# Guest Editorial: Flipped Classrooms in STEM

LORENA A. BARBA
George Washington University
Washington D.C.

AUTAR KAW
University of South Florida
Tampa, FL

AND

JOSEPH M. LE DOUX
Georgia Tech and Emory University
Atlanta, GA

What does a traditional engineering classroom look like? Students sitting down in rows listening to the professor giving a lecture. There may be a question every so often, a bit of discussion, or feedback from the professor on student work. Every week, students may get a "problem set" assigned as homework, which they will often struggle to complete, alone or in collaboration. And what does a flipped classroom look like? Students come prepared after reading or watching a video (their "homework"), and the class meeting with the professor is inquiry-based and interactive, allowing for assimilation of knowledge through group-based problem-solving. This new form of blended learning is gaining support not only from avant-garde teachers, but from learning researchers as well.

Some observers of this wave argue: "This is old news. Humanities classes have always been taught this way!" They are right, of course. Law and literature students always had to do their reading ahead of class, and come prepared for discussion and analysis. What is different now is that, (1) the format is being adopted across STEM disciplines; (2) the ubiquity of mobile devices and broadband (and a plethora of apps for creating and self-publishing multimedia content) is enabling widespread adoption; and (3) new research on how people learn is giving support to the effectiveness of the approach.

This special issue collects research papers on the effects of introducing flipped classroom in engineering higher education. In K-12 education, the idea was popularized by high-school teachers Jon Bergmann and Aaron Sims—both recipients of the Presidential Award for Excellence in Math and Science Teaching—after they stumbled on the benefits of recording pre-class videos nearly a decade ago (Bergmann and Sams, 2012). Their experience was mostly anecdotal, but it has influenced a large cohort of school teachers.

The guest editors for this issue independently adopted self-produced class videos and other elements of the flipped classroom, at about the same time and even before Bergmann and Sims.

We met in person at the 2013 *"Frontiers of Engineering Education Symposium,"* held by the National Academy of Engineering, where the flipped classroom was a centerpiece of interest. Since then, more engineering educators across the nation are adopting technology to share content with students and designing engaging class activities to support the learning of complex topics. The papers in this issue report formal evaluations of these efforts, gauging the effect they have on student learning.

AEE made a call for papers reporting research studies on flipped classrooms in STEM fields. We sought papers exploring the effectiveness of the flipped classroom in STEM courses using parameters such as student performance, course experience, institutionalizing of findings, and long-term retention. Papers needed to be based on sound pedagogy and accepted statistical analysis. We first asked for submission of an extended abstract. Out of the 14 abstracts received we invited nine to submit full papers. After an extensive peer-review process, eight papers were accepted for publication in this issue.

Ferri, et al. used the flipped classroom to bring more hands-on learning in a course on Linear Circuits for non-electrical-engineering majors. They implemented it in nine sections and on a sample size of 300 students. They used content from a MOOC (massive open online course) from Coursera for student consumption outside the classroom. The hands-on learning not only included active and collaborative opportunities but also small-scale laboratories as well. They found that there was a positive impact on student learning and student confidence.

Le Doux and Waller implemented a problem-solving studio (PSS) learning environment for an entry level course in Conservation Principles of Biomedical Engineering. In this system, students in groups of two solve problems with another group of two. These teams are kept the same through most of the semester. Help is made available to students through in-class mentors and the instructor, which allows them to adapt the support to student needs. They concluded that the PSS approach improved engineering problem-solving skills as well as conceptual learning.

Saterbak and Wettergreen used the flipped classroom in a freshman Engineering Design course. Before flipping the course, it was project-design-based, with already a large active-learning component to it. Lecture component that was 30% of the pre-flipping course was replaced by in-class exercises, and analysis and design problems. The work is still on-going to find the impact of the flipped classroom, but initial results show no statistical difference in student learning. This may reinforce some findings in other studies that "improvements from a flipped classroom may simply be the fruits of active learning" (Jensen, Kumar and Godoy, 2015).

Clark, et al. studied a school-wide implementation of flipped classes in multiple engineering disciplines ranging from first-year to senior-year courses. They found several advantages of flipped instruction, including improved student discussion and questions, enhanced problem-solving, and deeper engagement. Interestingly, they found that freshman and seniors rated their flipped-classroom environments statistically lower than did sophomores and juniors.

Clark, Kaw, and Besterfield-Sacre used blended, flipped and semi-flipped approaches in various sections of a numerical methods course for undergraduate mechanical engineers. Their results suggest that flipped instruction is more beneficial than blended learning for both lower and higher-order skills development, although students preferred blended instruction over the other classroom environments.

Webster, Majerich and Madden implemented the flipped classroom for an undergraduate course in Fluid Mechanics. The students watched short online videos before class, worked in pairs solving problems in class, and had individual weekly quizzes. Instructors and teaching assistants were available just-in-time. Although the study was limited by using different instructors and small sample sizes, effects on learning in the flipped classroom were found to be marginally significant via a final examination, and highly significant via a post-concept inventory.

Karabuut-Ilgu and Jahren used the flipped classroom for a junior-level course in Construction Equipment and Heavy Construction Methods. The face-to-face traditional lecture was replaced by online content consisting of video lectures and quizzes, and the class time continued with laboratory content and added open-ended and realistic problems in the classroom. The flipped classroom effects were statistically significant, with 49% of the students in the hybrid format receiving a grade of A, in contrast to 37% receiving a grade of A in the traditional format.

Schrlau, Stevens and Schley deployed the flipped classroom for an undergraduate course in Heat Transfer. They used online materials for out-of-class preparation and had student-centered activities in the classroom. In addition, they used open-ended case studies to improve student engagement and relate to real-world applications. To compare the flipped class with the traditional classroom, they used course grades, and assessed conceptualization and application. They found that the flipped classroom students outperformed the traditional format students in all areas. Based on these results, the flipped classroom is getting institutionalized and has been adopted now in their Fluids Mechanics course as well.

The papers in this issue deliver mixed results for the effectiveness of the flipped classroom. We should acknowledge, however, the statistical limitations of some studies. In addition to statistical significance, it is imperative that we emphasize the effect sizes and statistical power as well (Ellis, 2010). Whether large or small, effect size should be reported in all studies. An outcome showing statistical significance but small effect size could imply that the intervention is not worthy of deploying at large scale. We also need access to negative, positive and nonsignificant results. Planning the studies for sufficient statistical power, on the other hand, decreases the risk of missing real effects and in fact, decreases the risk of publishing false positives.

Taking into account the broader literature, there is a growing body of evidence supporting that active learning is superior to traditional lecture methods. The weight of this evidence led Freeman et al.—after carrying out an extensive meta-analysis that compared active learning to lecture approaches—to suggest that it no longer makes sense to conduct studies using the traditional lecture method as a control (Freeman, et al., 2014). We tend to agree.

We also think it is time to move beyond studies that compare courses broadly categorized as "lectures with active learning" or "flipped" or "blended". Studies such as these help make the case for active learning but they rarely provide instructors with concrete guidance on how to design individual activities or interventions that promote learning. The learning sciences research community has to move beyond the vague term "active learning" and begin to identify specific and directly observable student behaviors while they engage in the learning process (Chi and Wylie, 2014). This will enable researchers to assess the impact of learning design choices on student engagement and learning, and will provide instructors with actionable guidelines they can use to create and assess new and powerful learning activities for their own courses.

Do students learn more in active learning environments such as blended and flipped classrooms? To definitively answer this question, we need to find out what kinds of active learning works best, when, in what context, and why, through studies with adequate statistical power that report effect sizes.

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## AUTHORS

**Lorena Barba** has a Ph.D. in Aeronautics from the California Institute of Technology and BSc/PEng degrees in mechanical engineering from Universidad Técnica Federico Santa María, Chile. She is currently an Associate Professor of Mechanical and Aerospace Engineering at the George Washington University in Washington, D.C. She is an advocate of open-source software for science and open educational resources, and shares her courseware on iTunesU and YouTube. She is also interested in education technology, social learning and the spread of massively open online courses, as well as innovations in STEM education, including flipped classrooms and other forms of blended learning. She received the NSF Faculty Early CAREER award (2012), was named CUDA Fellow by NVIDIA Corp. (2012), is an awardee of the UK Engineering and Physical Sciences Research Council (EPSRC) First Grant program (2007), is an Amelia Earhart Fellow of the Zonta Foundation (1999) and a leader in computational science and engineering internationally. Her research includes computational fluid dynamics, high-performance computing, computational biophysics and animal flight. She can be reached at labarba@gwu.edu.

**Autar Kaw** (autarkaw.com) is a Professor of Mechanical Engineering at the University of South Florida. He has been at USF since 1987, the same year in which he received his Ph. D. in Engineering Mechanics from Clemson University. He is a recipient of the 2012 U.S. Professor of the Year Award. With major funding from NSF, he is the principal contributor in developing the multiple award-winning online open courseware for an undergraduate course in Numerical Methods. The OpenCourseWare (nm.MathForCollege.com) annually receives 1,000,000+ page views, 1,000,000+ views of the YouTube audiovisual lectures, and 150,000+ page views at the NumericalMethodsGuy blog. His current research interests include engineering education research methods, adaptive learning, open courseware, massive open online courses, flipped classrooms, and learning strategies. He has written four textbooks and 80 refereed technical papers, and his opinion editorials have appeared in the St. Petersburg Times and Tampa Tribune. He can be reached at kaw@usf.edu.

**Joe Le Doux** (pwp.gatech.edu/bmeac/) is an Associate Professor in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University, and the Associate Chair for Student Learning and Experience. His research interests are in diagrammatic reasoning, engineering judgment, and innovative student-centered learning environments. His current research is focused on understanding how students experience the problem-solving studio (PSS) environment, and how these experiences affect their approaches to learning within the PSS course, as well as in subsequent courses. He earned a B.S. and a M.Eng. in Chemical Engineering from Cornell University and a Ph.D. in Chemical and Biochemical Engineering from Rutgers University. He can be reached at joe.ledoux@bme.gatech.edu.