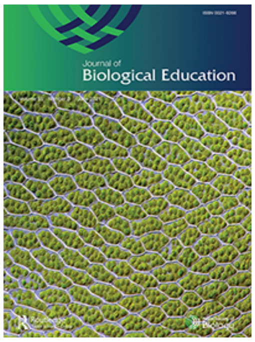

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Jigsaw dissection activity enhances student ability to relate morphology and ecology in aquatic insects

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ABSTRACT

Functional feeding guild classification of aquatic insects is partly based on mouthpart morphology, but the link between mouthpart morphology and ecological feeding roles is often missed by students in the classroom. We implemented a Jigsaw activity in a freshwater biology course to help students connect morphology and ecology. Paired students dissected two common (to the whole class) and one unique aquatic insect's mouthparts and predicted their ecological feeding roles. Students then divided into new groups and taught peers about their unique insect. A pre- and post-activity survey measured students' ability to relate morphology and feeding roles. Open-ended questions graded via a rubric showed students scored significantly higher and provided more answers discussing feeding roles. Likert-type questions probing students' perceptions of mouthpart importance resulted in marginally higher importance ratings of mouthparts for identification but no differences for insect feeding. On an end-of-the-semester assessment, students generally rated the activity as helpful. Some reported the activity to be difficult due to small insect size. The activity enhanced students' understanding of the link between mouthparts and feeding roles but may have decreased their engagement due to perceived difficulty. Further modification alleviating difficulty may improve student perceptions while retaining knowledge gains.

KEYWORDS

Jigsaw; cooperative learning; laboratory; entomology; mouthparts

Introduction

In this study, we explored the use of a Jigsaw activity for the dissection of aquatic insect mouthparts. The Jigsaw activity here involved pairs of students becoming 'experts' on one unique type of aquatic insect mouthparts. The pairs were then reassigned into new groups, with one student from each of the unique mouthpart pairs. Students in the new groups taught their peers about their unique insect, facilitating peer-learning in improving student understanding of the relationship between morphology and function in organisms. This relationship is important both as an ecological concept and in organismal classification, but the connection is often missed by students. The taxonomic classification of organisms was originally based upon morphological characteristics, and although classification methods have now grown to encompass genetic technologies, morphology remains an important aspect of understanding differences between species (Dunn 2003; Wheeler 2008). While the use of taxonomic characters for identification is on the decline as genetic technologies expand, the link between morphology and ecology helps to define a student's understanding of structure and function within organisms (Wheeler 2008).

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Aquatic insects, for example, are classified into functional feeding guilds describing their trophic relationships (Cummins and Klug 1979; Wallace and Webster 1996; Merritt, Cummins, and Berg 2008; Cummins 2018). Guilds, such as shredders, collector-gatherers, scrapers, and predators, represent a combination of mouthpart morphology and behavioural adaptations and provide a way to make inferences about species' feeding relationships (Cummins and Klug 1979). The shape of the mouthparts can be particularly important in determining potential food resources for an aquatic insect by limiting the types of food that can be ingested. Mouthpart morphology is therefore often used to make initial hypotheses about insect feeding roles, which relate to the ecological role of an aquatic species within its environment (e.g. Ramírez and Gutiérrez-Fonseca 2014; Cummins 2018). As such, aquatic insects can serve as model organisms for helping students understand the links between structural adaptations and ecological functions such as feeding roles.

Science education research has revealed that ecology can be a challenging subject for biology students due to the large amount of information that needs to be integrated and, similarly, zoology can be difficult because of new terminology (Okebukola and Jegede 1989; Fauzi and Fariantika 2018). Learning about the ecological feeding roles of aquatic insects has the potential to be overwhelming for students since it requires students to combine concepts from both zoology and ecology to understand new terminology, classifications, and relationships between organisms. Some studies, however, have shown that cooperative learning can help students connect information between basic observations, such as those related to morphology, and the ecological role of organisms (Koprowski and Perigo 2000; Mangtorn and Helldén 2007). Cooperative learning is an active learning technique which places greater learning responsibility into students' hands as active participants and can increase student achievement in higher education science courses, including within the laboratory (Smith, Hinckley, and Volk 1991; Colosi and Zales 1998; Springer, Stanne, and Donovan 1999; Lord 2001).

Cooperative learning includes a variety of strategies to engage students. One type of cooperative learning commonly implemented in classrooms is Think-Pair-Share, which is known to increase student engagement and critical thinking skills (Lyman 1981; Kaddoura 2013; Kothiyal et al. 2013). The instructor first poses a question for students to think about individually. Each student then shares their thoughts with another student in pairs, where they need to defend their answers and reach a consensus. Finally, student pairs share with the whole class, stimulating classroom discussion. Cooperative learning can also include structured group problem-solving, such as in Process Oriented Guided Inquiry Learning (POGIL). POGIL was originally developed for the chemistry classroom in the 1990s but has since been utilised in a variety of courses and has been shown to increase student achievement and likelihood of passing a course (Moog et al. 2006; Moog and Spencer 2008; Brown 2010; Johnson et al. 2011; Walker and Warfa 2017). POGIL exercises take place during class sessions in groups of 3–4 students who are each assigned a specific role (i.e. recorder, presenter, manager, reflector) which changes among the members of the group each time a POGIL is conducted. Students are given some sort of model and set of questions which they work collaboratively to examine, while the instructor serves as a facilitator.

Another often-used cooperative learning method is the Jigsaw, which has been successfully implemented in various types of science laboratory exercises (e.g. Smith, Hinckley, and Volk 1991; Colosi and Zales 1998; Koprowski and Perigo 2000). The Jigsaw expands upon cooperative learning in that students are not only responsible for learning within a group, but they need to become the 'expert' on an aspect of the material in order to then teach their classmates what they have learned (Aronson and Goode 1980; Colosi and Zales 1998). By teaching their peers, the student better learns and understands the material themselves (Colosi and Zales 1998). The positive effects of Jigsaws have been seen in courses covering topics of morphology and classification, which are key concepts for understanding links between mouthpart morphology and feeding roles. For example, Koprowski and Perigo (2001) implemented the Jigsaw method within an anatomy class where pairs of students were assigned to one organism for the course. Each week, the class explored a different organ system with the pairs focusing on their unique organism. These student pairs then taught their peers about their organism's specific organ system. Results indicated that students found the technique to be effective in helping them learn about each system across organisms. In another study, Sezek (2013) compared the achievement scores of students who were taught classification of invertebrates by either a Jigsaw method or a traditional teacher-focused method and found that students within the Jigsaw group scored significantly higher on a post-test designed to measure their knowledge gains than those taught via traditional methods. The success of the Jigsaw approach in such biology courses indicates that it can be a powerful and effective tool that may also help students make connections between mouthpart morphology and feeding roles in aquatic insects.

The freshwater biology course taught at the University of Maryland includes a laboratory section with a strong focus on identification and taxonomy of aquatic insects based on morphological traits. Early in the semester, students begin learning to classify aquatic insects into orders based upon morphological traits while sampling during field trips. After a month of field trips, students return to the lab to learn about the ecology and identification of families within these insect orders. Prior to beginning identification work, students historically completed a mouthpart dissection activity which introduced them to key terms and morphological traits for later identification purposes. This activity failed, however, to help students make connections between morphology and feeding guilds, which is one of the course instructor's goals. As such, we redesigned the dissection activity as a cooperative learning activity with a Jigsaw component to expose students to a greater diversity of mouthparts than time would otherwise allow, providing a stronger basis for them to make hypotheses regarding morphology and function as well as directly connect with the concept. Student understanding of this link was examined with a pre- and post-activity survey, and the overall helpfulness of the activity towards their learning was assessed at the end of the semester. With this data collection, we sought to investigate if students would (1) Gain understanding of the importance of mouthpart morphology for ecological feeding roles, (2) Find the activity to be helpful towards their learning, and (3) Find the activity an enjoyable aspect of the course.

Methods

The Jigsaw activity, as detailed below, involves dissection of aquatic insect mouthparts. In previous years, although dissections were performed in pairs, students were not connecting mouthpart morphology and feeding ecology. To better connect these concepts for students, a Jigsaw was used to allow students to take greater ownership of their learning and enable the instructor and the graduate student teaching assistants (TAs) to demonstrate a greater range of insect mouthparts. Here, we describe the course, its goals, the specific Jigsaw activity, the assessments used to evaluate the activity, and the analysis of the assessments.

Course background

Freshwater Biology is a four-credit upper-level biology course (BSCI 467) taught in the fall at the University of Maryland College Park, United States of America, with three one-hour class sessions and one three-hour laboratory session each week. The class sessions are taught by a faculty member (the course instructor) while the laboratory sessions are taught by TAs, one for each of the two sections. The course instructor and TAs meet weekly to harmonise teaching between laboratory sections, prepare the week's tasks, and ensure that the course content is clear. The course is generally taken mostly by seniors, and both sections fill quickly for a maximum of 48 students. The class sessions, mostly traditional lectures given by the course instructor with a few lectures by guest speakers, covers various topics in freshwater biology including key aspects of still and flowing waters, trophic interactions, water quality issues, and ecological restoration. Some class sessions

Table 1. Laboratory section major assignments and point breakdown. Assignments total 300 points out of the course total of 750 points.

Assignment	Points
Order practical (in field)	50
Midterm practical	50
Final practical	50
Mouthparts dissection in-class activity	10
Mouthparts dissection online surveys	10
Insect Collection	80
Participation	50
Total	*300*

involve POGIL exercises on topics of the consequences of water, seasonality of lentic and lotic waters, hydrographs and hydrology, the process of science, and aquatic insects and water quality. See all course topics in Supplemental Material Table 1.

The laboratory sessions focus on aquatic insect taxonomy, and grades derive mainly from laboratory practicals about ecology and identification of aquatic insects and an insect collection (Table 1). The first month of the course includes a series of field trips to collect aquatic insects at streams and wetlands, while the rest of the semester involves mini-lectures by the course TAs on the ecology and identification of aquatic insect orders. See all topics in Supplemental Material Table 1. Paired students complete an aquatic insect collection from the field trips, and the identification of their specimens occurs during lab after the mini-lectures. These student pairs are assigned at the beginning of the semester based upon abilities and interests. During the first laboratory period, students are given a brief introduction to key differences between aquatic insect orders and independently complete a pre-test that does not count towards their grade. This pre-test requires students to identify aquatic insects to order using provided keys. After completing the pre-test, the TA reviews their answers and has them return to any organisms that were incorrectly identified until all answers are correct. The number of attempts on this pre-test helps the course instructor and TAs to sort students into the assigned pairs so that a weaker student can be paired with a stronger student. In addition, students fill out a brief questionnaire in lecture, and the answers (e.g. regarding future career goals) are used to further pair students.

Mouthpart dissection activity

Every year in week six or seven of the course, after the field trips but prior to the mini-lectures on aquatic insect orders, students perform a mouthpart dissection activity during a laboratory session to familiarise themselves with aquatic insect morphology necessary for later identification. In years prior to 2017, students were required only to dissect *Pteronarcys* sp. shredding stonefly specimens. In 2017, this activity was modified to include dissection of both *Pteronarcys* sp. and a predatory perlid stonefly in order to help students see differences in morphology based upon feeding guilds. This activity received further modification in 2018 with the goal of guiding students to a greater understanding of the importance of morphology to function in terms of feeding for aquatic insects by including a larger number of functional feeding guilds. The activity modification that was tested in 2018 and is reported here used a total of six organisms and was completed by both sections of the course, totalling 48 students (n = 24 per section).

Prior to the activity, the TA gave a short lecture to introduce students to generalised insect mouthpart structures and explain the concept of functional feeding guilds. Students then worked in their assigned pairs to dissect three different specimens. Each pair dissected a predatory perlid stonefly (Plecoptera: Perlidae) and a shredding *Pteronarcys* sp. stonefly (Plecoptera: Pteronarcyidae), and each pair was assigned a third organism out of four options. The options included cranefly shredders (Diptera: Tipulidae: *Tipula* sp.), predatory backswimmers

(Hemiptera: Notonectidae), scraping/grazing mayflies (Ephemeroptera: Heptageniidae: *Stenonema* sp.), and assorted predatory odonate larvae (Odonata: Anisoptera). Each of these additional specimens had modified mouthparts that varied greatly from those seen in the perlid and *Pteronarcys* sp stoneflies. Specimens had been collected from local streams and ponds and were kept preserved in 80% ethanol until the activity, and the largest in size of those collected were used for the activity.

During the dissections in pairs, students were required to remove, identify, and label the major mouthparts from their specimens on an index card, using provided tools and a dissecting microscope. Their dissections were verified by the section TA. Students worked on a worksheet (see Supplementary Material) in their dissection pair which required comparing and contrasting the mouthparts of each specimen and forming a hypothesis about which functional feeding guild the specimens may represent. When students had completed their dissections in pairs, the pairs were split up and new groups of four students were formed. The groups consisted of one student from each of the unique third organisms (Jigsaw), allowing students to share their unique observations with the group on the mouthparts and their hypotheses on functional feeding guild. As each pair only had one specimen, students then took turns looking under the microscope at the dissected mouthparts of the unique specimens. After groups were finished discussing their findings and observations, the class was reconvened and a discussion ensued regarding observations and hypotheses about the functional feeding guilds of each organism. Completing the worksheet and activity in class was worth 10 points out of 300 total possible points within the laboratory section towards student grades and was graded on completion and not on correctness. Students' responses on the worksheet are not included in this study.

Activity assessments and data analysis

Students completed an identical pre- and post-activity survey provided electronically on the course management website. The surveys were each worth five points, given for completion of each survey (10 points for completion of both surveys out of 300 within the laboratory portion of the course). The pre-survey was available for one week prior to the laboratory section when the activity was performed, and the post-activity survey was available for one week after the laboratory section. The survey contained a total of six questions, four of which were open-ended and two Likert-type questions. These questions (see Tables 2 and 3) were intended to assess to what extent students gained an understanding of the following: (1) How mouthparts play a role in determining functional feeding guilds, (2) Ways to determine what an insect eats, and (3) Recognising that functional feeding guilds are important in classification of aquatic insects and in understanding their ecological roles. Answers for the pre- and post-activity surveys were separately downloaded from the course management website. To deidentify answers but keep them paired for a given student, each student was assigned a random number and answers were sorted by number prior to analysis. The ID numbers and identities were kept in a separate, password-protected file from the deidentified answers. All students ($n = 48$) completed both surveys and provided consent for their responses to be used via informed consent forms included in the pre-activity survey.

Student answers to the open-ended questions were categorised into major themes (see Table 2) and scored on a scale of 0–2. A score of 0 indicated the answer was incorrect or not related to the question, a score of 1 indicated the answer was correct but generally did not incorporate aspects of how mouthpart morphology relates to functional feeding guilds, and a score of 2 indicated an answer demonstrated understanding of the topic of mouthpart morphology and functional feeding guilds. Scores were assigned by the first author and an independent aquatic ecologist, and average percent of agreement was 95.3. Scores across all four open-ended questions were summed and compared via a paired two-tailed t-test for pre- and post-activity answers. Responses to themes were always greater than 100% of the number of students when added due to multiple answers being provided by each student for each question. Likert-type questions were asked regarding the

Table 2. Major themes within student answers, number of responses on each survey within the themes, and example of student answers related to themes for the four open-ended questions. Note that the sum is always greater than 100% of students as answers required multiple responses per question.

Question	Theme	Number of Pre-Activity Survey Responses	Number of Post-Activity Survey Responses	Example
(1) What are some ways to classify/categorize insects? List at least 3.	Morphology (non-mouthparts)	76	46	'Morphology (filaments, antenna, gill placement)'
	Mouthparts	31	42	'Look at mouthpart structures. Scoop, sucking, chewing, etc.'
	Feeding Guilds	0	21	'The things they eat (shredder vs. predators)'
	Life Cycles & Development	18	17	'By life cycle (holo vs. hemimetabolous)'
	Phylogeny	22	15	'Phylum, Class, Order, etc.'
	Habitat	5	13	'Aquatic or terrestrial'
	Ecological Role & Behavior	3	4	'Niche space'
	Physiology	2	1	'Gills/respiration'
(2) What are some ways scientists may determine what an insect eats? List at least 2.	Mouthparts	41	55	'What kind of mouthparts it has'
	Studies & Observations	23	23	'Observe in nature'
	Habitat	12	16	'Where it is located (depth – benthic zone, etc. or location in stream in riffles/current or pools'
	Gut Analyses	14	9	'By looking at what is in its stomach'
	Morphology	9	8	'Legs'
	Organismal Relationships	3	5	'Comparing its diet to that of a similar insect who's[sic] diet is known'
(3) What are some methods of obtaining food used by insects? List at least 3.	Functional Feeding Guilds & Mouthparts	47	127	'Collector/filterers, shredders and scrapers, predators'
	Feeding Behavior	42	9	'Hiding and catching as food passes'
	Non-Insect Methods	20	6	'Buying from third party'
	Food Categories	16	5	'Plants, other insects, microbes'
	Other Appendages	6	4	'Grabbing with tarsi'
	Detection	11	1	'Use chemical cues to find food'
(4) Why does it ecologically matter what an insect feeds on?	Food Webs & Trophic Levels	29	32	'Because they usually feed on the proportion of the food web that makes up the foundation! So the majority of the biomass (bottom of the food pyramid) in an ecosystem is encompassed by these organisms, so if they were removed or impacted all organisms above them in the food pyramid would be affected.'
	Ecosystems	25	28	'Whatever the insect feeds on contributes to the overall ecosystem. There will be ecosystem services and functions provided by the things that eat'
	Energy & Nutrients	8	14	'Transfers carbon in the ecosystem'
	Populations	13	10	'If a certain food is lost or too abundant, it can impact the population size and distribution of a predator'
	Other Interactions	3	5	'Helps us understand biotic interactions in the community'

importance of mouthparts to the identification of aquatic insects and their feeding choices on a scale of 1-not important to 5-very important (Table 3). Likert-type question responses were also compared between pre-and post-activity surveys via paired two-tailed t-tests.

An anonymous end-of-the-semester assessment was conducted during a class session. The assessment included Likert-type questions asking students to evaluate the helpfulness of various course activities both in the classroom and laboratory on a scale of 1-least helpful to 5-most helpful. Each activity included an area for comments. The assessment also asked students what they most and least enjoyed, as well as other additions or changes they would recommend in the course. Responses for the mouthparts activity and any comments that mention the activity are considered here to investigate whether students found this activity helpful and were engaged and enthusiastic about it. A total of 45 students completed the assessment, with ten students providing comments with their ratings.

All data analyses were conducted in R v. 3.6.1 (R Core Team 2019) using packages car (Fox and Weisberg 2019), rcompanion (Mangiafico 2019), ggplot2 (Wickham 2016), and cowplot (Wilke 2019). This project was reviewed and approved by the University of Maryland College Park Institutional Review Board (Project #1,318,732).

Results

Pre- and post-activity surveys

Open-ended question response themes

Student responses to Question 1: 'What are some ways to classify/categorize insects?' were grouped into eight themes: 'Morphology (non-mouthparts)', 'Mouthparts', 'Feeding Guilds', 'Life Cycles & Development', 'Phylogeny', 'Habitat', 'Ecological Role & Behavior', and 'Physiology'. These themes encompassed morphological, taxonomic, and ecological classifications, and we arranged them from highest to lowest number of post-activity survey responses in Table 2. Responses shifted between the pre- and post-activity surveys to a greater number of answers focusing on feeding and mouthparts. In the pre-activity survey responses, students did not recognise that functional feeding guilds were a way to classify insects as no students included it as method of classification; it became a common answer, however, on the post-activity survey. Mouthparts were mentioned occasionally as a type of morphological means for classification and categorisation of insect in the pre-activity survey, though less commonly than other morphological features. In the post-activity survey, the number of answers including mouthparts increased while general morphologically related answers decreased. Most of the other themes received around the same number of explanations between pre- and post-survey responses.

Student responses to Question 2: 'What are some ways scientists may determine what an insect eats?' were categorised into six themes (Table 2): 'Mouthparts', 'Studies & Observations', 'Habitat', 'Gut Analyses', 'Morphology', and 'Organismal Relationships'. These themes covered physical and biological characteristics as well as more specific experimental methods. Similar to Question 1, student responses to this question showed an increase in the number of answers mentioning mouthparts as a way to determine what an insect eats in the post-activity survey compared to other themes. Mouthparts were also the most common response by far, mentioned more than twice as much as the next most-mentioned theme in the post-activity surveys and nearly twice as much as in the pre-activity surveys. Most of the other themes remained fairly consistent in number of responses between surveys. Responses about habitat did show a small increase again here, as also occurred in Question 1.

The student responses to Question 3: 'What are some methods of obtaining food used by insects?' fit into six themes (Table 2). Response themes were 'Functional Feeding Guild & Mouthparts', 'Feeding Behavior', Non-Insect Methods', 'Food Categories', 'Other Appendages', and 'Detection', which included classification schemes, behavioural and physical adaptations, and responses that did

Table 3. Pre- and post-activity survey questions and mean scores (± SEM).

Question	Pre-Activity Survey	Post-Activity Survey
Question 1: What are some ways to classify/categorize insects? List at least 3.	0.81±0.06	1.38±0.09
Question 2: What are some ways scientists may determine what an insect eats? List at least 2.	1.75±0.07	1.94±0.04
Question 3: What are some methods of obtaining food used by insects? List at least 3.	1.29±0.11	1.81±0.08
Question 4: Why does it ecologically matter what an insect feeds on?	1.52±0.08	1.63±0.07
Summed Scores Q1-4	*5.38±0.18*	*6.75±0.17*
Question 5: How important are mouthparts to identification of aquatic insects? Rate on a scale of 1-5, where 1 is not important and 5 is very important.	4.07±0.10	4.34±0.13
Question 6: How important are mouthparts to determining what an insect feeds on? Rate on a scale of 1-5, where 1 is not important and 5 is very important.	4.52±0.12	4.55±0.13

not answer the question such as the non-insect methods. Across these themes, responses showed similar trends to the previous two questions with an approximately three-fold increase in the number of responses including something about functional feeding guilds or the physical process of using mouthparts to feed in the post-activity survey responses; this response outnumbered any other responses to any question or across either survey. Every other theme decreased in number of responses between the pre- and post-activity survey.

For Question 4: 'Why does it ecologically matter what an insect feeds on?', student responses were grouped into five themes (Table 2), 'Food Webs & Trophic Levels', 'Ecosystems', 'Energy & Nutrients', 'Populations', and 'Other Interactions', covering various ecological topics. Responses showed less pronounced trends than the other questions in terms of student responses recognising the relationship between mouthpart morphology and feeding ecology, but this question required greater incorporation of material into higher order thinking. More answers discussed something about food webs or trophic levels in the post-activity survey, which are key when considering the feeding relationships of organisms, but they also recognised general ecosystem responses and specific nutrient and energy cycle requirements of an ecosystem. Only the 'Populations' theme decreased in responses between surveys, while there were small increases in responses for each of the other four themes, which tended to cover larger-scale interactions between organisms in an ecosystem.

Statistical analysis of survey questions

Student responses to open-ended questions were then scored from 0–2 based upon their connection to functional feeding guilds and mouthparts (0 = incorrect or not related to the question, 1 = correct but generally did not incorporate aspects of how mouthpart morphology relates to functional feeding guilds, 2 = understanding of the topic of mouthpart morphology and functional feeding guilds). There was a significant increase in the score of these open-ended questions (Question 1–4) on the post-activity survey over pre-activity survey (two-tailed paired Student's *t*-test: $t = 8.95$, $df = 47$, $p < 0.001$; Table 3). Overall, students' answers on the post-activity survey included more references to functional feeding guilds and mouthparts (Table 2), with specifics for each question described above. In the Likert-style questions, student ratings showed mixed results with generally high ratings (Table 3, Questions 5 and 6). Regarding the question, 'How important are mouthparts to identification of aquatic insects?', the relative importance marginally increased in the post-activity survey ($t = 1.82$, $df = 47$, $p = 0.075$). Student ratings (on a scale of 1–5, where 1 is not important and 5 is very important) did not change between the surveys in regards to the question, 'How important are mouthparts to determining what an insect feeds on?'. Although the majority of students rated mouthparts as important or very important on both surveys, there were shifts in student ratings (Figure 1). In general, for Question 5 the percent of students listing the mouthparts as 5-very important increased from about 29% to over 50% of responses, due largely to decreases in ratings of 3 from ~15% to 4% of responses and in ratings of 4 from ~53% to 40%. Smaller changes were seen in response for Question 6, which had higher overall ratings on both surveys, showing decreases in ratings of 4 from 25% to ~15% and increases in ratings of 5 from ~67% to ~74%.

End-of-the-semester assessment

A total of forty-five students completed the end-of-the-semester assessment. Students rated this activity a 3.9 ± 0.16 (mean ± SE) out of 5, where the scale was from 1-least helpful to 5-most helpful. The distribution of responses included zero ratings of one, five ratings of two, thirteen ratings of three, eight ratings of four, and nineteen ratings of five. Sixty percent of the responding students (27 of the 45) rated the activity as very helpful or most helpful (ratings 4–5). Ten of the 45 students (22%) provided a comment about the mouthparts activity. Seven of these comments described the activity as difficult or frustrating, with five of those students mentioning that it was difficult because of the small size of the mouthparts. Comments included statements such as 'Mouthparts too small' and 'Difficulty performing dissection'. Two students further indicated that the activity was the part of the course they least enjoyed. However, of the ten responses, five indicated that the activity was useful and/or fun, even if it was difficult/frustrating. For example, one student commented 'Good to learn, but complicated to see with small macroinvertebrates' and another commented 'Challenging but fun'.

Discussion

In previous years of this freshwater biology course, the course instructor noticed that students were rarely making the connection between how mouthpart morphology related to aquatic insect feeding roles within aquatic ecosystems and sought to provide a means within the laboratory for students to see this connection. Jigsaw activities in biology laboratory courses, including activities in anatomy and classification similar to the activity here, have resulted in increased student learning and appreciation for the subject (Koprowski and Perigo 2001; Sezek 2013), suggesting it might benefit student connections for this concept. This study therefore examined to what extent a modified

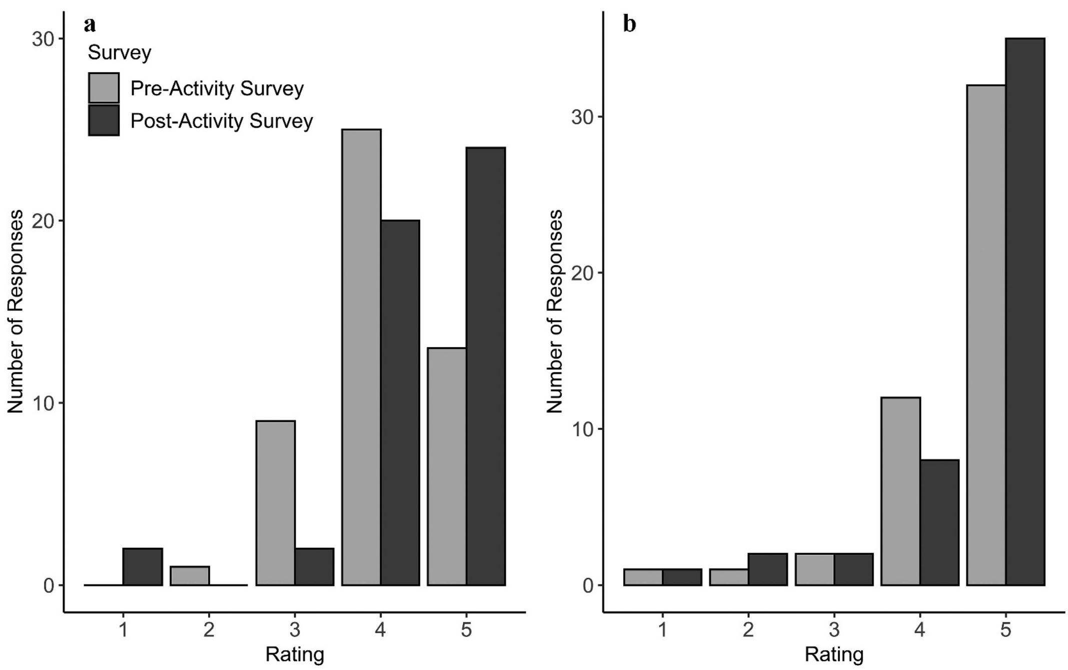

Figure 1. Student ratings from pre-activity and post-activity surveys on a Likert-type scale from 1-not important to 5-very important to (a) Question 5: How important are mouthparts to identification of aquatic insects? And (b) Question 6: How important are mouthparts to determining what an insect feeds on?

mouthparts dissection activity that used cooperative learning via the Jigsaw method increased student understanding of the importance of mouthpart morphology for ecological feeding roles and whether students found this activity helpful and enjoyable. Student responses on pre- and post-activity surveys indicated that they learned about functional feeding guilds and their relationship to mouthparts, as scores significantly improved on the post-activity survey and categorised answers showed increased numbers of responses including mouthparts and functional feeding guilds. The end-of-the-semester assessment indicated that the class generally found the activity to be helpful to their learning, and while some enjoyed it, others perceived it to be difficult. The activity therefore appeared to enhance student understanding of the link between morphology and feeding roles in aquatic insects, although further modification may provide greater benefit to future students in the course.

Cooperative learning has been used in a number of STEM-related fields, including biology (e.g. Smith, Hinckley, and Volk 1991; Springer, Stanne, and Donovan 1999; Koprowski and Perigo 2001; Lord 2001; Sezek 2013). In this study, we used cooperative learning to enhance students' understanding of the link between mouthpart morphological and ecological feeding roles of aquatic insects by implementing a Jigsaw component to a mouthpart dissection activity. We expected to see improved scores in post-activity surveys over pre-activity surveys as students were able to manipulate, observe, teach to peers, and make hypotheses about the ecological role of different aquatic insect mouthparts. The results met our expectations as students scored significantly higher on the post-survey responses via a grading rubric evaluating their responses, indicating the activity was effective at conveying key concepts. Students also provided a greater number of responses including terms related to ecological feeding guilds and ways to use mouthparts to feed, indicating gained understanding of the link between morphology and feeding roles. Positive effects of cooperative learning have been seen in other studies testing similar classification and morphological concepts. As described in the introduction, both a comparative anatomy class (Koprowski and Perigo 2001) and a class teaching invertebrate classification (Sezek 2013) found that Jigsaw activities enhanced student learning around these concepts. With this activity, students demonstrated increased knowledge about functional feeding guilds and the role of mouthparts in determining feeding roles of aquatic insects. In our freshwater biology class, cooperative learning via a Jigsaw activity was an effective tool for student learning of a difficult topic, supporting previous work.

Likert-style questions showed minimal changes in average ratings between the pre- and post-activity surveys as students provided high ratings on both surveys. Students in general ranked mouthparts as important or very important in both pre- and post-activity surveys, and there were small shifts from lower ratings to ratings of five between the surveys. The overall rating of the importance of mouthparts to insect identification did show a small increase, albeit of marginal significance, in the post-activity survey. Direct, hands-on examinations of the different forms of mouthparts may have provided greater appreciation for their need in identification. Students had already begun to learn to distinguish insect orders by mouthparts earlier in the semester, and this activity may have further solidified their preconceptions. In contrast, there were no differences in pre- and post-survey activity scores regarding the importance of mouthparts to determining what an insect eats and smaller shifts in number of responses between ratings. This appears to be in opposition to the answers provided by students to the open-ended Question 2, where mouthparts were increasingly mentioned as a way to determine what an insect eats in the post-survey; mouthparts were the most common answer provided in both surveys. Students may have already been cognisant of the role mouthparts play in limiting food choices for insects; this idea is something that appears in much of the literature describing aquatic insects in terms of functional feeding guilds (e.g. Cummins and Klug 1979; Ramírez and Gutiérrez-Fonseca 2014; Cummins 2018). They may have been exposed to this idea in lecture, or it may be a concept that inherently made sense to them already. It also suggests that greater emphasis may be needed regarding the importance of mouthparts in determining insect feeding guilds, including some additional discussion or activity. Further investigation within the classroom is needed to determine which of these is true.

We expected to see that students would rate this activity as helpful to their learning and that they would be enthusiastic about this activity. The results did not exactly match our expectations, and assessment results appear to somewhat contrast to pre- and post-activity survey results which showed increased achievement scores. A review of students' comments provided on the assessment indicated that some reported the activity to be difficult, and the top reason reported was the small size of many of the insects involved in the activity. While the overall average helpfulness rating of 3.9 out of 5 indicates that this was generally a helpful exercise, 40% of students indicated it was less helpful for them. The perceived difficulty may have therefore impaired its perception as helpful to students. Work with high school science students has indicated that when students perceive an activity or concept as difficult, they are more disengaged (Patall et al. 2018), and this lowered engagement may have been true here leading to lower enjoyment, as measured by ratings of activity helpfulness.

Further adaptation of the activity to remove or reduce this perceived difficulty may result in greater engagement, enthusiasm, and perceived helpfulness of the activity. For instance, students could be provided with the large insects used in previous years, like *Pteronarcys* sp., to dissect with a partner. They could then be placed in groups to examine the modified mouthparts of a unique aquatic insect that has been dissected for them by the TA and make observations and hypotheses, with multiple unique insects available to different groups. These groups could then be broken into new groups (Jigsaw activity) where students who observed each insect could share their findings, similar to what occurred here. Removing the dissection component of the smaller specimens may allow students to achieve the same activity learning goals without the frustration mentioned in the comments regarding the small insect size for dissection, leading to an activity that is better perceived and more impactful for student engagement and learning.

Conclusions

Overall, the results of the surveys indicate that the modified mouthparts activity using a Jigsaw approach achieved its goals of increasing student understanding of the links between mouthpart morphology and ecological feeding roles of aquatic insects and was generally viewed as helpful to student learning. Jigsaws have been shown to promote learning in STEM courses (e.g. Springer, Stanne, and Donovan 1999) and have been effective in classes with similar goals (e.g. Koprowski and Perigo 2001; Sezek 2013). The findings of these previous studies are supported here. While student enjoyment of the activity was mixed based upon student comments of perceived difficulty, this activity led to clear gains in knowledge as seen in student responses on the post-activity survey compared to the pre-activity survey and helped student learning as rated on end-of-the-semester assessments. As such, this activity was successful in supporting student learning and, with minor modification, can provide an even more engaging and intellectual experience on a challenging topic.

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