential conflict of interest was reported by the authors.

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