EXPERIENCES WITH ACTIVE LEARNING IN CS 3

Ross Sowell, Yixin Chen, Jeremy Buhler, Sally A. Goldman, Cindy Grimm, Kenneth J. Goldman
Department of Computer Science and Engineering
Campus Box 1045
Washington University
One Brookings Drive
St. Louis, MO 63130
314 935-6160
{rsowell, chen, jbuhler, sg, cmg, kjg}@cse.wustl.edu

ABSTRACT

We report on our experiences with transforming CS 3 to an active-learning format. We have now had three separate instructors at our institution begin to integrate active learning into the course. Their approaches to integrating active learning and their experiences with it were quite different. We describe the various approaches of the instructors to the transition, provide synopses of the most effective active-learning exercises that were used, and summarize the lessons learned from these experiences. We expect that this information will be useful to anyone that desires to incorporate active learning into his or her CS 3 or similar course.

INTRODUCTION

Educational research provides strong evidence that active and collaborative learning result in a deeper and more integrated understanding of concepts, as well as significant improvement in student retention in degree programs [2, 7, 10, 16, 17, 18]. Engaged students remember concepts longer, enjoy the learning process more, and are more likely to continue. Collaborative learning builds important communication, teamwork, and leadership skills [8]. In addition, active learning in the classroom provides an opportunity to teach the creative design process through discussion and critique of student work.

In the last decade, many studies in the computer science education community have emphasized active learning. The majority of these describe general techniques [4, 11, 12, 13, 14, 15, 19] or focus on active-learning in CS 1 and CS 2 [1, 3, 5, 6, 9], while CS 3 has to this point received relatively little attention. Barriers to the widespread adoption of active-learning in CS 3 include a lack of sufficient evidence that such a transition is beneficial and for concerns of the need to cover a lot of material. Also, it takes significant time for an instructor to design and implement appropriate active-learning exercises for this type of course.

In this paper, we present our experience in transforming our CS 3 course to an active-learning format. The CS 3 course at our institution is entitled “Algorithms and Data Structures”. Students study fundamental algorithms, data structures, and their effective use in a variety of applications. The course emphasizes the importance of data structure choice and implementation for obtaining the most efficient algorithm for solving a given problem. The topics covered generally include: divide-and-conquer algorithms, worst-case asymptotic analysis, sorting algorithms, decision tree lower bound technique, hashing, binary heaps, skip lists, B-trees, and basic graph algorithms. Enrollment numbers are typically between 30 and 45 students for any

given session. Prior to the Spring 2008 semester, this course was always taught in the traditional lecture format.

In the past three years, we have had three different instructors teach the CS 3 course both in the traditional style and with active learning. Each instructor had a slightly different approach to the active-learning transformation and experienced varying degrees of success. We describe the various approaches, supply a collection of sample active-learning exercises that were successful, provide instructor reflections on their experiences, and summarize our lessons learned.

APPROACHES TO THE ACTIVE-LEARNING TRANSFORMATION

In the Fall 2008, Spring 2008, and Spring 2009 semesters, three different instructors that had previously taught CS 3 in the traditional, lecture-based style, taught the course again, this time incorporating active learning. Each instructor took a different approach and experienced varying degrees of success. These approaches differed in terms of the frequency and length of the active-learning sessions, whether or not lectures were recorded and assigned before class, whether or not the work was graded, and how the work was presented and discussed. The different approaches are detailed below:

- *Instructor A, Spring 2008*. In preparation for the transition to active learning, the lectures that the instructor gave in a previous offering of the course were recorded. These videos were made available to the students online, in addition to lecture notes recorded on a Tablet PC, and the textbook. In preparation for active-learning classes, the students were assigned to either watch a 15-20 minute video or complete the corresponding reading in the text. The instructor gave a short and easy quiz about the material assigned for preparation in order to learn which students had prepared. Sometimes the questions were "What is something you learned?" or "What is something that you are not clear about?" and sometimes very simple factual questions were asked. Roughly half of all the classes included some active-learning exercise. Students would divide into groups of their own choosing to work on the exercise. The instructor would circulate and help groups as questions arose. Generally, the sessions would last 30-40 minutes, with an additional 10-15 minutes of discussion afterwards. For this discussion, the instructor would ask for volunteers to share their solutions with the class, and alternate solutions were compared. Each group was asked to submit one sheet of paper with their names on it from their class work. This was graded solely on participation, which accounted for 5% of the course grade.
- *Instructor B, Fall 2008*. All class notes were recorded on a tablet PC and were posted online one or two days after class. Once every three or four classes, roughly half of the class would be devoted to an active learning session. Students were asked to divide into groups of 3-4 to work on the exercise. The instructor would circulate during the session and provide guidance and answer questions as needed. In some cases, the instructor would ask for volunteers or call on a specific group to put their solution on the board for class discussion. The work done was not graded in any way.
- *Instructor C, Spring 2009*. Half of nearly every class was devoted to an active-learning exercise. To accommodate this, students were expected to do additional reading outside of class. Roughly 15 minutes would be spent in the student-selected groups of 3-4 students each, working on the exercise. Then, two or three groups would be asked to

present their solutions to the class. These would be discussed and critiqued by the other classmates as well as the instructor. The presenters would be chosen on a volunteer basis, but everyone was encouraged to present at least once during the semester. The instructor would record the names of the presenters and this would factor into a participation score that accounted for 10% of the course grade.

SAMPLE EXERCISES

There are many factors to consider when choosing an exercise for an active-learning session. If a classical problem can be presented in such a way that the students discover the algorithm or data structure on their own, then they are more likely to remember it and apply it in appropriate situations. Also, problems that have multiple solutions lend themselves well to active learning, as the presentation of alternate solutions makes students think critically about which solution they feel is preferable. Problems with multiple layers of difficulty allow for students with varying levels of understanding to make progress at their own speed and continue to be challenged.

We include a selection of successful active-learning exercises that we have used below. A complete list of exercises is available online at http://www.cse.wustl.edu/~rsowell/ActiveLearningExercisesCS3.html.

Adversary Lower Bound Technique

n Coins Problem. In this problem there are 10 coins one of which is lighter than the other 9 coins but looks the same. There is a balance scale that the algorithm is to use to determine the fake coin. The algorithm wants to minimize the number of times the scale must be used. The students are divided into groups of four. Two students in each group are to define an algorithm for the 10 coin problem. The other two students define an adversary strategy. The two algorithm designers exchange strategies. The students are asked to prove how many weighings are optimal for 10 coins and then to try to generalize to *n* coins, and when you do not know if the fake coin is heavy or light. Based on this, it is much easier to introduce the lower bound for comparison based sorting. A benefit of this approach is it helps students learn how to write an algorithm and adversary strategy in a way that is clear and easy to understand without necessarily going to the level of code or pseudocode.

Trees and Hashing

B-Trees. After talking about secondary storage and its organization into pages, the students are asked to think about how to group the nodes in a balanced binary search tree into pages to minimize the worst case number of disk pages required in a search. This does a good job of motivating B-Trees as a generalization of binary search trees. Then, in later lectures we show how B-Tree insertion can allow you to keep the trees balanced. This also helps make it easy for the students to see the relationship between 2-3-4 trees and red-black trees.

Open Addressing Game. Students are asked to form two groups. They all leave their seats and then try to find a seat assignment using an open addressing scheme. One group uses a simple hashing function, while the other group uses a double hashing function. Each student must record how many conflicts they resolve before he or she finds a seat in which to sit. The

students are then asked to discuss why one group (double hashing group) saw much fewer conflicts. This discussion went very well. Most students understood open addressing much better, and figured out the explanations for the efficiency difference between the two hashing functions, both analytically and intuitively.

Graphs

Robots. You are given a maze (an *n* x *n* grid with some edges between grid squares marked as walls that the robot cannot pass through). You are given a start location S and a goal G for the robot and asked to find the fewest steps the robot can make to get from S to G. After solving this problem the students were given the harder problem where you have two robots that start at S1 and S2. The robot starting at S1 has goal location G1 and the robot starting at S2 has goal location G2. In each time step both robots can move, however, they cannot share the same location. Find the minimum time steps needed for both robots to reach their goals (and also find the corresponding solution). This second version is much harder since it requires them to change the state space so that each vertex in the graph corresponds to a pair of robot locations. This worked out very well. Even the students who did not figure out how to solve the second version benefited when we went over the solution at the beginning of the next class.

Savage and Human Game. Students were asked to play a river-crossing flash game "savage and human". Then they were asked to formulate it into a graph theory problem. It went very well as most students found it very interesting and figured out that it amounts to finding a shortest path in the state space graph. They can start to see that many real-world planning and scheduling problems can be translated into a graph theory problem.

Dijkstra's Algorithm. After we discussed breadth-first search (BFS) and proved that it can find the shortest path for graphs where each edge has a unit weight, the students were asked to generalize the idea to graphs with positive weights. After being given the hint of breaking each edge with weight *k* to *k* edges with unit costs, some students were able to derive Dijkstra's algorithm and easily prove its correctness, using the BFS result as a lemma. It was a satisfying experience for students who can figure it out, and it helps students gain a deeper understanding of Dijkstra's algorithm.

INSTRUCTOR REFLECTIONS

- *Instructor A, Spring 2008*. The instructor had a generally positive experience with the active-learning transformation. Many students appreciated being able to re-watch portions of the lecture at their own convenience. One item that she felt was particularly important was to try to incorporate different levels of difficulty into each exercise. For slower groups, they at least have the satisfaction of understanding the first level or two, while more advanced groups are still challenged with the later levels. When circulating the class, she thought it was important to visit the groups that did not seem to be doing anything first. Sometimes they needed a little help to get started. She also noted that it was important to carefully consider what material to include for active learning. For example, anything that the student has seen previously, is far less interesting for active learning. Finally, she felt that collecting sheets of paper from each group was helpful, as browsing through them gave her some idea of the thought process of some of the groups that she did not get to visit.

- *Instructor B, Fall 2008*. The instructor had a largely negative initial experience with the active-learning transition. Whether it was the content or difficulty or organization, his students did not seem to get a lot out of it, even though they would do the work. Some students did not seem to have an opinion one way or the other, but others actually resented it. They did not understand why they were doing more exercises similar to their homework in class. The instructor is not sure if he chose the best exercises to try active learning with, and intends to make another attempt at active learning in the future.
- *Instructor C, Spring 2009*. The instructor observed that students were more engaged, more interested, and generally got more out of the class when they participated in the discussion. The students also exercise independent, creative thinking, rather than just learning what is in the text. It also serves as an advantage for the instructor, since he gets the opportunity to better know the students. The drawbacks include that sometimes the discussion veers off topic or a group presents a very strange algorithm. In these cases, it is the instructor's responsibility to steer the discussion back on track. He also noted that he is unable to cover the same amount of material in class, so some things have to be left to the reading. Students must do more reading to cover the same material. He feels that the students who participate learn more, but not everyone wants to participate. The main issue is how to adapt to all types of students.

CONCLUSION AND FUTURE WORK

We have presented the experiences of three instructors that each incorporated active learning into CS 3. We have described the various approaches and techniques used, provided a set of exercises that were successful, and presented the reflections of the instructors on their experiences. Our experiences with active learning in CS 3 have yielded successful techniques that are now recommended to others as well as posed challenges for future investigation.

Successful techniques include:

- Recording the traditional lectures. Students appreciate being able to watch the lecture or read the text to prepare for class. Having the lectures indexed allows the student to watch only the portions that he or she needs. Being able to re-watch difficult portions of the lecture is another asset.
- Brief, easy quizzes at the beginning of class can help encourage student preparation for active learning and alert the instructor to students that are not prepared.
- Exercises with multiple solutions and multiple levels of depth work best for active-learning sessions.

Challenges include:

- How to select the student groups? Letting students choose their own groups or assigning them based on seating may not be the best option. Students have different levels of experience, and it may be best to group them according to their level of experience and ability.
- How to effectively integrate peer review? So far, most of the critique has come from the instructor or from other students in a class discussion. It would be nice to have one group critique the algorithm, data structure, or proof of another group.

- Most of the lecturing is done at the beginning of class, followed by the active-learning session. It may be more effective to lecture briefly, and then begin the active-learning session. The session could then be interspersed with brief, informal lectures throughout.

ACKNOWLEDGMENTS

This work is supported by the National Science Foundation under CPATH Grant No. CNS-0722328. Any opinions, findings, and conclusions expressed are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] Beck, L. L., Chizhik, A. W., and McElroy, A. C., Cooperative learning techniques in CS 1: design and experimental evaluation, *SIGCSE Bull.*, 37, (1), 470-474, 2005.
[2] Bransford, J. D., Brown, A. L., and Cocking, R. R., editors, *How people learn: brain, mind, experience, and school*, Washington, D.C.: National Academy Press, 2000.
[3] Briggs, T., Techniques for active learning in CS courses, *J. Comput. Small Coll.*, 21, (2), 156-165, 2005.
[4] Chinn, D., Martin, K., and Spencer, C, Treisman workshops and student performance in CS. *SIGCSE Bull.*, 39, (1), 203-207, 2007.
[5] Gehringer, E. F. and Miller, C. S., Student-generated active-learning exercises, *SIGCSE Bull.*, 41, (1), 81-85, 2009.
[6] Gonzalez, G., A systematic approach to active and cooperative learning in CS 1 and its effects on CS 2, *In SIGCSE '06: Proceedings of the 37th SIGCSE technical symposium on Computer science education*, 133-137, 2006.
[7] Hake, R., Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses, *Am. J. Phys.*, 66, (1), 64-74, 1998.
[8] Johnson, D. R. and Smith, K., Cooperative learning returns to college: What evidence is there that it works? *Change*, (July/Aug), 26-35, 1998.
[9] Lau, K.-K., Active learning sheets for a beginner's course on reasoning about imperative programs, *SIGCSE Bull.*, 39, (1), 198-202, 2007.
[10] Laws, P., Sokoloff, D., and Thornton, R., Promoting active learning using the results of physics education research, *UniServe Science News*, 1999.
[11] McConnell, J. J., Active and cooperative learning: tips and tricks (part I), *SIGCSE Bull.*, 37, (2), 27-30, 2005.
[12] McConnell, J. J., Active and cooperative learning: more tips and tricks (part II), *SIGCSE Bull.*, 37, (4), 34-38, 2005.
[13] McConnell, J. J., Active and cooperative learning: further tips and tricks (part III), *SIGCSE Bull.*, 38, (2), 24-28, 2006.
[14] J McConnell, J. J., Active and cooperative learning: final tips and tricks (part IV), *SIGCSE Bull.*, 38, (4), 25-28, 2006.
[15] Pollard, S. and Duvall, R. C., Everything I needed to know about teaching I learned in kindergarten: bringing elementary education techniques to undergraduate computer science classes, *SIGCSE Bull.*, 38, (1), 224-228, 2006.
[16] Prince, M., Does active learning work? a review of the research, *Journal of Engineering Education*, 93, (2), 223-231, 2004.

[17] Redish, E., Saul, J., and Steinberg, R., On the effectiveness of active-engagement microcomputer-based laboratories, *American Journal of Physics*, 45-54, 1997.
[18] Sawyer, R. K., editor, *The Cambridge Handbook of the Learning Sciences*, New York, NY: Cambridge University Press, 2006.
[19] Schweitzer, D. and Brown, W., Interactive visualization for the active learning classroom, *SIGCSE Bull.*, 39, (1), 208-212, 2007.