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CourseSource

Essay

Implementing active learning approaches into an upper-division biology course

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Abstract

In this essay, we present our strategy for implementing active learning strategies into an upper division course on Human Genetics. Our principal goal was to shift from a traditional didactic course design, to one that more clearly placed the responsibility for learning on to the course participants. A key part of our objective, was to incorporate active learning approaches that more saliently lend themselves to student contemplation of material. We pursued the goal of incorporating active learning in a variety of ways, including the use of personal response clicker questions, partner discussions, small group discussions, class-wide presentation of topical questions, and a final comprehensive individual presentation. The approaches we describe were effective and favorably received, as reflected in positive post-course reviews from student participants. The tools and techniques we integrated in our course design are flexible, and are widely applicable to other subjects and disciplines. Our hope is that these approaches may be flexibly adapted for a variety of different courses to improve course experiences for students and instructors alike.

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BACKGROUND

Many instructors would agree that implementing effective teaching practices is an attractive goal, especially given the growing literature documenting the effectiveness and advantages of active learning teaching strategies across diverse disciplines (1-4). Many remain uncertain, however, of how to incorporate active learning into a course design and others see a lack of relevant information and materials as obstacles to implementation (1). For example, while there are a number of published strategies for teaching specific topics or modules (5-9), there are relatively few resources that discuss the implementation of active learning in college genetics courses in a holistic fashion (10,11). Further, instructors may be reticent to merge active learning approaches into their curriculum for various reasons. Insufficient training, time, and incentives are most often invoked as the factors limiting faculty from adopting these new pedagogical approaches (12). For instance, one project that sought to integrate active learning modules with professional development within a physiology curriculum suffered attrition of nearly half of the instructor participants. Those participants that remained failed to incorporate the active learning modules into their curriculum, owing to a variety of obstacles, including class size enrollment increases, a union strike, and inadequate funding (13). Clearly, instructors seeking to adopt new strategies face diverse external obstacles.

Additionally, active learning approaches may differ from how the instructors themselves were taught (12), they may feel unsure of how an active learning approach will be received by students, they may be discouraged by cynicism among colleagues (14) and administrators (13), or they may be unconvinced of the effectiveness of such teaching practices (1,15,16). A recent study investigated the process by which faculty adopt new teaching techniques. Strikingly, this study revealed that personal experiences are prioritized over empirical evidence when making decisions regarding certain active learning teaching strategies (14).

Efforts to engage future (i.e., inexperienced) faculty into student-centered teaching approaches have been successful (17). However, even when active learning methodologies are successfully adopted, faculty in STEM fields may be reluctant or unable to publish their strategies and results, especially pre-tenure (18). As a step towards demystifying the practical incorporation of these learning strategies into curricula, we present our experience of integrating active learning exercises into an upper-division course on Human Genetics. Herein, we provide a summary of the development, practical preparation, and implementation of this course. To provide the most helpful context to the reader, please first refer to Fig. 1, which provides an outline of the structure of each course meeting. We also provide evidence of the effectiveness of our approach, based on knowledge gains measured through a pre- and post-course assessment. Such assessment is especially important in light of research that suggests that simply lecturing less in favor of adding active approaches does not automatically guarantee increased knowledge gains for college biology students (19). The empirical evidence we provide demonstrates that students made substantial knowledge gains in the subject of human genetics over the course of the semester. We feel our approach is consistent with the notion that active learning be the preferred practice for biology instruction (4). Further, our hope is that our positive experience and the demonstrated efficacy of our approach may serve as a template for others interested in creating a course rich with active learning exercises to optimally support student learning. The themes of Scientific Teaching we address include Active Learning, our Assessment Rationales, and Inclusive Teaching Strategies. Human Genetics has been delivered four times over the course of four spring semesters. The enrollment is capped at 35 students, and has been led each time by the lead author of this paper, an associate professor at the University of Cincinnati Department of Biological Sciences. The second author, an assistant professor at the College of Wooster, has served as a guest lecturer of this course, and has incorporated several active learning strategies into the curriculum at his home institution.

COURSE DEVELOPMENT & PREPARATION

Choose the Right Textbook

A key consideration for any course is a well-written and presented textbook. Evidence shows that instructors who are willing to devote sufficient time to carefully consider how potential textbooks meet the needs of both teachers and students can expect more favorable reactions to required reading (20). For our course, we utilized a textbook that is highly accessible to undergraduates, which included several excellent case studies that accurately illustrated many key concepts in Human Genetics (21). Additionally, the organization and structure of the textbook lent itself to the assignment of topical questions for every course meeting (see below).

Identifying Critical Conceptual Themes: Consider the Material

Our second step was to devise a set of topical questions for each student to consider for every course meeting. Our process of developing these questions involved the following: for each book chapter, the course instructor read and considered the material in much the same way an undergraduate student would approach a reading assignment. After reading the material through, we would then reflect on what were the most important concepts to derive from the text. From there, we would then 'reverse engineer' a series of questions which illustrated and underscored one of the important conceptual

Format of a "typical" course meeting

	What?	When?	Why?
Before Class	Reading	Before class	Fundamental material
	Topical questions	Before (and during) class	Lower/Higher order thinking
	Homework	Before class (due 9:30a)	Reinforce material
Course Meeting Time	Quiz	PRS clicker questions (5 min)	Ensure reading and comprehension
	Discussion of chapter	Interactive (~10 min)	Elicit thoughts, comments about material
	"Human Genetics in the News" or activity	Interactive (~10-20 min)	Up-to-date discussions about current events
	Group Discussion of topical questions	Interactive (~30-40 min)	Group level discussion; promote higher order thinking

Figure 1. The format of a typical course meeting is diverse and draws on numerous active learning techniques. Our course meeting format comprises activities that must be completed before class (blue double-arrow), namely reading, homework and completion of topical questions. In-class activities (orange double-arrow), include handing in homework, taking a 'real-time' quiz, discussion of material and topical questions, as well as discussion of the Human Genetics in the News topical material.

themes of the chapter. The instructor devised each set of the topical questions. With respect to organization, our approach was reminiscent of a "backwards design" approach (for more information, please see the following link: https://cft.vanderbilt.edu/guides-sub-pages/understanding-by-design). Each chapter yielded between six and eight topical questions, and we aimed for one chapter to be the focus of a single course meeting (for an example of one chapter's topical questions, see Supporting File S1: Implementing Active Learning - Example Human Genetics Topical Questions). The majority of these questions are unchanged from year to year, however we note that questions may be modified periodically to reflect changes in the field of Human Genetics. The process of reading the material, considering it, and devising topical questions took about 1.5 hours of instructor preparation per chapter. Below, we present the format (independent study followed by group discussion) by which these questions were covered during the semester.

Give Yourself Enough Time

An important consideration for instructors is timing. Many of us balance numerous obligations throughout an academic term and the time that it takes to design relevant course materials is consistently viewed as an obstacle to the implementation of active learning methodology (1,15). This course was developed and organized by an untenured, research-active faculty member balancing teaching with a variety of commitments such as grant writing, student mentoring, and service activities. Since insufficient time is one of the barriers known to restrict adoption of active learning strategies (12), we strongly suggest that ample time be set aside in the semester preceding course delivery to thoughtfully construct topical questions and review the material. The approach we provide here greatly reduced the stress of course preparation during the semester, facilitated a more confident and relaxed presentation of the material, and created enough time during the semester to introduce news items relevant to Human Genetics as a component to the course (see below).

IMPLEMENTATION

Syllabus - Course Schedule

The course schedule was developed with the motivation to create a structured meeting schedule (Fig. 1), and provide students an organized and transparent set of expectations. This Human Genetics course met ~25 times throughout the term and, with the exception of exam days and final presentations, all course meetings lasted 80 minutes and followed an identical format (Fig. 1). Adhering to the same format for each meeting ensured that each student came into class with expectations for the meeting that were aligned with those of the instructor. Each course meeting included reading one chapter in the textbook (averaging ~25 pages), completing a set of assigned homework problems, and preparing answers to the set of topical questions for class discussion.

Before the Course Meeting

Students had access to the entire semester of course meetings through the syllabus and online course webpage (administered by Blackboard). Access through Blackboard enabled students to anticipate what was expected of them for each course meeting. Preparing for a typical course meeting included completing background textbook reading, homework for the current week of material, preparing answers to the set of topical questions, and arriving in class ready to discuss the material within a group. Topical questions were downloaded from the course webpage as a blank digital template (e.g., .docx files), which facilitated student completion of the exercise. To promote accountability, students submitted their homework answers prior to the start of each course meeting. Homework was later graded for completion rather than accuracy, and correct answers were provided through the course website. We avoided grading homework for accuracy because we feel this approach lessens the temptation to find published answers to the questions elsewhere, and encourages students to interact with the material without the pressure to get the right answer. Having said this, a recently-published teaching inventory highlights compelling reasons for providing feedback through graded homework and assignments (22), so we would suggest that instructors adopting a similar model carefully weigh the benefits of these differing approaches.

During the Course Meeting

At the start of each meeting, students were provided an outline for the day, and a short quiz was delivered using personal response system clickers. The clicker activity accomplished at least three goals, because it: 1) primed each student to think about the day's material, 2) held students accountable for the reading assignments, and 3) enabled the instructor to identify potential areas of misunderstanding early in the course meeting. For instance, students occasionally asked follow-up questions regarding the clicker questions. In these circumstances, the instructor spent sufficient time addressing any concerns or confusion. We note that each quiz is worth 5 out of a possible 5 points, and the students were awarded points for correct answers. There are ~20 quizzes in a given semester, and the quiz grade is worth 10% of each student's final grade. The content of each quiz was comprised of questions drawn directly from the chapter reading assigned for each course meeting. Therefore, we aimed to ensure that the material being queried was timely and able to be easily answered if the student had performed the reading assigned for that day. In this way, the quizzes aligned with (and reinforced) our goal of having students arrive prepared to discuss the material each course meeting. For additional information on the empirical value of promoting student reading prior to course meeting, see (23).

After each quiz, we next performed either a relevant in-class exercise, or discussion of a topic drawn from a recently published news article relating to the subject of Human Genetics (i.e., Human Genetics in the News). Once this exercise ended, students were then instructed to break into groups of ~8 - 10 (Fig. 2A-C). Each group was composed randomly and consisted of one designated leader (Fig. 2C). Prior to each course meeting, the instructor shuffled the note cards with each student's name, and randomly placed them to the group chart (Fig. 2). Placing the cards was facilitated by the use of Velcro tabs on the backs of each note card and the poster chart. Students could easily find which group they were placed into when the poster chart was displayed during the course meeting. The instructor also maintained a record of group leaders (Fig. 2) to ensure leaders rotated equitably, i.e.

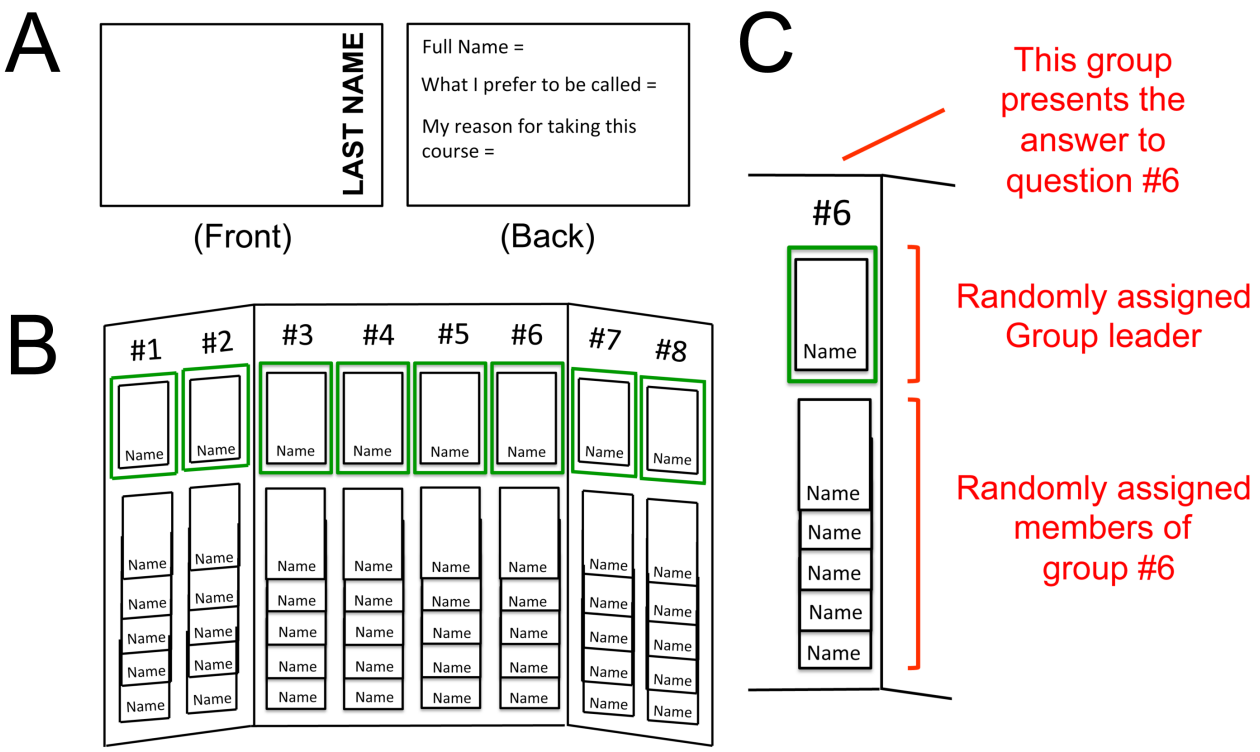

Figure 2. We utilize a simple system for random assignment of groups for each course meeting. On the first day of class, the lecturer provides a 3″ x 5″ index card to each student. The student writes their last name on the front of the card, and on the back of the card provides their formal name, preferred name, and short reason for taking the course (A). Using Velcro tabs, all of the cards are utilized for random group assigning by placing them to a tri-fold foam poster stand (B). The number at the top of each column (e.g., 6) indicates group number, and which topical question each group will present. Each group will have a single leader whose name appears in the green box at the top of each column. All remaining group members are indicated in the column below the group leader (C).

each student served as a group leader once every 4 - 5 weeks. Once assembled into groups, the students spent the next ~15 minutes discussing their individual answers to the day's topical questions in their small groups. During this time, each group spent additional time focusing on one particular topical question (Group Discussion, Fig. 1). The assigned topical question would later be presented to the entire class, following prompting by the instructor. Prior to the large group discussion, the instructor circulated around the room, touching base with each of the smaller groups to answer questions, helping guide small group discussion, etc. Guidance on discussion of the topical questions lasted ~30 - 40 minutes.

During the final ~20 minutes of class, the entire class came together for the large group discussion. The instructor sequentially moved through each of the topical questions, allowing the designated leaders to present their group's response. Other members of the class were asked to contribute additional thoughts or responses that served to augment the quality of answers, and stimulate productive discussions of the material. At the close of each question discussion, the instructor had the opportunity to correct any incorrect responses or misconceptions. We note that answers were not provided for the topical questions since: 1) the students should be able to find correct answers if they consider the material carefully, and 2) reliance on class discussion for answers provided motivation for students to attend and actively participate in class meetings.

Teaching Exercise: Human Genetics in the News

Each in-class Human Genetics in the News exercise followed the same basic format: the instructor identified recent news items relevant to topics covered in Human Genetics, performed background research on the topic, presented the news item to the class, and then solicited discussion and feedback. At the start of the semester, the students were also made aware that content from these exercises would be covered on the course exams. A simple Google news search for the term "human genetics" yielded thousands of results, and many of the resulting stories impacted directly on our study topics. For instance, we have covered well-known individuals with progeria (an advanced aging disease), legislation relevant to the Federal Genetic Information Non-Discrimination Act (GINA), genetic variants that may be protective against post-traumatic stress disorder, genetic variants that may be associated with daredevil behavior, and individuals diagnosed with genetic disorders who elect to use assisted reproductive technology to ensure their offspring are not affected by the disease. These topics always elicited enthusiastic discussions, and students were reminded that there is no single correct answer. When discussing these timely topics, students frequently reflected informally around how it was the first time they had considered certain viewpoints. In addition, these exercises provided a powerful opportunity to augment information learned from the textbook, and enabled the course to remain current with respect to the subject. For examples of topics we have covered over the past few years,

please see Supporting File S2: Implementing Active Learning - Examples of 'Human Genetics in the News' topics discussed from 2014 - 2017.

In Class Exercise: Human Pedigree Design and Interpretation

A key instructional goal of any Human Genetics course, and critical skill for future clinicians or counselors, is the accurate representation and interpretation of family pedigrees (24). In this activity, the instructor provided a study document in advance of the course meeting that provided conventional terms, symbols, and instructions for creating a family pedigree. The principal goals of this exercise were to practice fluency with pedigree construction, including accurate use of symbols, delineation of relationships, and interpretation of familial relations. At the start of the exercise, the instructor modeled proper construction of a pedigree. In our case, we illustrated with a personal example of three family generations. The instructor talked through the generations in a conversational way (for example, using first names), and then depicted relations using appropriate symbols. The pedigree construction exercise is typically performed on the fifth or sixth course meeting, when the use of human pedigree charts is first presented in the curriculum (see Fig. 1).

The students then assembled into pairs, and every student began creating their own pedigrees. Students were instructed to remain sensitive to each person's privacy. The instructor informed the students that they could either use a personal example, or create a fictitious pedigree. Irrespective of their choice, they were asked not to disclose if their pedigree was real or imaginary. Students were asked to depict their position on the pedigree. Students then swapped pedigrees with a partner who had five minutes to study their partner's pedigree. After a period of five minutes, each partner then interpreted the pedigrees to the authors, who then verified or corrected the interpretations. Feedback and exchange between students was largely conversational, e.g., "You are the third of six children; you have two older brothers (who are dizygotic twins) and three younger sisters." In this portion of the activity, students' interpretations served as a means of validating the accuracy and quality of their partner's pedigrees. The students found the pedigree activity quite enjoyable, and we feel it achieved the goals of providing practice in the construction and accurate interpretation of human pedigrees.

Final Poster Presentation

Each student was required to present a poster representing a comprehensive review of a topic in Human Genetics (e.g., a human genetic disease or a human phenotype with a genetic basis). In the past, students have presented on the following topics: Evolution of lactase persistence in humans, genetic basis for sickle cell anemia, and the genetics of being injury prone. Students selected their topics (with instructor approval) by mid-semester. Prior to the presentation, students provided a copy of their poster slides and a short narrative that constituted a portion of their overall presentation grade. On the day of the presentation, half of the students in the class hung their posters in a large corridor and performed a series of five-minute oral presentations to the other half of the class, who serve as 'poster referees'. After each short presentation, referees formulated questions and queried the presenters. During the next course meeting, the initial poster referees now presented their posters, and the other half of the class served as referees. The poster presentation activity was designed to replicate a major scientific conference setting and complemented much of the semester-long course material. Students were encouraged to dig deep into the material to interpret their topic to a naïve audience. Prior to selecting their topics, the instructor presented an example presentation inclusive of the required components of the poster presentation. Alongside the example poster, the instructor provided a clear checklist of items necessary for each presentation. We note that this checklist of items was reinforced with the rubric used for grading. During the poster session, the instructor visited each poster individually to provide a formative assessment based on the rubric (also provided to the students in advance). Although some students expressed anxiety around presenting before a large group, the collective exercise was very well received by presenters and referees based on informal and qualitative comments provided at the end of the poster presentation, as well as at the end of the course.

COURSE ASSESSMENTS

Pre- and Post-Course Assessments

In the second and third years of course delivery, we implemented a pre- and post-course assessment of our own design to determine the xtent to which new knowledge was acquired throughout the semester. We note that our assessments were drawn from exam questions delivered in prior semesters, and do not constitute a published inventory. We are unaware of any published inventories that specifically focus on Human Genetics, although several inventories are available for other genetics subject topics (25-27). The results of these assessments were surprising. The pre-course assessment was administered on the first day of class and included 40 questions presented in a diverse format: true/false, multiple choice, matching and short answer. We note that this format was similar to a typical exam format, with the exception that longer-answer narrative questions that are typically included on exams were not included in this tool. The post-course assessment was delivered near the final course meeting of the semester, and included the same questions and format as the pre-course assessment. In order to quantify improvements in student knowledge, normalized gains were calculated (28). Both assessment periods revealed dramatic improvements in course-wide performance. In our first year of performing a pre-course assessment, we had 29 students participate, and the average score was 51.5% (+/- 6.9%). On the last day of class, 28 students took the same assessment yielding an average score of 85.1% (+/- 10.2%). The analysis revealed a mean normalized gain of 70.9% (+/- 12.6%) for students who took both assessments (n = 23). In our second year of performing the assessment, the average score of the pre-course assessment was 56.4% (+/- 9.3%; n = 33), while the average score of the post-assessment was 87.3% (+/- 6.8%; n = 25), representing a mean normalized gain of 69.0% (+/- 21.3%; n = 26). In sum, over the course of two semesters, we observed a normalized gain of 69.9% (+/- 17.6%; n = 49), representing medium-to-high gains as defined elsewhere (28). We feel these scores indicate clear and positive gains by students in this class over the course of the semester.

Grading Rationale

One of the over-arching goals of this course was to assess students in diverse ways. We found that providing different assessment opportunities was most sensitive and inclusive of different ways of learning. For instance, some students may be weaker test takers, so providing several opportunities to receive points (e.g., homework, presentation) allowed students to recover from a poor exam performance without losing hope for a high grade. A second goal of our grading scheme was to support students' interactions with the material in ways that reflected our active learning instructional approach. For instance, we wanted to reinforce student motivation to read material in advance of the course meetings, and a short quiz helped ensure students achieved this goal. Additionally, we wanted to encourage students to think about the material before they arrived in class. By providing points for completion of homework, we reinforced student motivation to practice thinking about material prior to a mid-term exam. We feel our approach was successful, since the vast majority of students completed the homework assignments. Further, we encouraged completion of homework (and checking their work with a key) by drawing from these assignments to produce exam questions throughout the semester. Moreover, we prioritized homework completion over homework correctness to encourage student autonomy by forcing them to follow up on the correct answers (which were provided after the course meeting). The breakdown of our grading scheme was the following: ~20 homework assignments = 10%; ~20 in-class quizzes = 10%; three mid-term exams are each worth ~15% (45% total); one final poster presentation = 15%; final exam = 20%.

CONCLUSIONS

To support the interests of other instructors motivated to integrate active learning teaching practices into a course design, we present a case study based on an upper-division Human Genetics course. Our approach to the development and practical preparation of this course illustrates that that preparation for such a course represents a minimal burden for instructors balancing many responsibilities. The techniques and activities we implemented in this course demonstrate some of the diverse tools an instructor may utilize to maximize student learning and engagement with the material. We feel these techniques were highly effective based on student knowledge gains measured through a pre- and post-course assessment. Over the past four semesters delivering this course, several components of the class have changed. At the close of each semester, students were asked to complete a comprehensive evaluation that included, among other things, what aspects of the course they felt were effective, and which were ineffective. We were pleased to find that course evaluations in the four years we have been teaching this class have been quite positive, consistently scoring higher than the averaged evaluation metrics for our department. We have also implemented changes in response to these evaluations, including: (1) increasing the number of 'Human Genetics in the News' discussions from 8 to 16 for each semester, in response to the enthusiasm students have for this portion of the course; (2) revisiting and revising (if necessary) the topical questions to reflect advances in Human Genetics research; and (3) providing more opportunities for extra credit for students wishing to recover from a poor exam grade that they felt did not reflect their effort or knowledge. Overall, we hope that the strategies we present may be flexibly adapted for a variety of different courses, and improve course experiences for both students and instructors.

SUPPORTING MATERIALS

- Supporting File S1. Implementing Active Learning - Example Human Genetics Topical Questions
- Supporting File S2. Implementing Active Learning - Examples of 'Human Genetics in the News' topics discussed from 2014 - 2017.

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