Journal of Effective Teaching in Higher Education

The Jigsaw Design Challenge: An Inclusive Learning Activity To Promote Cooperative Problem-Solving

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Abstract. This article highlights an innovative take on the jigsaw format, an inclusive and cooperative active learning strategy, implemented in an upper-level engineering elective course. After students complete the usual two steps of the jigsaw method—first gaining mastery in “expert groups” and then collaboratively teaching their peers in “jigsaw groups”—they then complete a third step in their jigsaw groups, in which they work together on an authentic design problem, offering a practical take on applying course content. This activity was implemented in three courses offered both in person and remotely (online only). We share how this innovation can promote learning, problem-solving, perspective sharing, and teamwork in contexts with students from different backgrounds and levels of experience.

Keywords: cooperative learning; jigsaw; active learning; design challenge

Although the traditional lecture-based format is still pervasive in many disciplines, active learning strategies have increasingly been recognized as beneficial for deeper student learning (Prince, 2004), longer-term retention of concepts and ideas (Laal & Laal, 2012), improved ability to apply concepts to new contexts (Roehl et al., 2013), improved collaboration and communication skills (Minifie & Davis, 2013), improved social presence and engagement (Minifie & Davis, 2013), and promotion of inclusive learning environments (Johnson, 2019).

Notably, performance is significantly improved using active learning approaches compared to traditional lecturing. In one meta-study, for example, that focused on undergraduate science, technology, engineering, and mathematics (STEM) courses, active learning techniques varied significantly (type, duration) and included activities such as group problem-solving, worksheets or tutorials completed during class, use of personal response systems, and studio or workshop course designs (Freeman et al., 2014). Students engaged in traditional lecture-based formats were 1.5 times more likely to fail than those in active learning environments. Exam scores in active learning courses showed a 6% increase compared to lecture format courses.

More specifically, a subset of active learning, *cooperative learning*, has shown positive outcomes in many fields. Cooperative learning is based on the premise that cooperation is more effective than competition among students for producing positive learning outcomes (Desai & Kulkarni, 2016; Slavin, 1980). Courses integrating more interactive classroom formats (including cooperative activities) showed higher learning gains and better conceptual understanding (Knight & Wood, 2005). Cooperation further promotes interpersonal relationships and effective teamwork (Desai & Kulkarni, 2016), improves self-esteem (Johnson et al., 1998a; Johnson et al., 1998b), and enhances motivation (Tran, 2019).

One specific cooperative approach, *jigsaw*, is particularly well-suited for multidisciplinary settings or settings where students must be exposed to different theoretical or methodological approaches, especially in those courses that are more applied. The jigsaw technique was originally developed by Elliot Aronson in the 1970s to enhance empathy in racially and socioeconomically diverse high school settings (Aronson, 1978; Aronson & Bridgeman, 1979). This approach involves peer-teaching and cooperative interactions that minimize the culture of competition and enhance learning and summative performance on both group and individual levels and can increase individual self-confidence (Aronson, 1978; Crone & Portillo, 2013). It also encourages problem-solving and learner accountability through peer-to-peer instruction (Goolsarran et al., 2020) and can enhance individual construction of knowledge, improve individual comprehension of texts (Booker, 2021; Namaziandost, 2020), and improve retention of key concepts (Nolan et al., 2018). The jigsaw technique has since been generalized and adapted numerous times in many disciplines across higher education with relevant examples in engineering (Desai & Kulkarni, 2016), chemistry (Knight & Wood, 2005), medical education (Goolsarran et al., 2020; Kumar et al., 2017), language learning (Namaziandost et al., 2020), and psychology (Crone & Portillo, 2013; Nolan et al., 2018).

Commonly, the jigsaw method employs two steps: (1) students first learn together in "expert groups," gaining mastery over a specific content area and (2) the groups are reconfigured into "jigsaw groups" so that there is one expert from each area in each new group who will then teach the other students (Aronson, 1978).

In this article, we take a case study approach to describe how we expanded on the jigsaw activity in one biomedical engineering course, detailing how we developed and implemented an innovative third step as a "twist" to the more common jigsaw format. Rather than completing the jigsaw activity after the first two steps, Jonathan Rivnay (the course instructor) asked the jigsaw groups to synthesize the distinct topics to complete a unique and randomly assigned design problem, thus building on the cooperative nature of the activity with an authentic task. Authentic learning experiences situate tasks and skills for future use, help students develop deeper knowledge, and allow students a means to transfer concepts and knowledge to new contexts (Herrington & Herrington, 2006).

As we describe below, students were asked to reflect on their experience of completing the activity and compare their approach for the design challenge with published works tackling the same engineering problems. The combination of a cooperative group activity involving peer-teaching (jigsaw) with problem-solving borrows from multiple aspects of cooperative learning (Desai & Kulkarni, 2016) while giving a practical and authentic take on applying course content. The method also fosters an inclusive learning environment, where all students are involved and help one another learn the content effectively.

While we focused on the implementation of this innovation in a specific upper-level engineering context, which is typically attended by students of varying majors or training backgrounds, we contend that this modified jigsaw activity could be useful in any course that features multidisciplinarity or is comprised of students from different educational backgrounds (or majors) or who possess varying levels of experience. We think that this approach would be beneficial in any learning context in which understanding multiple perspectives, teamwork, and problem-solving are essential tasks, especially in courses that feature authentic or real-world questions and problems.

Course Context and Description

This pedagogical innovation was carried out in a new upper-level engineering elective course at Northwestern University, a private research-intensive university located in the Midwest United States that was co-taught by Rivnay. The course is an elective with no prerequisites that met twice weekly over a 10-week term. The jigsaw innovation was carried out in three separate iterations of the course over three years, with only minor modifications. The first two iterations occurred during traditional in-person lecture periods while the third was online-only, mixed asynchronous/synchronous due to the COVID-19 pandemic. The course also coordinated with an associated lab course that was assessed separately but tightly integrated with the main course.

The course content focused on materials and device design considerations for wearable and implantable bioelectronic devices for medical diagnostics and therapeutics. By the end of the course, students were expected to be able to (1) identify and appreciate the multidisciplinary, collaborative environment needed to design and implement bioelectronic devices; (2) understand the basics of bioelectronic diagnostics and therapeutics; (3) identify the importance of core engineering topics for designing effective and long lasting bioelectronic devices; and (4) analyze scientific primary literature, perform literature searches, and synthesize new ideas from them. Within the learning objectives, there were sub-objectives focusing on teamwork, cooperation, and collaboration through problem-solving and practical applications of core concepts.

The course is interdisciplinary by design, each year drawing a mixture of undergraduates and graduate students from different engineering and STEM fields. Across the three course offerings, the balance between male and female and between undergraduates and graduate students (masters/PhD) was roughly equal (first offering: $N = 34$, 16 male/18 female, 18 undergrads/16 grads; second offering: $N = 18$, 9 male/9 female, 10 undergrads/8 grads; third offering: online only, $N = 39$, 24 male/15 female, 20 undergrads/19 grads). The training levels of students spanned sophomore undergraduates through second year PhD students, with most enrolling in senior year of undergraduate or first year in the graduate program. Such demographic information was determined from enrollment information; additional information on race and/or ethnicity as well as gender was not available nor collected for this work. The most represented disciplines were biomedical engineering and materials science and engineering with some participation from mechanical, electrical, computer engineering, and biology. From an introductory survey, it was determined that approximately one to two thirds of students reported that they are currently or have in the past engaged in research that they would classify "bioelectronics" and that fewer than ten percent of students had taken a formal course in this subject matter in the past. The activity and assessment were considered part of regular coursework and, as such, are not considered human subjects research by our university. Student responses were examined in aggregate. Individual comments were anonymized and de-identified and only used to illustrate larger points.

The Jigsaw Activity

Preparing the Students

To prepare the students for the jigsaw activities, Rivnay made a concerted effort to establish the importance and need for group interaction early in the course, help students feel comfortable and at ease with teamwork, and manage their expectations. Furthermore, he highlighted the multidisciplinary nature of the subject matter (bioelectronics) to draw parallels with the diversity of majors and scholarship of the student cohort itself. Finally, he noted that such diverse team-like settings are a norm in industry, government laboratories, and research laboratories.

To help students be more comfortable with collaborative active learning strategies, he implemented think-pair-share activities and small group discussions into his lectures from the outset. He also incorporated discussion-based literature critiques into the course to build up the expectation for group interaction. Early on, students were split into small groups and assigned an academic article on a specific topic. Individually, students submitted a 1–2-page critique of the paper. That same day, the students who were assigned the same article met to discuss the reading and their critiques. Afterwards, the different papers were compared, contrasted, and discussed in either a whole-class setting or in individual groups in which each student read a different paper. This mirrored the general format of the jigsaw assignment below, priming the students for the more complex activity.

Jigsaw Implementation

The 4–5-person expert and jigsaw groups were preassigned manually based on major and year in the program to ensure that at least one topical expert was in each jigsaw group. Jigsaw groups were not revealed until after the expert group portion of the activity was completed. On the first day, Rivnay spent about 30 minutes outlining the components, describing expectations and assessments, highlighting practical and real-world parallels, and generally motivating the students, explaining how cooperative peer learning would be beneficial (see Table 1 for a breakdown of the schedule and activities). He also briefly described the findings and results found in jigsaw-based literature and placed four relevant articles (Desai & Kulkarni. 2016; Doymus, 2008; Kumar, 2017; Davidson & Major, 2014) on the learning management system (LMS) for the interested student.

Table 1

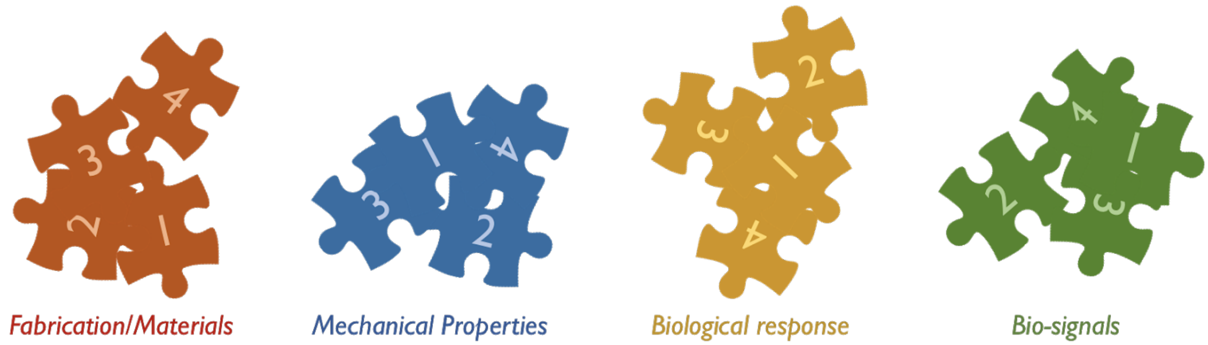
First iteration modified jigsaw activity flow, including timing/duration, in class activities, and assignments due

Day, *duration*	Activities, flow	Assessments due
Thur [1] – end of class, 30 min	• Motivate activity • Describe flow, assessments • Assign expert groups • Pass out expert prompts • Allow group 10 min to meet and plan	
Tue [1] – entire period, 90 min	• Assign jigsaw groups • Take turns peer teach/learn • Hand out jigsaw quiz	Expert group write-up
Thur [2] – entire period, 90 min	• Draw design prompts randomly • Free brainstorm 15 min in jigsaw groups • Complete design challenge prompt • Hand out debrief assignment	Jigsaw quiz (individual) Jigsaw group design writeup (in class)
Tue [2] – beginning of class, 15-30 min	• In class debrief: share with class what groups came up wit • Open reflection	Debrief writeup Canvas survey

In the first step, students were placed into expert groups in order to deeply learn about one specific topic area as “experts” (Figure 1). For this project, the topics are *fabrication/materials, mechanical properties, bio-signal transmission,* and *biological response,* all areas requiring special attention when designing a bioelectronic probe/device. As experts, students needed to identify key terms, processes, and governing equations associated with their specific topic and prompt, which will guide their researched content and approach to peer-teaching. In addition, they are asked to highlight key tradeoffs and application-specific weights for these fundamental topics as they relate to the global topic (bioelectronic devices) depending on factors ranging from use case, required lifetime, type of signal/implementation, etc. The nature of these topics would be specific to the course and activity envisioned, providing suggested starting points to guide the expert groups' research including a short list of general, required, and topical bullet points with associated papers and review reference citations.

Figure 1

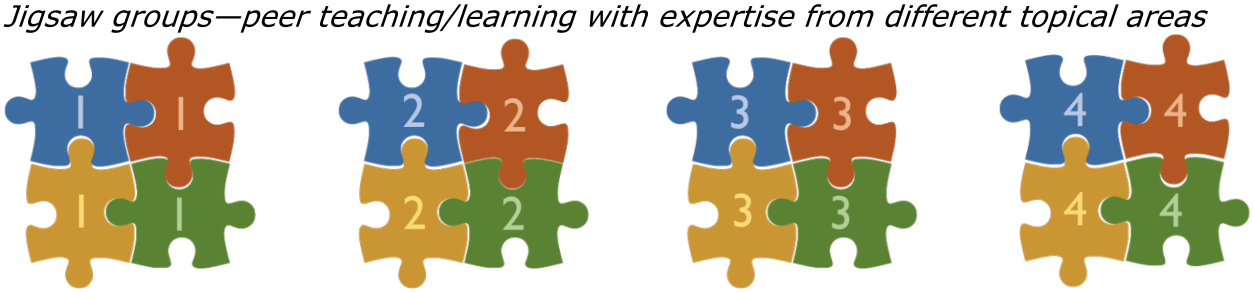
Expert (or Topic) groups—tasked with researching and teaching a topic in-depth



Students were placed in the 4–5 person teams preformed by the instructor for all group activities (8 groups in the first and third iterations and 4 groups in the second iteration). Initial expert (or topic) groups (see Figure 1) were assigned to ensure diversity of academic class; however, where possible, the student's major was used to match them to the closest possible expert topic to ensure a level of topical familiarity by at least one or two group members (e.g., mechanical engineers in the mechanical properties group or biomedical engineers/biologists in the biosignals/biological response group). Experts from each expert/topic group come together to form a jigsaw group in which each member has in-depth knowledge in a complementary area. Within each group, peer-teaching facilitates knowledge transfer, so everyone learns about the other topic areas (see Figure 2).

Figure 2

Jigsaw groups—peer teaching/learning with expertise from different topical areas



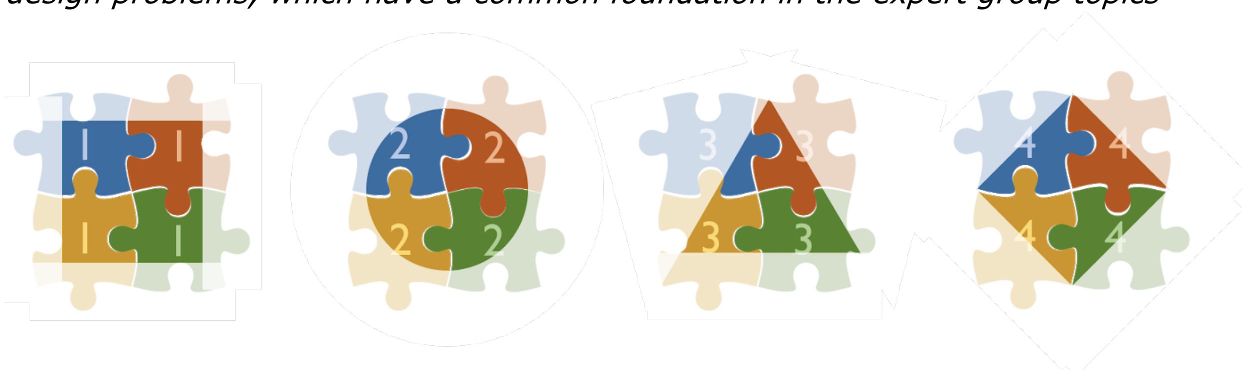
The Innovation (Design Challenge)

Rather than ending the cooperative team interactions with the jigsaw group peer teaching and learning, students met for a second session with their jigsaw group and were randomly assigned a design challenge. The challenge consisted of a short prompt describing a use-case of a bioelectronic device. For example, students might be asked to design a skin-worn device to record ECG signals and temperature to monitor babies in the neonatal intensive care unit, a skin patch to monitor local skin impedance and biochemical cues during wound healing, or a device to monitor intracranial pressure after trauma or neurosurgery.

The design challenges are all different and nuanced but are linked by a similar set of design considerations related to the expert topics. The groups spend time brainstorming their design prompt and then collaborate to complete a prompt. This part of the activity highlights the multidisciplinary and teamwork aspects of bioelectronics in an applied way. Rather than learning about abstract concepts such as those in the expert topic groups, students must apply these concepts as a team to solve the design challenge (see Figure 3).

Figure 3

Jigsaw design challenge—cooperative teamwork to solve distinct practical design problems, which have a common foundation in the expert group topics

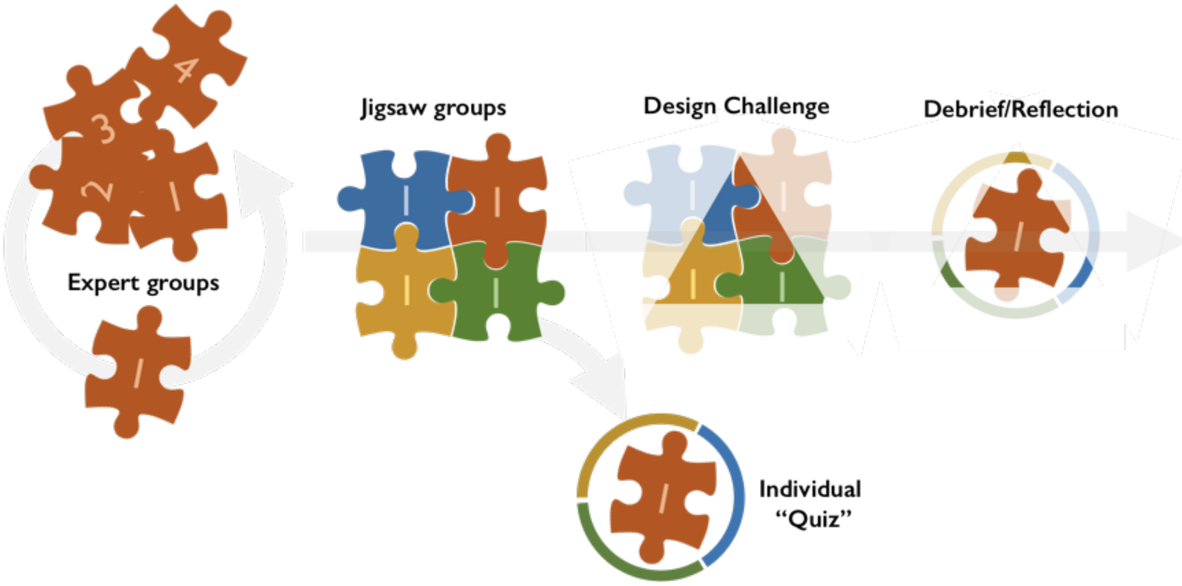


Finally, working individually or in their jigsaw groups, students were asked to look into literature and assess how their approach compared to current and relevant bioelectronics research and development. They then individually reflected on the entire activity through a written prompt and survey.

The entire activity progressed as visualized in Figure 4 over the course of 2–3 weeks (see Figure 4). The class-period by class-period breakdown (timing, duration), specific activities, and associated assignments are described in Table 1.

Figure 4

Flow and modified jigsaw activity from the perspective of one student (denoted as orange puzzle piece "1")



Variance in later offerings

In the second and third iterations, the instructor extended the time allotted for expert group preparations (Week 1) and allotted more time for debrief and reflection. The third iteration was entirely remote, adding additional complications. To account for this, the jigsaw quiz assessment was removed, more time was allotted for jigsaw group teaching and learning, and the jigsaw design challenge was accomplished over 24 hours (rather than in one 90-minute class period). Students were asked to abide by the honor code and not use outside resources so that they did not base their design on a published approach. The extended time was especially useful in a remote setting where technical issues and non-ideal working environments preclude students from an ideal collaborative virtual work environment during the scheduled class time.

Assessment

Students were informed that the jigsaw activity would be in lieu of a formal, written midterm assignment/exam. In the first iteration, this activity was called a "jigsaw midterm" while later it was simply referred to as a "jigsaw activity." The aggregate scoring made the entire jigsaw activity worth 25% of the course grade with the following breakdown: expert group summaries (30%), individual quiz (10%), jigsaw design challenge write-up (40%), and debrief write-up/survey (20%). Participation in the jigsaw groups in class was largely confirmed by presence, and absence or severe tardiness was docked on an individual basis as it adversely affects the team. Otherwise, group portions were graded as a group (same grade).

The expert group documents were assessed based on a provided prompt, looking for concepts and depth of understanding but also some mention or discussion of how the students in the expert group will approach the task of teaching their peers. In the current iteration, this task is meant to guide the students' outside research such that they address at minimum a set of preassigned topics that are required. They are asked to go beyond this, however, and identify other interesting topics to cover within their expert group and to cite their sources.

The individual jigsaw quiz (first and second iteration) is an eight-question take-home quiz covering the topics "required" of the expert groups and thus expected of all jigsaw group members after their peer-teach sessions. This is akin to the assessment in the original Aronson implementation. Class notes and a "cheat sheet" from their jigsaw peers is allowed, and the total value of the quiz is low (encouraging completion, but not penalizing students if their jigsaw group faltered in peer teaching/learning). As noted above, this assessment was removed in the later iterations due to the pandemic, and the results of the activity as a whole were not affected.

The design challenge write-up is the core component of this assignment. It highlights how the students worked as a team, applying core theoretical concepts to a specific applied task. The nature of the questions encourages creativity in design, but there is no "right" or "wrong" design solution. The students are asked to justify and defend their design choices based on the expert topic areas. This approach adheres to real-world engineering design and, as an authentic assessment, (Villarroel et al., 2018) also models how expertise is identified in the disciplines that the students are studying (Sternberg, 2003).

Finally, the debrief write-up is meant to be brief; however, in the end, this is actually a long activity, and the initial fear on the part of Rivnay was that such a multi-part activity was risky and cumbersome. The debrief was assessed based on the students' reflection on their own design and how it compared with those in current literature, allowing students to draw parallels between the priorities and tradeoffs they navigated with those of published researchers.

Evaluation and Findings

In each iteration, we collected information about student perceptions of the jigsaw process using both formal and informal measures in all three iterations of the course. In addition to the 1–2 page reflection described above, students completed a Classroom Assessment Technique (CAT) (Angelo & Cross, 1993), which consisted of an anonymous survey administered through the learning management system course site. The survey consisted of 10 quantitative and qualitative questions (see below for examples) related to collaborative group work, peer-to-peer learning, and perceptions around their own learning. Rivnay also collected informal feedback from the teaching assistants from end-of-term standardized student evaluations and made notes about his observations of the group interactions and discussions. In the third iteration, which occurred during the pandemic, the activities were carried out via online zoom groups, which were not readily observable. Observations consisted of the perceived level of engagement and participation of team members, total duration of discussion, and depth of discussion beyond key concepts (in peer teaching, for example).

Overall, the survey, the debrief write-up, the informal feedback from students, and the observation during the jigsaw component collectively indicate that students appreciated the goals and purpose of the cooperative activities and learned from the experience although they certainly noted aspects that could be improved upon or changed.

Informal Observation and Feedback

The instructor's in-class observation indicated that students were initially hesitant to engage with each other at the start of the course but became more conversant when they were asked to regularly engage in small group discussions throughout the term. In the jigsaw activity, most students seemed engaged, even enthusiastic, in both the peer teaching and design challenge portions. Some groups seemed to fly through the peer teaching and then would sit quietly for 20–30 minutes or more, requiring some guiding questions to maintain conversation through instructor or teaching assistant intervention. These informal observations were confirmed by what the students noted in the reflective debrief and the survey.

Reflective Debrief

As prompted, students compared their own group's design project with similar engineered devices or approaches discussed in the scholarly literature. Students commented on the feasibility of their own designs, noting places where improvements or enhancements could be made given sufficient time and resources. A few individuals noted crucial components or factors that they had left unexplored or otherwise failed to consider. Many distinguished what would have led to more optimal solutions. All were able to critically evaluate their own work, contextualizing their application of key concepts in their own design to research activities in the field.

Class Survey

Quantitative Findings

The survey results from all 92 students indicated that the group work component was overwhelmingly positive. Greater than 92% of students agreed (A) or strongly agreed (SA) when asked about the groups working well together, and 85% valued learning from peers. Students were less comfortable as topic experts in their jigsaw groups, with only 78% reporting that they felt comfortable (A+SA). Most notably when asked if the jigsaw activity was helpful in demonstrating the multidisciplinary and cooperative nature of bioelectronics, there was a positive response (A+SA) of 91% (2% D+SD).

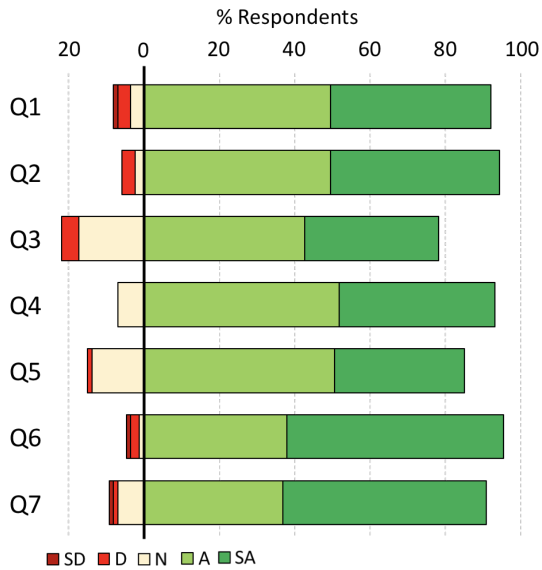
These findings resulted from the following questions where respondents were asked to rank their agreement:

1. I felt that my expert group worked well together
2. I felt that my expert group divided up tasks evenly/fairly
3. I felt comfortable as a topic expert in my jigsaw group
4. I felt that my contributions were valued by my peers
5. I found it valuable to learn from my peers
6. My jigsaw group worked well as a team to solve the design problem
7. The jigsaw activity was helpful in demonstrating the multidisciplinary and cooperative nature of bioelectronics research and development.

The tabulated responses to all questions are presented graphically in Figure 5.

Figure 5

Quantitative debrief survey results



Note: Results from year to year were in good agreement. Color coding as noted in legend, from right to left: strongly agree (SA), agree (A), neither agree nor disagree (N), disagree (D), and strongly disagree (SD). n = 91

Qualitative Findings

Expectations. Students were first asked about their expectations for the jigsaw activity and how their experience compared in practice. Out of the 91 responses (34, 18, 39), two-thirds of the students (n = 59) noted that they found the experience to be better than expected, commenting that the activity helped them learn the material, and they found the collaboration with peers more enjoyable as well.

> I honestly thought the jigsaw activity was going to be the bane of my existence. I dreaded it the moment [the professor] brought it up in class. However, and I'm happy to see... this activity really was engaging and pretty fun actually. To not just be tested on materials we have to study but be able to freely apply our knowledge that we've gained from our time at [the university] but also from learning about the topic in our topic groups. The culmination of it was really inspiring to me and I feel like I learned a lot about how to think of different aspects when creating a biomedical device. It felt really gratifying.

Fourteen students (4, 4, and 6) noted that the activity met their expectations, with nearly all indicating this in positive terms. Fifteen students (7, 5, and 3) indicated that the activity did not meet their expectations, with most noting that the activity was harder or more time-consuming than expected. Several students gave responses that could be described as "mixed," with some parts positively exceeding their expectations, and some parts not meeting them.

> The workload in [the] expert group is heavier than my expectation before, because we got a lot of things to study and we also have to generate handout, slides, as well as cheat sheet to teach our jigsaw groupmates. I think it's really cool to become an expert in one area, though the process can be overwhelming.

Perceptions of cooperative aspects. Students were also asked to explain the extent to which cooperating with their peers helped them learn. Several gave responses that could be coded in more than one category. Of the 91 students (34, 18, 39), 80 students (31, 16, 33) commented positively on the collaborative aspect of learning from their peers and being able to talk over ideas. One student noted the following:

> It was useful to discuss the different topics in the expert group, as it helps you to think further than what's written in the papers. It was interesting to see the group dynamic during the design approach. We were also able to have constructive discussions about certain aspects. Defending your point of view and explaining its advantages is an incredibly good way of learning in my opinion.

While another student suggested these benefits:

> Explaining concepts/information to others was a great way to cement it in my mind and force me to think critically about what I learned. It also helped to see how others in my expert and jigsaw group thought about the subject material. With a lecture you only observe the profs. [sic] way of thinking; with individual projects you only observe your own way of thinking; but with this project I was able to observe seven other people's approaches to researching/understanding subject material.

Additionally, 18 students (9, 1, 8) noted that having to teach the material to a peer helped them learn the material more deeply.

> Having to teach my peers about my topic motivated me to learn the material well before the activity. Also, having a practical outlet for the information right after learning it helped cement some of the knowledge.

However, it should be noted that 17 students (7, 2, 8) said that they found it difficult to learn from their peers although several of these students were the same who commented on learning more deeply from teaching the material.

> I did not feel [I] became an expert for my peers. My group did what we could to find information, but I personally felt we hit a brick wall with finding information and didn't know how to get around it. Also, to be honest, I felt like I was flailing around the entire process not fully sure what to do but no idea how to ask for help either. I conceptually understand but when I got to physically doing it, I became stuck.

Improvements and Revisions

While the majority of the students felt the peer-teaching session was valuable for discussing ideas and learning from others, about 10% of the students indicated that they felt their peers did not take the activity seriously. A few students also commented that they did not feel that they were "experts" and did not feel comfortable teaching their peers. Additionally, students also noted aspects of the activity that could be improved, encouraging Rivnay to make the following changes:

1. **Allocate more time to the activity:** Many students thought more time could have been allocated to the first step of the activity, allowing expert groups to do research and formulate a teaching plan as well as to the third step with the design challenge. However, a few students indicated the opposite, wishing that less time had been devoted to the activity overall.

2. **Provide more explicit instruction:** Some students indicated that more direction in the expert topics would have been beneficial. Others commented that the knowledge they had gained while exploring a very broad area in the topic/expert group was not effectively used owing to their specific design prompt.

3. **Make quizzes ungraded:** Some students were concerned about being evaluated individually, particularly for the handful who viewed the teaching by their peers to be suboptimal. In the original jigsaw activity of Aronson, this component is meant to provide motivation for the peer-teaching tasks, which is why the instructor employed it in the first iteration. However, the addition of another cooperative jigsaw session (Design Challenge) seemed to motivate the students, suggesting that the quiz did not play an overly important role in motivating the students to

participate fully. Indeed, when the instructor removed the quiz component in later offerings, there was little qualitative change in performance or student interaction.

The instructor used the student feedback to make several crucial changes to the structure, assessment, and communication of the jigsaw activity. Additionally, he recognized the need to do the following:

1. **Get buy-in from students:** The entire activity requires buy-in that can be built over the course of 3–4 weeks using discussion-based activities and group work and through adequate motivation in an introductory lecture or activity introduction.

2. **Clarify the rationale underlying group formation:** After some students conveyed displeasure about not being able to select their own groups, Rivnay spent more time explaining the importance of forming the groups around their relative experience. He was more transparent and intentional about the learning objectives associated with the manually formed groups, emphasizing the cooperative nature of the activity (Desai & Kulkarni, 2016).

3. **Revise language:** Rivnay also rethought using the term "expert" (in "expert group") because it seemed to set unrealistic expectations for the students, even when using this term in quotations and despite qualifying with the use of the word *relative.* In the second iteration we began using the term "topic groups" instead, with each student in the jigsaw group a "topic lead." Comments related to concerns over the need to be an expert decreased following this change.

Discussion

The consistent and positive response to the jigsaw activity was striking across a three-year span, particularly since the third iteration was administered fully online within the context of the pandemic. Even though students spoke informally about the difficulties of engaging with their teammates during this third iteration (an idea that had not been expressed in the pre-pandemic in-person iterations), they were careful to attribute their disengagement to being online (and to the pandemic) rather than to the jigsaw activity itself, which they still viewed as mostly positive. Given that their overall performance did not decline in comparison to the previous two iterations, this suggests that the jigsaw activity—including the design challenge twist—is portable across teaching modalities (for both in-person and online contexts).

The jigsaw activity, with its design challenge twist, provides a crucial cooperative learning opportunity within an authentic real-world context (Herrington & Herrington, 2006). Offering far more than a simple discussion-based group learning activity, this jigsaw innovation could be readily extended to other courses, particularly in those in which multifaceted design and system considerations spanning disciplines may be necessary or current research and development efforts are rapidly evolving. Such an approach would also be fruitful in those learning contexts where instructors wish their students to develop expertise around key topics or concepts (Nolan et al., 2018) and, even more critically, develop confidence around that expertise (Crone & Portillo, 2013). While Rivnay did not specifically seek to measure improvement in self-esteem or confidence in implementing this activity, research on jigsaw, as conducted in a variety of contexts, indicates that employing such cooperative-based activities can elicit positive changes in confidence (Crone & Portillo, 2013), self-esteem (Johnson et al., 1998a) and motivation (Tran, 2019).

Additionally, the debrief on the design challenge will allow students to make connections to real-world literature and examples in more authentic ways than what they might experience through simply writing a research paper or taking an exam (Herrington & Herrington, 2006). Similarly, the debrief, during which students share their design approaches with other jigsaw teams, is intended to demonstrate how the same set of core expertise and rationale could be applied towards vastly different applications and use-cases. This type of debrief could be adapted to other contexts, where the expertise of a given field or discipline is modelled as is the notion that cooperation in a real-world context relies on experts sharing and making sense of their own and one another's knowledge. While the jigsaw activity with design innovation requires thought, care, and transparency to implement effectively, it provides an invigorating way to help students acquire and communicate key concepts and ideas and offers an authentic opportunity for students to learn cooperatively and deeply.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgements

The authors gratefully acknowledge the organizational and intellectual support of Northwestern's Searle Fellows Program as well as financial support from the National Science Foundation grant no. NSF DMR-1751308.

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