

Board 75: Instructor Use of Movable Furniture and Technology in Flexible Classroom Spaces

Dr. Aaron W. Johnson, University of Michigan

Aaron W. Johnson is a postdoctoral research fellow at the University of Michigan. He received his Ph.D. in Aeronautics and Astronautics from the Massachusetts Institute of Technology in 2014, after which he served as a postdoctoral research fellow at the Tufts University Center for Engineering Education and Outreach. Aaron also obtained a master's degree from MIT in 2010 and a bachelor's degree from the University of Michigan in 2008, both in aerospace engineering.

Dr. Jessica E S Swenson, University of Michigan

Jessica Swenson is a post doctoral fellow at the University of Michigan. She was awarded her doctorate and masters from Tufts University in mechanical engineering and STEM education respectively. Her current research involves examining different types of homework problems in undergraduate engineering science courses, flexible classroom spaces, active learning, responsive teaching, and elementary school engineering teachers.

Mr. Max William Blackburn, University of Michigan

Max Blackburn is a fourth year undergraduate Electrical Engineering student at the University of Michigan, focusing in Power systems and Energy. He is currently assisting Dr. Cynthia Finelli with research concerning the effects of flexible learning spaces and formative assessment techniques.

Ms. Candace Rose Wiwel, University of Michigan

Candace Wiwel is a third year undergraduate student studying Naval Architecture and Marine Engineering at the University of Michigan.

Jessica P Hernandez

Dr. Cynthia J. Finelli, University of Michigan

Dr. Cynthia Finelli is Associate Professor of Electrical Engineering and Computer Science, Associate Professor of Education, and Director and Graduate Chair for Engineering Education Research Programs at University of Michigan (U-M). Dr. Finelli is a fellow in the American Society of Engineering Education, a Deputy Editor of the Journal for Engineering Education, an Associate Editor of the IEEE Transactions on Education, and past chair of the Educational Research and Methods Division of ASEE. She founded the Center for Research on Learning and Teaching in Engineering at U-M in 2003 and served as its Director for 12 years. Prior to joining U-M, Dr. Finelli was the Richard L. Terrell Professor of Excellence in Teaching, founding director of the Center for Excellence in Teaching and Learning, and Associate Professor of Electrical Engineering at Kettering University.

Dr. Finelli's current research interests include student resistance to active learning, faculty adoption of evidence-based teaching practices, the use of technology and innovative pedagogies on student learning and success, and the impact of a flexible classroom space on faculty teaching and student learning. She also led a project to develop a taxonomy for the field of engineering education research, and she was part of a team that studied ethical decision-making in engineering students.

Instructor Use of Movable Furniture and Technology in Flexible Classroom Spaces

Abstract

Flexible classroom spaces, which have movable tables and chairs that can be easily rearranged into different layouts, make it easier for instructors to effectively implement active learning than a traditional lecture hall. Instructors can move throughout the room to interact with students during active learning, and they can rearrange the tables into small groups to facilitate conversation between students. Classroom technology, such as wall-mounted monitors and movable whiteboards, also facilitates active learning by allowing students to collaborate. In addition to enabling active learning, the flexible classroom can still be arranged in front-facing rows that support traditional lecture-based pedagogies. As a result, instructors do not have to make time- and effort-intensive changes to the way their courses are taught in order to use the flexible classroom. Instead, they can make small changes to add active learning.

We are in the second year of a study of flexible classroom spaces funded by the National Science Foundation's Division of Undergraduate Education. This project asks four research questions that investigate the relationships between the instructor, the students, and the classroom: 1) What pedagogy do instructors use in a flexible classroom space? 2) How do instructors take advantage of the instructional affordances (including the movable furniture, movable whiteboards, wall-mounted whiteboards, and wall-mounted monitors) of a flexible classroom? 3) What is the impact of faculty professional development on instructors' use of flexible classroom spaces? and 4) How does the classroom influence the ways students interpret and engage in group learning activities? In the first year of our study we have developed five research instruments to answer these questions: a three-part classroom observation protocol, an instructor interview protocol, two instructor surveys, and a student survey.

We have collected data from nine courses taught in one of ten flexible classrooms at the University of Michigan during the Fall 2018 semester. Two of these courses were first-year introduction to engineering courses co-taught by two instructors, and the other seven courses were sophomore- and junior-level core technical courses taught by one instructor. Five instructors participated in a faculty learning community that met three times during the semester to discuss active learning, to learn how to make the best use of the flexible classroom affordances, and to plan activities to implement in their courses. In each course we gathered data from the perspective of the instructor (through pre- and post-semester interviews), the researcher (through observations of three class meetings with our observation protocol), and the students (through conducting a student survey at the end of the semester). This poster presents qualitative and quantitative analyses of these data to answer our research questions, along with evidence-based best practices for effectively using a flexible classroom.

Introduction

Flexible classroom spaces are non-traditional classrooms containing movable furniture that can be arranged into different layouts. This furniture, along with other technology such as movable whiteboards and wall-mounted monitors, makes it easier for instructors to effectively implement active learning [1]. When instructors want to implement small group active learning, they can have students re-arrange the tables so that students are sitting in groups of 3-6, all facing each other. The instructor can also direct students to use the whiteboards or wall-mounted monitors to better facilitate working together during the active learning.

Many universities have *studio classrooms* where tables are fixed in small groups, and these classrooms offer the same advantages for active learning as flexible classrooms (e.g. [2]–[7]). However, the difference between studio classrooms and flexible classrooms is that flexible classrooms can also support traditional lecture-based pedagogy. An instructor who wishes to lecture in a flexible classroom can have the students arrange the tables into rows that face a front projection screen or whiteboard. Studio classrooms cannot support traditional instructor-centered pedagogies in the same way, and instructors are forced to substantially adapt their course to the classroom or lecture to students as they sit in small groups. Forcing instructor-centered courses to take place in studio classrooms has even been found to have negative effects on students. In a study by Lasry, Charles, and Whittaker, holding lecture courses in studio classrooms resulted in lower student gains on a concept inventory than lecture courses held in a traditional classroom and student-centered active learning courses held in either classroom [8].

Unlike studio classrooms or traditional classrooms, flexible classrooms support both active learning and lecture pedagogy. They provide a space where instructors can more easily implement active learning, and they also remain well-suited for lecture, which is still the predominant pedagogy used in undergraduate education [9], [10]. Instructors teaching in a flexible classroom can be encouraged to add small opportunities for active learning into their course, rather than making a time- and effort-intensive change to completely restructure their course around active learning.

This paper describes research conducted during the second year of a National Science Foundation-funded project investigating flexible classroom spaces. We first outline our four research questions for the project in the context of our conceptual model of the relationships between the instructor, students, and classroom. We then describe the set of research instruments used to collect data from nine courses taught in a flexible classroom during the Fall 2017 semester. We present a summary of the data collected and our planned analysis, and we then conclude with evidence-based best practices for effectively using a flexible classroom.

Project Description

Our project is based around a conceptual model that outlines relationships between three actors in any given course: the instructor, the students, and the physical classroom space. These relationships are shown in Figure 1. For more details of this conceptual model, please see [11].

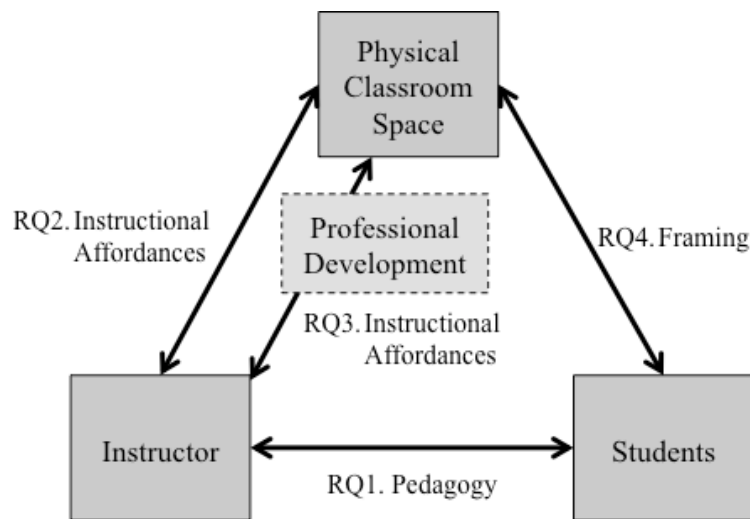


Figure 1. Conceptual model of relationships between the physical classroom space, the instructor, and the students.

Pedagogy

The relationship between the instructor and students is the **pedagogy** used in the course, and this is the focus of our first research question:

RQ1. What pedagogy do instructors use in a flexible classroom space?

We focus on two aspects of an instructor's pedagogy: his or her use of 1) teaching activities, specifically active learning, and 2) responsive teaching. Responsive teaching is an instructional practice that instructors use to elicit, notice, and respond to the “disciplinary engagement” of students in real-time during class [12], [13]. More details about responsive teaching can be found in our papers [14] and [15].

Instructional Affordances

One factor that may influence an instructor's pedagogy is the **instructional affordances** of the physical classroom space: i.e., the movable furniture, movable whiteboards, wall-mounted whiteboards, and wall-mounted monitors. These instructional affordances support active learning, and their presence may signal that instructors should use the classroom for more than just lecture. This is the focus of our second research question:

- RQ2. How do instructors take advantage of the instructional affordances (including the movable furniture, movable whiteboards, wall-mounted whiteboards, and wall-mounted monitors) of a flexible classroom?

While the instructional affordances support active learning, the mere presence of movable furniture or wall-mounted monitors does not change the teaching and learning that occurs. Rather, instructors must recognize and use these affordances for teaching and learning to be affected [16]. By design, it is possible for an instructor to use the flexible classroom for a instructor-centered, lecture-based course, and we have seen many instructors still employ lecture pedagogy in flexible classrooms. As a part of our research we are studying the effect that professional development—in the form of a faculty learning community of five instructors that met three times during the semester—had on instructors’ use of the instructional affordances. This is the focus of our third research question:

- RQ3. What is the impact of faculty professional development on instructors’ use of flexible classroom spaces?

Framing Affordances

Lastly, the way that students interpret learning activities during class may also be influenced by the instructional affordances of the classroom. We label this relationship between the students and the classroom as students’ epistemological **framing**, which is their “sense of what is taking place with respect to knowledge” ([17], p. 149). We investigate students’ perception of the classroom and the course learning activities in our fourth research question:

- RQ4. How does the classroom influence the ways students interpret and engage in group learning activities?

As RQ4 indicates, we have chosen to focus our study on the flexible classroom’s influence on students’ framing—an aspect of physical classroom spaces not previously studied—rather than its influence on students’ learning—an aspect of physical classroom spaces that has been researched in controlled studies. For example, previous research has shown that studio classrooms benefit student learning even when controlling for students’ ACT scores and holding the course and instructor constant [18]. Rather than repeating studies such as this, we intend to start a new thread of research on students’ framing in flexible classrooms. Furthermore, we do not have the data to be able to make controlled investigations of student learning. Our study is designed to be broad and focus on multiple courses in multiple flexible classrooms. As a result, we do not have control data that allows us to compare student learning with and without the flexible classroom.

Data Collection

We have studied nine of the seventy-nine courses that were held in one of the ten flexible classrooms at the University of Michigan College of Engineering during the Fall 2018 semester. Data about these ten classrooms, including room capacity and availability of several instructional affordances, are included in Table I. The nine courses we studied were taught by eleven instructors, as two first-year design courses were co-taught by an engineering instructor and a technical communications instructor. A list of the courses can be found in Table II.

Table I: Flexible classrooms at the University of Michigan College of Engineering

Classroom	Capacity	Moveable Furniture	Moveable Whiteboards	Wall-mounted Whiteboards	Wall-mounted Monitors
A	24	Yes	No	Yes	Yes
B	24	Yes	No	Yes	No
C	24	Yes	No	Yes	Yes (but students cannot easily connect)
D	36	Yes	Yes	Yes	Yes (with desktop computers)
E	48	Yes	Yes	Yes	Yes (with desktop computers)
F	56	Yes	Yes	Yes	Yes
G	56	Yes	Yes	Yes	Yes
H	60	Yes	No	No	No
I	62	Yes	Yes	Yes	No
J	84	Yes	Yes	Yes	Yes

Table II. Nine courses held in a flexible classroom were studied during the Fall 2018 semester

Course	Subject	Department	# of Instructors	Course Level	Class-room	Student Enrollment	FLC member?	# of Class Meetings Observed	Interviews Completed	# of Instructor Survey 1 Responses	# of Student Survey Responses
1	First-year design	Biomedical Engineering	2	100	I	53	No	3	Pre- and Post-sem. (both instructors)	3	12
2	First-year design	Computer Science	2	100	E	48	Yes (both instructors)	3	Pre- and Post-sem. (both instructors)	2	20
3	Thermodynamics	Biomedical Engineering	1	200	J	77	No	2	Pre-semester only	0	19
4	Engineering Materials	Material Science and Engineering	1	200	E	44	No	3	Pre- and Post-semester	2	16
5	Dynamics	Mechanical Engineering	1	200	A	19	No	3	Pre- and Post-semester	3	13
6	Statics	Civil Engineering	1	300	G	45	Yes	4	Pre- and Post-semester	3	9
7	Fluid Mechanics	Civil Engineering	1	300	F	36	Yes	3	Pre- and Post-semester	3	12
8	Fluid Mechanics	Aerospace Engineering	1	300	J	79	No	3	Pre- and Post-semester	3	33
9	Control Systems	Mechanical Engineering	1	400	J	63	Yes	3	Both	3	20

In order to help instructors take advantage of the flexible classroom, we conducted a **Faculty Learning Community (FLC)** with 5 of the 11 instructors. The FLC met once a month during the study for a total of three meetings. The format for the FLC was based on the Teaching Circle for Large Engineering Courses that Finelli designed to overcome barriers to faculty adoption of active learning [22]. In advance of each meeting, instructors were asked to read an article about studio classrooms [8], [23], [24]. During the FLC, participants discussed the readings, reflected on their own teaching, discussed their use of the flexible classroom, and planned an in-class activity that used the affordances of the classroom to support active learning. We also presented results of our previous studies on flexible classroom spaces and active learning and discussed the instructional affordances in each of the participants' classrooms.

We have developed five research instruments to address our four research questions: a three-part classroom observation protocol, an instructor interview protocol, two instructor surveys, and a student survey. For all nine courses we studied in Fall 2018, we aimed to observe two to four class meetings during the semester, conduct both a pre- and post-semester interview for each instructor, administer Instructor Survey 1 after each class observation, administer Instructor Survey 2 during each post-semester interview, and administer a student survey once in each class meeting. Table II includes information about each of these data collection points.

Instructor Interview

We conducted semi-structured pre- and post-semester interviews to allow the instructors to reflect on their goals for the course, teaching practices, and intended and actual use of classroom affordances. We used a series of open-ended questions to probe more about the pedagogy that instructors chose to use in the classroom (RQ1) and the reasons instructors used the instructional affordances in the ways they did (RQ2). We also asked questions about the professional development for the instructors who participated in it (RQ3).

Classroom Observations

We conducted classroom observations for each course using a structured protocol to measure three different aspects of an instructor's teaching and use of the flexible classroom. First, the protocol captures instructors use of active learning activities, which can range from something as short as asking students to turn and briefly discuss a concept with each other to longer problem solving sessions in small groups [19]. Second, the protocol captures instances of responsive teaching during question-initiated dialogue, and the researcher codes whether the questions asked and answers given show evidence of the students working to make sense of the course concepts. This second part of the observation protocol, called the **Teacher Eliciting, NOticing, and Responding (TENOR)** Protocol, is described in more detail in our companion paper [15]. Data collected from these two parts of our observation protocol, along with the instructor survey and interview described later, address RQ1. Third, to investigate how instructors take advantage of the affordances during their teaching (RQ2), the protocol captures the use of instructional

affordances as well as the position of the tables and chairs before, during, and after the class meeting.

Instructor Surveys 1 and 2

We surveyed instructors during the study using two separate survey instruments. First, we administered Instructor Survey 1 after each observed class. In this survey, instructors are asked four questions about their intended and actual lesson for the observed class and whether they made any changes to that plan as they were teaching. These questions are intended to gauge instructor responsiveness to students at a high level and allow us to understand how instructors engaged in responsive teaching during a particular class meeting (RQ1).

Second, we administered Instructor Survey 2 at the beginning of the post-semester interview. In this survey, instructors are asked to reflect on their teaching over the past semester through a 30-question survey. The questions, based on the Student Responses to Instructional Practices (StRIP) Survey [25], ask instructors about the pedagogy they used in the course. The survey responses are used to further understand the instructor's pedagogical choices (RQ1) and the influence of the professional development (RQ3). In our data collection, all instructors who participated in a post-semester interview also filled out Instructor Survey 2.

Student Survey

For all of the courses we observed, we administered a concurrent student survey a few weeks before the end of the semester to capture students' perceptions about their instructors' use of the affordances in the classroom. Some questions, taken from the Student Responses to Instructional Practices (StRIP) Survey [25], measure student responses to instruction and overall evaluation of the course (RQ1). We also added questions to investigate students' framing of in-class activities and interaction with each other (RQ4). Additional questions, taken from the University of Minnesota Office of Information Technology's Student Survey for active learning classrooms [26], measure how students perceived the classroom's effect on their learning (RQ4) and its effect on the instructor's use of the instructional affordances (RQ2).

Data Analysis

We have completed all data collection and are currently analyzing the data. To address RQ1 (*What pedagogy do instructors use in a flexible classroom space?*) we are examining the observation data, particularly the number and duration of active learning activities, and comparing our observations to what instructors report in the interviews and what students report in the survey data. The total number of active learning activities used over all observations is below (Table III).

Table III. Number of Active Learning Activities Used During Three Observed Class Meetings

Course	Subject	Department	Minutes Observed	Number of Activities
1	First-year Design	Biomedical Engineering	240	4
2	First-year Design	Computer Science	240	20
3	Thermodynamics	Biomedical Engineering	220*	3
4	Engineering Materials	Material Science and Engineering	150	5
5	Dynamics	Mechanical Engineering	240	27
6	Statics	Civil Engineering	200^	7
7	Fluid Mechanics	Civil Engineering	150	4
8	Fluid Mechanics	Aerospace Engineering	240	7
9	Control Systems	Mechanical Engineering	240	1

*Two class meetings were observed. ^Four class meetings were observed

In our initial analysis of the number of active learning activities, two courses stood out as more student-centered than the other seven—the first-year design course focused on computer science (Course 2) and the mechanical engineering dynamics course (Course 5).

We are studying how instructors and students used the classroom affordances to answer RQ2 (*How do instructors take advantage of the instructional affordances of a flexible classroom?*). We are analyzing both the percent of observed class meetings that used a particular affordance from the observation data and perceptions on the usefulness of the affordances of the course from the instructors (as reported in their interviews) and the students (as reported in the student survey). As Figure 2 shows, instructors used the classroom affordances more than the students, as would be expected. Instructors used the front screen and front whiteboard in 60% of observed class meetings, and used the wall-mounted monitors to project content in 44% of observed class meetings. However, students used the front screen, wall-mounted whiteboards, and clickers in at least 10% of observed class meetings.

To answer RQ3 (*What is the impact of faculty professional development on instructors' use of flexible classroom spaces?*), we are examining the classroom observations and interviews for differences between the five faculty instructors in the FLC and the six instructors who did not participate. Preliminary results from classroom observations show that participants in the FLC who did not already use active learning employed a new strategy once or twice, but they needed more coaching to feel comfortable consistently using it in their teaching. Lastly, to answer RQ 4 (*How does the classroom influence the ways students interpret and engage in group learning*

activities?) are examining student survey responses as well as their participation during observed in-class active learning activities.

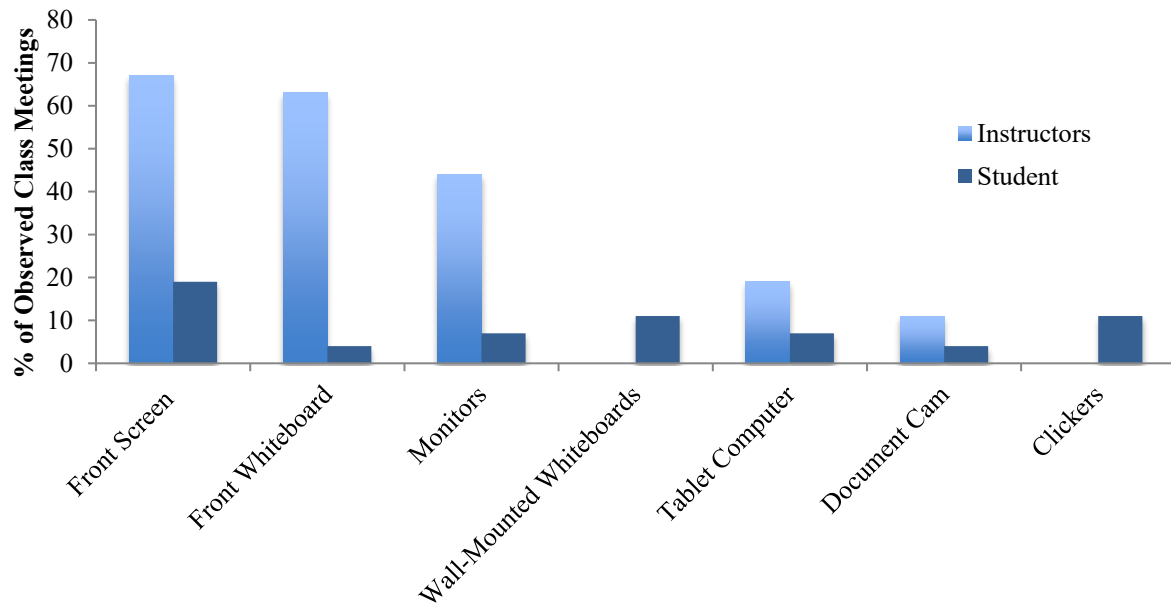


Figure 2: Use of Classroom Affordances by Instructors and Students

Recommendations

Based on our early findings, we offer recommendations for instructors using flexible classrooms. First, with regards to the technology affordances in a flexible classroom, we recommend that **1) instructors ask students to use wall-mounted monitors and whiteboards during collaborative group work.** Instructors in the flexible classroom found that student use of the wall-mounted monitors and whiteboards was beneficial for “eavesdropping visually” on students, as one instructor said in an interview during the pilot phase of the research. Having students display their work on a whiteboard or monitor helped to ensure that the entire group was on-task, and it also helped to make sure that each student was on the same page and participating in the work. Beyond keeping students accountable, the monitors and whiteboards helped instructors to monitor how students were progressing with the activity. The instructors could easily look around the classroom and see which students needed the most one-on-one attention.

With regards to the movable furniture, we encourage instructors to **2) think about different furniture layouts in which they can use the flexible classroom before the semester** and to **3) set the classroom norms at the beginning of the semester by teaching students how to rearrange the classroom into the furniture layouts that they will use.** During our pilot study, instructors commented in interviews that one of the barriers to rearranging the flexible furniture was the time and effort required to do so. A number of instructors mentioned that they chose to modify their activity to fit the layout of the classroom rather than take the time and effort to

rearrange the classroom. This barrier to using the flexible classroom was particularly prevalent when instructors did not start rearranging the classroom from the beginning of the semester. We found that classroom norms were set quickly, and that instructors felt hesitant to push against these norms as the semester progressed. However, when instructors set the classroom norms early in the semester, students quickly learn how to rearrange the tables. To support instructors in teaching students how to rearrange the classroom, we now provide instructors with a Microsoft PowerPoint file that contains diagrams of each flexible classroom. These diagrams have scaled outlines of the classroom with rectangles representing the tables in the room. Instructors have successfully used these layouts to show desired layouts to students, which enables them to rearrange the furniture more quickly and more easily

Lastly, we recommend that instructors work with course schedulers to **4) hold classes in flexible classrooms with a capacity that is greater than the enrollment of their course**. While we acknowledge that this is difficult, our research has shown that it is much easier for instructors and students to rearrange the furniture into different arrangements if the room is not completely full of students. Having some extra space also gives instructors a place to store tables, chairs, and movable whiteboards that are not currently being used.

Conclusions

In this study of flexible classroom spaces we are addressing four research questions that investigate the relationships between the instructor, the students, and the classroom: 1) What pedagogy do instructors use in a flexible classroom space? 2) How do instructors take advantage of the instructional affordances (including the movable furniture, movable whiteboards, wall-mounted whiteboards, and wall-mounted monitors) of a flexible classroom? 3) What is the impact of faculty professional development on instructors' use of flexible classroom spaces? and 4) How does the classroom influence the ways students interpret and engage in group learning activities? To answer these research questions we have developed five research instruments: a three-part classroom observation protocol, an instructor interview protocol, two instructor surveys, and a student survey. At this point in the study we have collected data from nine courses that were taught in a flexible classroom space during the Fall 2018 semester, and are analyzing the data to answer our research questions and further develop evidence-based best practices for using a flexible classroom space. As our results to date have shown, these classrooms facilitate active learning by enabling student collaboration, but can still be arranged in front-facing rows that support traditional lecture-based pedagogies.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. DUE-1711533. Any opinions, findings, and conclusions or recommendations expressed in this

material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

- [1] Johnson, A. W., Blackburn, M. W., Su, M. P., & Finelli, C. J. (2018). How a Flexible Classroom Affords Active Learning in Electrical Engineering. *IEEE Transactions on Education*. Advance online publication. doi: 10.1109/TE.2018.2867447.
- [2] Jamieson, P. (2003). Designing more effective on campus teaching and learning spaces: a role for academic developers. *International Journal for Academic Development*, 8(1-2), 119-133.
- [3] Chism, N. V. N. (2006). In D. G. Oblinger (Ed.), *Learning Spaces* (2.1-2.12). Retrieved from www.educause.edu/learningspaces [L]
[SEP]
- [4] Oblinger, D. G. (2006). In D. G. Oblinger (Ed.), *Learning Spaces* (1.1-1.4). Retrieved from www.educause.edu/learningspaces [L]
[SEP]
- [5] Montgomery, T. (2008). Space matters Experiences of managing static formal learning spaces. *Active Learning in Higher Education*, 9(2), 122-138. [L]
[SEP]
- [6] Baepler, P., Walker, J. D., Brooks, D. C., Saichaie, K., & Petersen, C. L. (2016). *A Guide to Teaching in the Active Learning Classroom: History, Research, and Practice*. Sterling, VA: Stylus Publishing. [L]
[SEP]
- [7] Knaub, A. V., Foote, K. T., Henderson, C., Dancy, M., & Beichner, R. J. (2016). Get a room: the role of classroom space in sustained implementation of studio style instruction. *International Journal of STEM Education*, 3(1), 1-22.
- [8] Lasry, N., Charles, E., & Whittaker, C. (2014). When teacher-centered instructors are assigned to student-centered classrooms. *Physical Review Special Topics—Physics Education Research*, 10(1), 010116.
- [9] Herreid, C. F., & Schiller, N. A. (2013). Case studies and the flipped classroom. *Journal of College Science Teaching*, 42(5), 62-66.
- [10] Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., ... & Levis-Fitzgerald, M. (2018). Anatomy of STEM teaching in North American universities. *Science*, 359(6383), 1468-1470.
- [11] Bork, S.J., Wiwel, C.R., Blackburn, M.W., Johnson, A.W., & Finelli, C.J. (2018). Impact of Flexible Classroom Spaces on Instructor Pedagogy and Student Behavior. *Proceedings of the 125th American Society for Engineering Education Annual Conference*. Washington, DC: American Society for Engineering Education.
- [12] Hammer, D., Goldberg, F., & Fargason, S. (2012). Responsive teaching and the beginnings of energy in a third grade classroom. *Review of Science, Mathematics and ICT Education*, 6(1), 51-72. [L]
[SEP]
- [13] Robertson, A. D., Scherr, R., & Hammer, D., Eds. (2015). *Responsive Teaching in Science and Mathematics*. Routledge: New York, NY. [L]
[SEP]

- [14] Johnson, A. W., & Finelli, C. J. (2017). Responsive teaching in undergraduate engineering courses. *Proceedings of the 124th American Society for Engineering Education Annual Conference*. Washington, DC: American Society for Engineering Education.
- [15] Johnson, A. W., Swenson, J. E. S., Blackburn, M. W. & Finelli, C. J. (2019). **The** Development of a coding scheme analyzing formative assessment in undergraduate engineering science courses. *Proceedings of the 126th American Society for Engineering Education Annual Conference*. Washington, DC: American Society for Engineering Education.
- [16] Norman, D. A. (2013). *The design of Everyday Things: Revised and Expanded Edition*. New York, NY: Basic Books. ^[L]_[SEP]
- [17] Scherr, R. E., & Hammer, D. (2009). Student behavior and epistemological framing: Examples from collaborative active-learning activities in physics. *Cognition and Instruction*, 27(2), 147-174. ^[L]_[SEP]
- [18] Cotner, S., Loper, J., Walker, J. D., & Brooks, D. C. (2013). "It's Not You, It's the Room"—Are the High-Tech, Active Learning Classrooms Worth It? *Journal of College Science Teaching*, 42(6), 82-88.
- [19] Paulson, D. R., & Faust, J. L. (1988). *Active and Cooperative Learning*. Los Angeles: California State University, Los Angeles. Retrieved from <http://www.calstatela.edu/dept/chem/chem2/Active/index.htm>
- [20] Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223-231.
- [21] Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410-8415.
- [22] Finelli, C. J., Daly, S. R., & Richardson, K. M. (2014, Apr). Bridging the research-to-practice gap: Designing an institutional change plan using local evidence. *Journal of Engineering Education*, 103(2), 331-361.
- [23] Taylor, S. S. (2009). Effects of studio space on teaching and learning: Preliminary findings from two case studies. *Innovative Higher Education*, 33(4), 217-228. ^[L]_[SEP]
- [24] Petersen, C. I., & Gorman, K. S. (2014). Strategies to address common challenges when teaching in an active learning classroom. *New Directions for Teaching and Learning*, 2014(137), 63-70.
- [25] DeMonbrun, M., Finelli, C. J., Prince, M., Borrego, M., Shekhar, P., Henderson, C., & Waters, C. (2017). Creating an instrument to measure student response to instructional practices. *Journal of Engineering Education*, 106(2), 273-298.
- [26] STSS Research Project: Student Survey. (2012, March 9). *University of Minnesota Office of Information Technology*. Retrieved from <https://drive.google.com/file/d/0B1CiRxiBPvw0T3RHVl9VLUG2am8/view>