

A revision of a traditional astronomy course through active learning

Raymond Zich, Amber Sammons, and Rebecca Rosenblatt
Department of Physics, Illinois State University, Normal, IL, 61790

We report on the conversion of a general education sophomore-level astronomy course from traditional lecture-based methods to a more active-learning course. The course was reworked into an active-learning environment through the addition of concept-oriented group worksheets, hands-on experimental activities, and planetarium-based lessons. We reflect on the process of this transition and report on factors that led to the adoption of active learning, factors that supported the change, and barriers faced while implementing this change. We compare and contrast these findings with other case studies of instructional change and theories of adoption. In addition, student learning pre to post was measured with the TOAST and LPCI, and qualitative data was collected in the form of 35-minute semi-structured interviews with each student to investigate student learning, attitudes, and perceptions of the course as a whole.

I. INTRODUCTION

In this paper we describe the process of transforming a conventionally taught astronomy course to a course founded on active learning. We will detail the course constraints and learning goals, the curriculum chosen to support this learning, and quantitative and qualitative data to support the effectiveness of the new active learning course. In addition, we will reflect on the reasons for transitioning the course to active learning, the process of this transition, lessons learned from implementing these reforms, and factors that facilitated and impeded reform.

II. DESCRIBING AND VALIDATING THE NEW CURRICULUM

A. The original course

The course, which was revised in this study, was originally developed by one of the authors as a traditional (lecture-based) single semester general education astronomy course. The course required a semester of general education physics as a prerequisite and used only algebra and trigonometry. It met for an hour and fifteen minutes twice weekly, in a traditional lecture room, and had no recitation or laboratory component. Class size usually was between 20 to 40 students of all college grade levels. The topics covered in the course were: sky geometry, stars, planets and solar system formation, the Sun, stars, galaxies, fusion, cosmology, constellations, and other sky features. These topics are consistent with most general education astronomy courses [1].

Historically, approximately 50% of the students in the course were preservice teachers in STEM fields as the course is a graduation requirement for these students, and a prerequisite for a content test and the educational Teacher Performance Assessment (edTPA).

B. The revised course

As taught, the revised class was a 50-50 hybrid, with half the time devoted to various types of active learning tasks, and the other half of the time spent on lecture, enhanced with clicker activities. The typical pattern for the class was to lecture and discuss during the first session of every week, and use the second session to complete learning activities associated with the topic being covered that week.

The astronomy content covered in the revised course was the same as the original course. These topics are listed in Table I. Active learning tasks covering these topics were added to the course, replacing half of the lecture content of the original course. The activities associated with each topic, and the activity type, are included in Table I. These active learning tasks were added to increase student engagement [2-4], deepen student understanding [3,4], and develop critical

thinking [2,3]. Much of the active learning work was done collaboratively [3,5]. The sizes of the groups varied, however, three students seemed to be the optimal size for productivity and learning.

The projects and tasks added to the course to implement an active learning course were group work/peer interaction coursework, hands-on activities and laboratory exercises, a classroom response system (TurningPoint clickers), and planetarium shows.

The active learning strategies involving peer interactions and group work that were added to this course included Think-Pair-Share, Lecture-Tutorials, and Ranking Tasks [2,6-10]. Think-Pair-Share, or Peer Instruction assignments, are activities where students consider a question or a situation, discuss it in small groups, and reach a consensus, which they then record via clickers or on a worksheet. Lecture-Tutorials are worksheets based on Socratic questioning that students complete in groups. Ranking Tasks are worksheets where students determine chronological or spatial order of astronomical events.

Hands-on activities and experimental laboratories were added in the course to give students experience with some of the physical phenomena associated with astronomy. In these activities students worked in groups of two or three to manipulate apparatus. A sky geometry/celestial sphere task became a hybrid activity combining a lecture-tutorial and a hands-on activity where students manipulated a celestial sphere and identified equinoxes and solstices, viewing locations of various phenomena, and other celestial phenomena. One of the experimental laboratories came from an introductory physics course laboratory manual *Experiments for Physics 105* [11], and another was developed, under the supervision of the in-

TABLE I. Weekly Topics and Activities
Activity types: Think-Pair-Share - TPS, Lecture-Tutorial - LT, Ranking Task - RT, Experimental Laboratory - EL, Planetarium Show - PS

Week	Topic	Activities	Type
1	Sky Geometry	Celestial Sphere	TPS
2	Ecliptic	Ecliptic & Kepler's Laws	TPS
3	Atom & Spectra	None	-
4	Solar System	Formation & Relationships	RT
5	Moon	Moon Phases	TPS & RT
6	Telescopes	Lens Lab & Telescopes	EL & RT
7	Planets	None	-
8	Sun	Sun as Star & Ringworld	TPS PS
10	Stars Intro	Standard Candle & Distances	TPS
11	HR Diagram	HR Diagram & Spectral Class	LT
12	Stellar Evolution	Analyzing Spectra	LT
13	Stellar Explosions	Crab Nebula	LT
14	Milky Way	None	-
15	Galaxies	Hubble's Law	LT
16	Cosmology	Spectroscopy	EL

structor, as an honors project in the course.

A lecture component was retained in the class in order to maintain completeness of coverage and to augment and reinforce the active learning component of the class. Lecture is an efficient and direct means to provide knowledge [2,8]. The lecture coverage was less detailed than is common, and additional content and detail were added through active learning tasks. Readings from the text and supplemental material were strongly emphasized in the course, with encouragement given to students to complete the readings. In order to make the lecture as interactive as possible, a classroom response system (clickers) was used to poll and engage students [9]. There is considerable evidence that clickers engage students in active learning, and are effective teaching tools [5,10,12]. Astronomy clicker questions for this course were taken from a variety of sources. Some were written by the instructor and some came from think-pair-share activities in *Learning Astronomy by Doing Astronomy* [13] and *Lecture-Tutorials for Introductory Astronomy* [14]. (These two texts were also the source for most of the Think-Pair-Share, Lecture-Tutorial, and Ranking Task activities described above.)

The class was taught in a planetarium, and the planetarium facilities were used during class to emphasize and illustrate the course contents. For example, sky geometry was illustrated using the planetarium projector, singular celestial objects and constellations were pointed out, the Milky Way as seen from Earth was shown, and a full show about Saturn was presented in conjunction with the section on jovian planets.

III. EVIDENCE FOR THE EFFECTIVENESS OF THE REVISED COURSE

There were two evaluations made of the revised course. Quantitative data was taken with two concept inventories of astronomical knowledge, and qualitative data in the form of interviews and a questionnaire were completed.

A. Concept inventories

The Test of Astronomy Standards (TOAST) and Lunar Phases Concept Inventory (LPCI) were administered as pre- and posttests, at the beginning of the course, and following the final. The TOAST is a widely used concept inventory that covers the range of topics commonly taught in general education astronomy courses. It consists of 27 multiple choice questions [15]. The LPCI is a concept inventory consisting of 19 multiple choice questions covering lunar phases and the mechanics of their appearance [16]. No pre- or posttest scores were available for classes prior to the transformation, so these results were compared with results reported from other institutions [15,16].

The mean pretest result from the TOAST was $41\% \pm 13\%$ correct, and the posttest mean was $54\% \pm 22\%$ correct. This was a gain of 13%, with an effect size of 0.58. This posttest

score of 54% compares favorably with results reported by Slater in TOAST development data. Slater reported mean posttest scores of 44% correct for undergraduate students who had taken a general education astronomy course and 50% correct for inservice teachers [15].

The mean pretest result from the LPCI was $36\% \pm 23\%$ correct, and the posttest mean was $51\% \pm 23\%$ correct. This is a gain of 15%, with an effect size of 0.65. These posttest scores were comparable to results reported by Lindell where a gain of 16% and a mean posttest score of 49% was reported for undergraduate students who had taken a general education astronomy course [16].

Overall the revised curriculum yielded encouraging results for both score and gain.

B. Interviews

In the final weeks of class each student participated in a semistructured interview consisting of 36 questions covering active learning, group work, general participant preferences, activities in the course, and overall view of the course.

The interviews were intended to investigate students' attitudes about active learning and group work as implemented in the class, whether the students found that active learning and/or group work helped their learning in the class, and how active learning and group work affected their attitudes toward the class. After the interview, students completed a written response section where they read a fictitious dialog about active learning and group work, and categorized their agreement with each statement and with the characters overall. This was included to get a global picture of each student's perceptions about active learning and group work, and to corroborate the students' statements during the interviews.

Examples of some of the questions are: "Which kind of classes do you prefer, classes that use active learning like worksheets or hands-on activities, or classes that are lecture based?"; "How did activities influence your learning in this class?"; and "How did activities influence your attitude in this class?". Reasons for the participant responses were also asked. Each interview took about 35 minutes to complete. At the end of the interviews, the participants were asked to read a dialog between three characters, Bob, a passive learner, Carol, a proponent of active and hands-on learning, and Hans, a learner who preferred solo learning. Examples of statements presented to the students are: Carol says, "I like group work and active learning. Working in groups helps me understand the material better," and Hans says, "I always end up doing all the work in a group." Participants were asked to rank their agreement or disagreement with each statement, then to state with which character they most closely identified.

The students highly approved of the active learning activities and group work in class. All of the participants registered approval, including comments like, "*More interesting than listening to lecture*" and "*Lecture when you don't care about*

the course". Of these students, a single student preferred lecture to the active learning/group work format. 50% of the students preferred hands-on and experimental (manipulative) activities to other types of activities. The collaborative effort to complete the activities was appreciated by the students. 80% of the students made statements such as, "Rely on the group to explain tough concepts". 50% of the students cited the efficacy of student explanations in understanding the material, "Explaining to others helps". 50% of the students explicitly made the claim the active learning and group work meant that they were more excited to come to class, or that they looked forward to coming to class. The results from the dialog were that 80% of the class identified most strongly with Carol, the figure who espoused active learning techniques.

A strong sense of class identity developed between the students, with class members regularly meeting in person or online to help each other study, remind each other of deadlines, and to complete assignments. Without prompting, the class created a Snapchat group, and would post information about assignments and astronomical phenomena. An example of this was a post about the first photograph of a black hole. When the first photograph of a black hole was announced, the students shared the photograph, and discussed the event on Snapchat without prompting by the instructor. They were then prepared to discuss the event during the next class. During the interviews, 80% of the students noted the unity which developed within the class, and claimed that it had originated from the group work done in class. Supporting comments were that the group work had, "brought the class closer together", and that "community improves other aspects" of the course.

The conclusion that may be drawn from the concept inventory outcomes and the results of the interviews is that student learning was as good or better than obtained with lecture-based teaching methods, and student enthusiasm and course satisfaction was much greater.

IV. REFLECTIONS ON THE DESIGN PROCESS

A. A textbook example of course change

The literature on adoption and course change often reports that adopters of new research-based instructional techniques feel dissatisfaction with teaching primarily via lectures and this motivates them to seek alternative approaches. Also, adopters often have, "A willingness to try and fail, access to knowledgeable others, and colleagues with whom instructors collaborate and innovate in their teaching" [17,18]. These were the exact circumstances that led to this course reform.

Part of the incentive to make the change was personal. One of the authors, over years of teaching, became dissatisfied with student test scores, engagement, and retention of knowledge resulting from conventional lecture-based methods. Looking for ways to improve instruction, this author became involved in physics education research (PER) and

through this began a course of study to earn a degree in curriculum and instruction. As he learned more about constructivist learning theories, active learning, and the research supporting the benefits of these teaching techniques, implementing these curriculum changes in his own teaching seemed like an effective solution to the problems encountered with lecture-based instruction. It was also an exciting prospect.

The instructor, one of the authors, was aware that current theories of learning show that better understanding and longer persistence of knowledge can be achieved by a constructivist approach [2,5,12]. Active learning, which has its roots in constructivist learning theory, is student-centered, and requires students to engage in meaningful activities that require them to think about the topics they are learning and accomplish some task as part of the learning. Active learning has been shown to improve critical thinking, maintain student concentration, increase knowledge retention, improve engagement and student satisfaction, and improve student-student and student-instructor interactions [2,19-22].

The instructor was also aware of drawbacks to active learning methods. Active learning takes more time than traditional lecture to cover the same amount of content [2]. Additional resources in the form of worksheets or apparatus are required for active learning, and additional preparation time is needed to create worksheets, tutorials, and exercises, and to gather and organize apparatus for hands-on activities. A further complication with active learning techniques is that the role of instructor is different. The instructor is not an authority bestowing knowledge, but is instead a facilitator. This is an entirely different skill set, and a role where the instructor may be untrained or is uncomfortable performing. There may also be a reluctance of students to engage, as they may prefer to be passive instead of enthusiastically participating in the activities [8,23]. Given the instructor's engagement with PER colleagues and education coursework, he felt prepared to attempt these pedagogical changes.

B. Steps and timeline for course revision

In converting the course from traditional lecture methods to active learning methods, the first step was to decide on the curriculum goals. In determining these goals a curriculum design strategy was followed. A learner centered design was used, in which the needs, interests, and goals of the students influence the curriculum choices [23,24]. After the goals were established the next step was to select a curriculum, or create a curriculum from parts of several curricula, based on meeting the course goals. The third step was to identify the time and resources needed, and available, and to modify the chosen curriculum and activities depending on those resources. The curriculum goals are shown in Table II.

Two months before the start of the semester we met for about 4 hours and chose the specific topics to cover in the course. A factor that affected several areas of the course design is the increased time required to teach with active learn-

TABLE II. Curriculum Goals

Course/Instructor
Increase student engagement
Present astronomy & physics knowledge
Deepen student understanding
Lengthen knowledge retention
Create desire for independent investigation
Connect astronomy with other sciences
Student
Learn astronomy content
Develop critical thinking
Discover relationships
Work effectively in groups
See astronomy as a whole

ing. It was not possible to add a laboratory or recitation time to the course; so, all of the material, including the activities, had to be completed in the same time as the original course. The order of presentation of the topics was decided, as was the amount of detail or weight to be given to each topic. There was considerable shuffling of the topics at this point in order to fit the material into the scheduled sessions, and ensure that the prerequisite knowledge for all topics was presented. Table I presents the course topics and the activities associated with each topic. In order to get the most benefit from the active learning activities, the activities had to be well matched to the topics, and time and effort were put into selecting activities which were a good fit with the topics covered. When suitable activities were not available, they had to be created or written, which required extra time. There was no canned celestial sphere activity, for example, and one had to be written and edited.

C. Difficulties faced and lessons learned

The initial difficulty arose in the first week of class. Despite the attempt to budget time, the majority of students did not finish the activity on the celestial sphere during class. The response to this was to continue the activity in the next class session. This had an unanticipated benefit. The students recognized the willingness of the instructor to work with them and had a better and more cooperative attitude about the class. The lesson gained from this was that flexibility is important. By changing the plan the message sent to the students was that the learning was valued and the schedule was centered around student needs.

Incorporating activities into the course was occasionally hindered by lack of resources. For example, a chosen activity on sky geometry had to be replaced because transparent plastic hemisphere critical to the activity were not available. The alternate activity worked well, and the lesson to be taken from this is, "Always have a Plan B."

Another difficulty occurred in trying to maintain the pace of the class. Occasionally during an activity a student or a group would work slowly enough that the rest of the class was held up waiting for the student or group to finish. One solution was to engage the rest of the class in a discussion or activity while the slower students finished. The slower student could also be allowed to finish at another time, however, this would defeat the purpose of group work. The best solution was to encourage students who finished more quickly to aid the slower students in the group and class. This both helped the student groups and fixed the problem.

V. CONCLUSION

We presented a report on the transformation of a general education astronomy course from lecture-based to active learning, and reflected on the rationale, process, and results of the transformation. The conversion of the course was motivated by a desire to obtain better student engagement, deeper understanding, and greater overall retention of knowledge. The pre to post results of the TOAST and LCPI show that there were performance gains as a result of the active learning curriculum, and that these gains were compatible with or slightly in excess of gains from lecture-based curricula.

Qualitative data shows that 80% of the students in the course preferred active learning activities to lecture, and 50% of those liked hands-on or manipulative tasks best of the assignments presented. As a result of group work and interactive projects in the class, a strong sense of community developed in the class, with students helping one another in and outside of class. 80% of the students commented on the sense of community and added that it made learning easier and other aspects of the class better.

In revisiting the lessons learned from the revision and implementation of this course, it was found that flexibility was a key aspect of success, both from the standpoint of achieving the instructional goals, and in gaining the confidence of the students. The confidence and cooperation of the students was a major asset to the success of the class. The sense of community that developed in the class greatly added to the productivity of the class.

These are results from an initial implementation of an active learning curriculum. It is anticipated that, as the curriculum is refined and difficulties worked out, that the results will show greater gains in concept inventory performance and long term similar results of student acceptance.

ACKNOWLEDGMENTS

Thanks are due to Rebecca Lindell for her help and insightful comments on the development of the revised course structure, and for some of the materials used in the course. Special thanks to the students who participated in the research activities of the course.

-
- [1] T. Slater, J. P. Adams, G. Brissenden, and D. Duncan, What topics are taught in introductory astronomy courses?, *Phys. Teach.*, 39(1), 52 (2001).
- [2] D. W. Hudgins, E. E. Prather, D. J. Grayson, and D. P. Smits, Effectiveness of collaborative ranking tasks on student understanding of key astronomy concepts, *Astron. Educ. Rev.*, 5(1), 1 (2006).
- [3] S. Freeman, et. al., Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410 (2014).
- [4] E. E. Prather, A. L. Rudolph, G. Brissenden, and W. M. Schlingman, A national study assessing the teaching and learning of introductory astronomy. Part I. The effect of interactive instruction, *Am. J. Phys.*, 77(4), 320 (2009).
- [5] D. H. Schunk, Learning theories: an educational perspective 7th Ed. Pearson (2016).
- [6] E. E. Prather, T. F. Slater, J. P. Adams, J. M. Bailey, L. V. Jones, and J. A. Dostal, Research on a lecture-tutorial approach to teaching introductory astronomy for non-science majors, *Astron. Educ. Rev.*, 3(2), 122 (2004).
- [7] E. Watkins and M. Sabella, Examining the effectiveness of clickers on promoting learning by tracking the evolution of student responses, *AIP Conference Proceedings* 1064, 223 (2008).
- [8] C. J. Miller, J. McNear, and M. J. Metz, A comparison of traditional and engaging lecture methods in a large, professional-level course. *Adv. in Physiol. Educ.*, 37(4), 347 (2013).
- [9] V. Kuo, P. Kohl, and L. Carr, Socratic dialogs and clicker use in an upper-division mechanics course, *AIP Conference Proceedings* 1413, 235 (2012).
- [10] K. Perkins and C. Turpen, Student perspectives on using clickers in upper-division physics courses, *AIP Conference Proceedings* 1179, 225 (2009).
- [11] Physics Department-Illinois State University, Experiments for physics 105, Stipes, 1997.
- [12] W. R. Alexander, Assessment of teaching approaches in an introductory astronomy college classroom, *Astron. Educ. Rev.*, 3(2), 178 (2004).
- [13] S. Palen and A. Larsen, Learning astronomy by doing astronomy, W. W. Norton Company, (2014).
- [14] J. Adams, E. Prather, and T. Slater, Lecture-tutorials for introductory astronomy, Pearson, (2004).
- [15] S. Slater, The development and validation of the test of astronomy standards (TOAST), *J. Astro. Earth. Sci. Educ.* 1(1), 22 (2014).
- [16] R. Lindell and J. Olsen, Developing the lunar phases concept inventory, *Proceedings of the 2002 Physics Education Research Conference*. New York: PERC Publishing (2002).
- [17] American Association for the Advancement of Science, Levers for change, *American Association for the Advancement of Science* (2019).
- [18] C. Henderson, M. H. Dancy, Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics, *Phys. Rev. ST Phys. Educ. Res.* 3, 020102 (2007).
- [19] R. J. Beichner, et. al., The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project, *Reviews in PER Vol. 1, Research-Based Reform of University Physics*, edited by E. F. Redish and P. J. Cooney, American Association of Physics Teachers, College Park, MD, (2007).
- [20] R. Beichner, L. Bernold, E. Burniston, P. Dail, R. Felder, J. Gastineau, M. Gjertsen, and J. Risley, Case study of the physics component of an integrated curriculum, *Am. J. Phys.* 67, S16 (1999).
- [21] N. Finkelstein and S. Pollock, Replicating and understanding successful innovations: Implementing tutorials in introductory physics, *Phys. Rev. ST Phys. Educ. Res.* 1, 010101 (2005).
- [22] C. Turpen and N. Finkelstein, Not all interactive engagement is the same: Variations in physics professors' implementation of Peer Instruction, *Phys. Rev. ST Phys. Educ. Res.* 5, 020101 (2009).
- [23] M. C. LoPresto and T. F. Slater, A new comparison of active learning strategies to traditional lectures for teaching college astronomy, *J. Astro. Earth. Sci. Educ.*, 3(1), 59 (2016).
- [24] L. Bao and E. Redish, Concentration analysis: A quantitative assessment of student states, *Am. J. Phys.* 69, S45 (2001).