Stories of Active Learning in STEM: Lessons for STEM Education

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Abstract

We live in a society where exposure to Science, Technology, Engineering and Mathematics (STEM) education plays a very important role in all aspects of life. Addressing social problems increasingly requires innovations that may involve basic science research, along with its applications and implications, environmental concerns and technology development. Moreover, innovations in education are also important, inasmuch as education is a significant tool for developing not only well informed and knowledgeable citizens, but also responsible and creative individuals who will ensure continuation of scientific inquiry with sustainable outcomes.

In this paper, selected best practices for effective teaching of STEM curricula are considered in terms of applying various active learning didactical approaches. A selection of the authors' teaching experiences in natural sciences, mathematics/ statistics and Information Technology (IT) courses is presented in the form of "stories". The integrated approach using active learning, problem solving, technology-driven learning innovation and other teaching strategies are analyzed in terms of selected dimensions: goals, learning outcomes, pedagogical methods and techniques used. Comparison and analysis of the similarities and differences of the selected practices in terms of these dimensions are used to develop a typology of best effective active learning strategies for STEM education. An explanation of these similarities and differences is attempted, using insights from diverse theories of education. Issues like citizen empowerment will be discussed.

1. Introduction

Active learning is a term used by educators to describe a more "learner-centered" approach to teaching. Although the definitions given by instructors may vary, it includes instructional activities that involve students in "doing things and thinking about what they are doing" (Bonwell and Eison, 1991). Active learning practices may range from simple methods such as class discussion and question-and-answer to case study analysis, role playing, peer teaching and flipped lessons. Active learning may be problem-based, experiential, collaborative and cooperative (Prince, 2004; Svinicki and McKeachie, 2012).

Teaching courses in STEM (science, technology, engineering, mathematics) disciplines poses the challenge of having to deliver large volumes of content while trying to promote deeper learning, and to stimulate student engagement, motivation and confidence. Students should be "seeking new information, organizing it in a way that is meaningful, and having the chance to explain it to others" (Huba and Freed, 2000). Active learning strategies were shown to both increase student performance in STEM disciplines (Freeman et al., 2014) and improve student attitudes (Prince, 2004). Active learning empowers students, as it helps them "become intellectuals who are responsible and expected to challenge and to resist knowledge as given" (Berry, 1998); they participate in the creation of knowledge. The aim of this paper is to identify effective teaching strategies and to provide a guide for future studies having as a goal to increase learning in the STEM disciplines.

2. Stories of Active Learning

Instructor feedback on five undergraduate courses was collected with the help of an open-ended questionnaire. Instructors were asked to provide specific information on their courses and to evaluate the active learning methods that they implemented. The answers were analyzed and five narratives were produced that are presented below.

2.1 Active Learning in the Sciences: Environmental Science and Biology

Case A (Introductory Environmental Science course with lab): The instructor teaching goals are associated with the learning outcomes of the course: transmission of basic knowledge, but also development of skills for critical evaluation, analysis and application to everyday life. More specifically, students are expected to develop scientific literacy and clarify misconceptions on environmental

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issues, develop an understanding of sustainability issues, critically evaluate the human impact on the environment and build practical and transferable skills, including ability for teamwork, lab work and scientific writing. A variety of active learning methods were used such as regular question-and-answer sessions, brainstorming, in-class debate, lab activities involving teamwork and lab reports, group discussion, screening of short videos followed by discussion, pause and in-class summaries. Blackboard course management system was used for posting information, lecture and lab material, assignments and web links, but also for providing instructor feedback on assignments. Lab sessions allowed collaborative learning to take place, as students worked in teams. Student-instructor interaction included feedback and guidance on group work and individual assignments.

Case B (Introductory Biology course with lab): The general teaching goals are similar to those of case A (knowledge acquisition, ability for critical evaluation of biological issues, practical and transferable skills); more specific focus is given to applications, relevance and connections of biology with everyday life and society; also to the use of digital and modern pedagogical methods. Question-and-answer, class discussions, in-class problem solving and lab activities involving team work were among the active learning methods used. The textbook companion site was extensively used for additional resources, quizzes and problems. Blackboard was used as in case A. Additional emphasis was placed on animations, online quizzes and exercises, use of audiovisual material and virtual labs (to enrich the practical labs). Student-student interaction was mainly through class discussion and lab work in teams and student-instructor interaction as in case A.

Case C (Greening the Campus course): Greening the Campus differs from the other courses as it was designed to be based on experiential learning and action research on campus, and with the aim to promote campus sustainability. An important course goal is to involve students more in the learning process: students should develop “ownership” of knowledge, become critical thinkers and learn to challenge taken-for-granted ways of being in society. Another goal is to promote collaboration of faculty and students on campus issues related to the environment and sustainability, while also providing opportunities for active involvement of technical services staff as sources of knowledge. An important active learning method used was the group project involving field work, data collection, field observations, data analysis and a final report; the projects conducted so far have focused on the study of specific campus technical and operations issues or on the study of the campus ecosystem. Lab activities and visits have been a regular component of the course. Blackboard was used as in cases A and B.

2.2 Active Learning in Math

Case D (Introductory Mathematics course): Primary goals of the instructor are to enable students to develop knowledge and understanding of basic mathematics needed for understanding quantitative information in real-life situations; to also engage students using active learning methods which provide opportunities for authentic learning and for developing skills useful for applying mathematical knowledge in and outside their specific discipline. In this course, the instructor engaged students through flipped lessons where students were first given preparatory out-of-class activity/ “homework” which consisted of 2 components: short lecture and exercise videos on the day’s topic and a short set of formative exercises designed to engage students in self-assessment of their understanding of the videos. The regular scheduled class time was then used to resolve students’ questions on the topic and to solve and discuss a variety of word problem applications in real-life situations. In-class activities to further engage students used active learning methods like question-and-answer, class discussion, and occasional mini-lecture with pauses and problem solving with think-pair-share. Blackboard course management system was used as in the previous cases as well as for conducting a brief survey on the flipped lessons.

2.3 Active Learning in Information Technology

Case E (Information Systems course**)**: In this more advanced Information Systems course, the main goals of the instructor were to help develop student research skills, in addition to the acquisition of knowledge, critical thinking and communication skills. More specifically, students should learn to set research objectives, develop research proposals and associate knowledge management to decision making. The active learning methods used were case studies requiring multidimensional analysis and class discussion facilitated by the instructor. Online platforms for collaborative work as well as knowledge mapping tools were also used. Collaborative learning was enhanced through sharing of resources and ideas among students; group discussions and student presentations took place during the development of students’ research model for knowledge management. Instructor feedback was provided during various steps of the research model.

3. Discussion

A comparison of the way the five instructors perceived and applied active learning shows similarities and differences. Three instructors described active learning as student-centered, involving activities that engage students in the learning process, with the instructor playing the role of the facilitator. Two described it as problem-based, interactive and collaborative.

In terms of teaching goals, all instructors aimed at transmitting knowledge and understanding, but also at developing skills for critical evaluation, analysis, application and connection with real world cases. Development of teamwork skills was considered a goal in three of the courses examined, while the development of research skills was an important goal in the more advanced Information Systems course.

All instructors aligned their teaching strategies with the learning outcomes of the course as well as with their teaching goals. All five courses used some form of collaborative work and promoted a strong student-instructor interaction. The study shows that as the level of engagement and the autonomy that the student develops increases, the level of learning also increases, as learners develop more “ownership” of the course material. Among the teaching strategies used, the ones promoting a higher student autonomy were the group field project of the Greening the Campus class and the flipped lessons of the math class. The field project, based on experiential learning, resulted in the development of practical and teamwork skills and enhanced students’ critical thinking and ability for research and scientific writing. In the lab activities of environmental science and biology, students receive a higher level of guidance and supervision, but also achieve a good level of learning, as well as development of both practical skills (data collection, processing and interpretation) and transferable skills (ability for teamwork and scientific writing). Prior exposure to similar material seems to increase the level of engagement and autonomy, as demonstrated in the case of students of the biology and environmental science classes who have already taken a first course in the discipline.

In the math class, the combination of the flipped lessons with individual work at home and the follow-up in-class activities with active learning indicated positive effects on both the students’ perception of the course as well as students’ learning. No single active learning method was seen as better than others; rather, the mix of a variety of methods altogether contributed positively to the learning process in this course.

Class discussions facilitated by the instructor and case study analysis produced learning in the Information Systems class. The presentation of students’ research projects, the group discussions and the feedback provided by the instructor and other students helped enhance students’ research skills that were a major goal of this course.

Other active learning strategies used by instructors as alternatives to traditional lectures were in-class debates, class discussions followed by video screenings, think-pair-share, problem solving, brainstorming, question-and-answer and pause and in-class summaries. In-class debate and group discussion after video screenings helped evaluate and resolve misconceptions on environmental issues in Case A. Journal entries encouraged freedom of expression and stimulated students’ emotions. Group discussion boards became an effective communication tool for some of the student groups. Other online tools such as online quizzes and animations contributed to learning for the students who engaged with them.

The study shows that different teaching strategies prove effective for different STEM courses depending on course goals. Furthermore, there were indications that factors such as the level of the course and the composition of the student population (mostly in terms of age, educational and cultural background, major) may play an important role in the success of the active learning method implemented.

4. Conclusion

The results of this study allowed the authors to discuss, compare and reflect on the effectiveness of various teaching strategies used in STEM courses. Further research may involve a more systematic evaluation of active learning strategies based on conducting studies with experimental and control groups using different teaching methods; multi-section courses in science and math may provide good ground for such research. Instructor and student feedback on effective active learning strategies can be provided through surveys and a measure of student achievement in experimental and control groups can be compared. A more thorough analysis of teachers’ conceptions of effective teaching could provide further insights into how transformative learning can be achieved.

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