On the Effects of Active Learning Environments in Computing Education

Tyler Greer
Computer Science
Western Washington University
greert2@wwu.edu

Qiang Hao
Computer Science & SMATE
Western Washington University
qiang.hao@wwu.edu

Mengguo Jing
Human Development and Family Studies
University of Wisconsin-Madison
mjing3@wisc.edu

Bradley Barnes
Computer Science
University of Georgia
bjb211@uga.edu

ABSTRACT

This replication study aims at both quantifying the effects of active learning classrooms in introductory programming courses (CS1) and overcoming some design and methodological limits of prior studies on this topic. 156 students enrolled in three different sections of the same CS1 participated in this study. The three sections differed from each other either in terms of learning pedagogies (conventional lecture vs. peer instruction) or physical learning environments (lecture hall vs. active learning classroom). This study did not replicate the findings of prior studies on this topic. Instead, this study found that when learning pedagogies were controlled, learning environments did not have significant influences on student performance. On the other hand, learning pedagogies were found to have significant influences on student performance. When peer instruction is conducted other than conventional lecturing, students tended to have significantly better performance. Such findings highlight the importance of active learning in computing education, and the feasibility of conducting active learning in CS1 despite of physical environment constraints. Additionally, such findings emphasize the necessity of replication studies on the topic of active learning environments, and invite debates on the investment decisions in active learning classrooms.

CCS CONCEPTS

• **Social and professional topics** → **Computer science education**; **Student assessment**; *Adult education*; • **Applied computing** → **Education**;

KEYWORDS

active learning environments, active learning classrooms, peer instruction, computing education

SIGCSE '19, February 27-March 2, 2019, Minneapolis, MN, USA

ACM ISBN 978-1-4503-5890-3/19/02…$15.00
https://doi.org/10.1145/3287324.3287345

ACM Reference Format:
Tyler Greer, Qiang Hao, Mengguo Jing, and Bradley Barnes. 2019. On the Effects of Active Learning Environments in Computing Education. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education (SIGCSE '19), February 27-March 2, 2019, Minneapolis, MN, USA.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3287324.3287345

1 INTRODUCTION

Active learning classrooms were designed on the assumption that conventional lecture halls may not provide the best environment for active learning activities. Conventional lecture halls, featured by bolted seats in rows and centered teaching stages, can physically limit communications and interactions among students, especially in-class activities such as group discussion and collaborations in a large-scale class [1]. In contrast, active learning classrooms are designed to have movable chairs, round tables, and typically multimedia equipments to decentralize the role of instructors and encourage peer communications among students [2, 3]. Despite such physical advantages, active learning classrooms can accommodate fewer students, and take much more resources to build [4].

Abundant studies have confirmed the positive effects of active learning pedagogies in enhancing learning and teaching across different fields, but significantly fewer studies have investigated the effects of active learning classrooms. Most studied investigating the effects of active learning classrooms were conducted by same groups of researchers at three institutions in the United States, including North Carolina State University [5, 6], Massachusetts Institute of Technology [1], and University of Minnesota [7, 8], in the fields such as physics, chemistry, and biology. Surprisingly, few studies have explored the effects of active learning classrooms in computing education despite that different active learning approaches have been adopted and studied in many computer science courses across the world.

It is important to understand the effects of active learning classrooms on student learning for at least three reasons. First, it takes significantly more resources to build an active learning classroom or convert an existing lecture hall to an active learning classroom [4]. Second, given the same space, an active learning classroom can accommodate much fewer number of students. Most importantly, despite of the positive findings of prior studies on this topic, many of them may not be generalized due to both research design and methodological limits, such as continuous introduction of confounding factors, misuse of predictive models, and lack of control of false positive results [8–10].

Building on the prior studies and responding to the calls for more educational replication studies, this study aims at (1) quantifying the effects of active learning classrooms in Introductory Programming courses (CS1) by replicating the study of Hao et al. [9], and (2) overcoming the identified research design and methodological limits of prior studies. The results of this study contribute to the fine-grained understanding of the roles of physical environments and pedagogies in learning and teaching of programming, and the extent to which the prior findings can be generalized.

2 RELATED WORKS

2.1 Active Learning & Teaching in Computer Science: Peer Instruction

Many active learning approaches to improve student comprehension and performance have been explored and tested in computing education over the last three decades, such as team-based learning, paired-programming and peer instruction [11–14]. Among the many test pedagogical approaches, peer instruction was studied most extensively. Peer instruction is a student-centered approach that flips the traditional lecturing by moving information transfer out and moving information assimilation into the classroom [15]. When peer instruction is practiced, students are typically required to finish pre-class reading and pre-class practices. During the class time the reading and practices would be discussed and more related practices would follow.

Peer instruction has been consistently found effective in both upper and lower level courses of computing education. Specifically, peer instruction has been reported effective in improving student achievement, satisfaction and self-efficacy [11, 16–23]. In addition, peer instruction was also found effective in improving student retention rate in introductory programming courses [24, 25]. Recent research on the scalability of peer instruction studied class evaluations of computer science courses across a wide range of class sizes, ranging from around 50 to more than 300. Although a small decline in course evaluation was found as the class size increased, the efficacy of peer instruction was found robust [26].

Peer instruction works more effective than conventional lecturing because instructor explanation is replaced and augmented with carefully designed questions that students committed time to work on [24]. Students get a chance to fill up their understanding gaps through discussing with each other [23, 24]. Despite of the efficacy of peer instruction, it may still lose its "magic" if not well implemented. Porter et al. [20] suggested that it is essential for the instructors to make the adopted pedagogy clear to students and adjust the grading structure for a better balance between correctness and participation. In addition, the implementation takes more time and efforts to prepare than conventional lecturing, especially in a conventional lecture hall. It is understandable that instructors sometimes can not afford the time to implement peer instruction given limited preparation time and limited resources.

2.2 Physical Learning Environments: Active Learning Classrooms

Learning and teaching in school mainly happens in classrooms. Educational researchers hypothesized that the physical learning environment can either enhance or inhibit learning in 1970s [2]. Active learning classrooms are designed to better facilitate discussion and collaborations within small groups and across the whole class. Instead of having a teaching center and fixed forward-facing seats, active learning classrooms are featured by open spaces, movable chairs, writing surfaces, and a strong integration of learning technologies. It is important to note that an active learning classroom requires more resources during its construction, even if it is converted from an existing conventional classroom. Furthermore, an active learning classroom accommodates a significant smaller number of students than a conventional one [4]. As is reported by Park and Choi [4], the conversion from a conventional lecture hall to an active learning classroom with 30 seats cost about one hundred thousands dollars.

Two main projects, SCALE-UP and TEAL, pioneered the study of the active learning classrooms. The SCALE-UP project was conducted at North Carolina State University and TEAL project was conducted at Massachusetts Institute of Technology [1, 5, 10]. As pioneers of classroom design, both SCALE-UP; TEAL classrooms are featured with facilities and technologies that engage students in active learning, such as "abundant whiteboard space, round tables, chairs with wheels, laptop computers, projectors and monitors, an audio systems designed to allow the students to both hear the instructor and to respond" [27]. The ACL project at the University of Minnesota followed this efforts in both classroom design and studying the efficacy of such classrooms [3, 7, 8]. The efficacy of active learning classrooms have been mainly studied through the three projects in the academic fields such as physics, chemistry and biology [1, 3, 5, 7, 8]. Hao et al [9] was identified as the first study that investigated the effects of active learning classrooms in the context of computing education. The majority of these studies concluded that active learning classrooms had significantly positive effects on student achievement [3, 4, 8, 9]. However, the findings of many of such studies were limited by both research design and statistical analysis (see section titled "Motivation for Replication").

2.3 Motivation for Replication

This study aims at a conceptual replication of Hao et al [9] that overcomes the design and methodological limits of both Hao et al [9] and other prior studies on this topic. Two noticeable limits of such studies included the lack of control of confounding factors and the lack of control of false positives. Many prior studies on this topic failed to control the influences of learning pedagogies when reaching the conclusion that active learning environments contribute significantly to student performance [2, 7, 9]. Additionally, several studies involved comparison of multiple factors between two groups, which would increase the chances of random significant results. Significance levels were not properly corrected in such cases [3, 5, 28]. Therefore, this study aims at overcoming both limits and quantifying the effects of active learning environments in learning and teaching of programming.

3 METHODS

3.1 Research Design

A Three-Group design was used with the goal to separate two factors in focus: the learning environments and pedagogical approaches. By design, three different sections of an introductory computer science course were conducted in a large research university in the southeastern United States in spring 2017. The three sections each covered the same content and tested the students with the same examinations. Each section of the course differed in its combination of the physical learning environments and the implemented pedagogical approaches:

- Course One (Conventional): Conventional classroom + Conventional Lecturing
- Course Two (Active): Active learning classroom + Active Learning & Teaching
- Course Three (Hybrid): Conventional classroom + Active Learning & Teaching

It is worth noting that the limited number of active learning classrooms at the institution made their usage and scheduling extremely difficult. More importantly, statistically speaking, three-group design can sufficiently separate two factors in focus [29]. As the result, a combination of "active learning classroom" and "conventional lecturing" is not necessary. Furthermore, three other factors were controlled. Such factors including major, gender and age.

3.2 Experiment Contexts and Data Collection

Courses One and Three were taught in conventional lecture halls while Course Two was conducted in an active learning classroom. Course One was taught through conventional lectures, where students were recommended to read the textbook outside of class time but received the content in a series of conventional lectures. In contrast, peer instruction, one active learning approach, was practiced in the learning and teaching of Course Two and Three, where students were assigned daily reading as well as a small quiz based on the textbook and videos that the instructor created; both of these were to be completed before the start of class. In addition, in Course Two and Three, students worked in groups of three to solve problems from material that they were required to read. The instructor as well as teaching assistants were available during this time to answer questions on the material.

To fully control potential confounding factors, all sections of the course were taught by the same instructor. Additionaly, three control factors (major, gender and age) were collected from the institutional data warehouse. All the three course sections received 100-point two midterm and one final exam, which were treated as student course performance.

4 RESULTS

4.1 Descriptive Summary

The descriptive summary of the 156 students is presented in Table 1. To examine the group differences in terms of age, gender, and whether or not a student was majoring in computer science, one-way MANOVA was utilized. Because there were more than two comparisons over the same groups, Bonferroni Correction was applied to the significance levels in order to avoid false positive results. The adjusted significance levels were:

$$*p < 0.016; **p < 0.003; ***p < 0.0003 \quad (1)$$

The results did not show any significant group differences in terms of major [F(3, 123) = .225, p = .879] or age [F(36, 375) = 1.179, p = .227]. However, a significant difference in terms of gender [F(3, 123) = 6.385, p = .000] was found. Students in Course Three appeared to be older than their counterparts from Courses One and Two. Given that students did not have knowledge of the sections when registering the course, the difference is likely due to randomness. Although each section of the course was majority male (greater than 56% in all sections), it is worth noting that the percentage of female students is not significantly lower than male students.

Table 1: Descriptive Summary of Participants

	Course One (Conventional)	Course Two (Active)	Course Three (Hybrid)
Number of Students	69	42	45
Major			
CS Major	43.50%	33.30%	40%
Non-CS Major	56.50%	66.60%	60%
Gender			
Male	68.10%	61.90%	77.80%
Female	31.90%	38.10%	22.20%
Age (Mean Value)	19.452	19.976	21.022

4.2 Separating the Effects of Learning Environments and Pedagogical Approaches on Student Performance

MANCOVA was applied in order to examine the effects of pedagogical approaches and learning environments on the students' three exam performance (two midterm and one final exams). In this test of MANCOVA, the following control variables were used: age, gender, and whether or not students were majoring in computer science. All two-way and three-way interactions among the independent and control variables were taken into examination. Given that there were three exam performances to be compared across the three groups, Bonferroni Correction was applied to the significance levels in order to avoid false positive results. The adjusted significance levels were:

$$*p < 0.016; **p < 0.003; ***p < 0.0003 \quad (2)$$

Utilizing Pillai's trace, the pedagogical method factor was found to be significant (p < .016), and was the only factor or interaction that was found significant in the test. The results of the multivariate tests of all attributes on the exam results are presented in Table 2.

Table 2: Multivariate Tests

Attributes	Value	F	Significance Level
age	0.051	2.507	0.061
major	0.003	0.16	0.923
gender	0.05	2.481	0.064
ct	0.056	2.803	0.042
pm	0.085	4.382	0.006*
major * gender	0.008	0.399	0.754
major * ct	0.012	0.556	0.645
major * pm	0.025	1.215	0.307
gender * ct	0.009	0.418	0.74
gender * pm	0.024	1.154	0.33
major * gender * ct	0.035	1.686	0.173
major * gender * pm	0.055	2.722	0.047

major: whether majoring in computer science; ct: classroom type; pm: pedagogical methods
* p < .016; **p < .003; ***p < .0003

Discriminant Analysis was used to follow up the MANCOVA test to further confirm the findings from MANOVA. Two discriminant functions were revealed. The first explained 92.6% of the variance, canonical R2 = .10, whereas the second explained only 7.4%, canonical R2 = .008. In combination, these discriminant functions significantly differentiated Course Three from Course One and Course Two (λ = .894, $\chi 2$ = 17.1, p = .009**; see Figure 1 and 2), but removing the first function indicated that the second function did not significantly differentiate Course One from Course Two (λ = .991, $\chi 2$ = 1.317, p = .518; see Figure 1 and 2). In other words, a significant difference was found when the adopted pedagogical approaches were different, but no significant difference was observed when the learning environments were different.

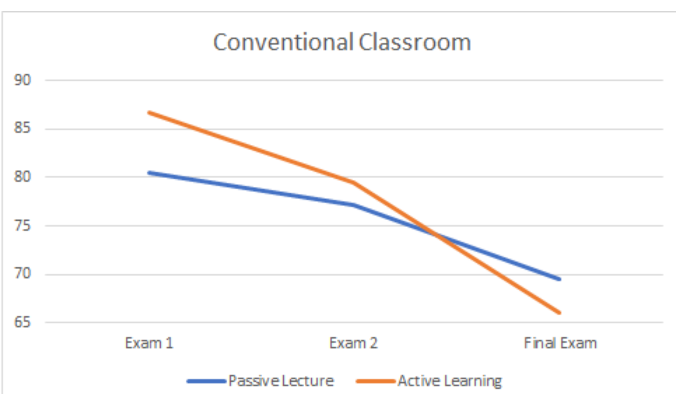

Figure 1: Student Performance Comparison between Course One and Three

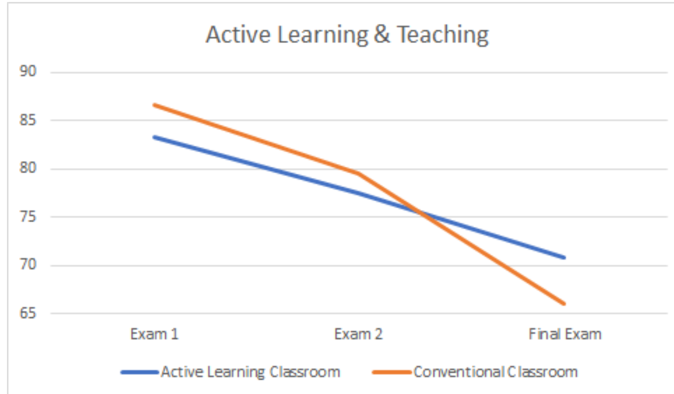

Figure 2: Student Performance Comparison between Course Two and Three

5 DISCUSSION

5.1 Efficacy of Active Learning: Does the Effect Come from the Environment or the Pedagogy?

Different from the finding of Hao et al [9] and many other prior studies [2, 7], this study found the effects of active learning environments on CS student performance to be insignificant. With a between-group design and strict control over significance levels, this study successfully separated the effects of learning environments from other potential confounding factors, among which the pedagogical approach is the most important one.

When controlling for other factors, significant differences were detected between different pedagogical approaches but not between learning environments. This finding reveals that the essence for effective learning and teaching lies more on the pedagogy than the physical space. Indeed, a well-design, technology-infused room with round tables allow students "face time" with peers and form groups naturally, while traditional lecture halls, especially those with chairs bolted in place, emphasize the instructor over the student and make group formation awkward and contrived. However, all these advantages are not guaranteed by the room per se, and effective learning are well facilitated with active learning and teaching pedagogies even in traditional classrooms.

In addition, our finding suggests to make better use of high-cost active learning classrooms with quality support from pedagogy and faculty rather than treat it as a one-time investment for ultimate solution. Overemphasis on the power of learning environment might be misleading as it weakens the roles of more essential factors. As a good example, the *Transform, Interact, Learn, Engage* classrooms at the University of Iowa are designed to support active learning, but faculties must undergo intensive training before they are allowed to teach their courses in such classrooms [27]. Unless faculty receive specific training about how to effectively use the tools to implement active learning and teaching pedagogies and how to design learning activities that are a good fit for the room, it is hard to say these rooms foster or constraints student learning.

5.2 Investment on Active Learning: Should We Invest in People or Classrooms?

Many large and well-funded institutions have initiated construction projects to bring active learning classrooms to their campuses. As such new classrooms full of technology become ready, instructors at such institutions have enthusiastically embraced them. However, not every institution has the capability of doing the same. As is reported by [4], upgrading a conventional classroom to an active one with 30 seats took more than one hundred thousand at their institution.

The findings of this study suggest that active learning and teaching can be conducted in conventional classrooms as effectively as in active learning classrooms. In other words, institutions with limited resources may not be able to build many active learning classrooms, but can still put resources into training their faculties on active learning practices. For instructors, at least CS faculties, having no access to active learning classrooms may not be a good reason for not practicing active learning. Although it can be less convenient to do so in a lecture hall, the benefits to students are still substantial. On the other hand, it is worth noting that having active learning classrooms should not be treated as the panacea by institutions. A recent study found that there was no significant increase in the use of active learning pedagogies in the collaborative classroom [30]. Without intentional training, faculties may choose the pedagogical approaches they are most familiar with despite of the physical spaces.

6 LIMITATIONS AND FUTURE STUDIES

The generalizability of the findings in this study could be limited for three reasons. First, all participants of this study came from the same course at the same institution. The course was solely taught by the same instructor during the experiment period. A different instructor or different sample of students might render the results different. Future studies may consider replications on a larger scale that involves multiple instructors from different institutions. Second, only one active learning approach, peer instruction, was practiced in the experiment. It is possible that peer instruction is least negatively affected by the learning environment compared with other learning and teaching approaches. Although peer instruction is well studied and highly applicable in computing education, it may not the same case for other fields such as chemistry or physics. If a different active learning approach is practiced in the experiment, the results might be different. Third, the pre-class activities, in-class activities, assignments, and exams given in the experimental course was designed and developed by the instructor. Future studies may consider using well-tested and publicly accessible activities and assignments (e.g., Nifty Assignments) and validated exams to strengthen the measurements.

7 CONCLUSIONS

This study intends to replicate the study of Hao et al [9] and overcome the identified research design and data analysis limits of Hao et al [9] and other prior studies on this topic. With a three-group design and strict significance-level corrections, this study did not replicate the findings of prior studies on the positive effects of active learning environments. Instead, we found that active learning pedagogies had significantly positive influences on computer science student performance, but active learning environments did not. Such findings highlighted the importance of active learning pedagogies in computing education, and the necessity to reflect on whether we should invest more in active learning classrooms. This study calls for more replication studies on the effects of active learning environments in computing education and other fields, and invites more debates on investment decisions on active learning classrooms.

REFERENCES

[1] Yehudit Judy Dori. Educational reform at mit: Advancing and evaluating technology-based projects on-and off-campus. *Journal of Science Education and Technology*, 16(4):279–281, 2007.
[2] Aimee Whiteside, D Christopher Brooks, and JD Walker. Making the case for space: Three years of empirical research on learning environments. *Educause Quarterly*, 33(3):11, 2010.
[3] D Christopher Brooks. Space matters: The impact of formal learning environments on student learning. *British Journal of Educational Technology*, 42(5): 719–726, 2011.
[4] Elisa L Park and Bo Keum Choi. Transformation of classroom spaces: Traditional versus active learning classroom in colleges. *Higher Education*, 68(5):749–771, 2014.
[5] Maria T Oliver-Hoyo, DeeDee Allen, William F Hunt, Joy Hutson, and Angela Pitts. Effects of an active learning environment: Teaching innovations at a research i institution. *Journal of Chemical Education*, 81(3):441, 2004.
[6] Robert Beichner. The scale-up project: a student-centered active learning environment for undergraduate programs. *An invited white paper for the National Academy of Sciences*, 2008.
[7] Paul Baepler, JD Walker, and Michelle Driessen. It's not about seat time: Blending, flipping, and efficiency in active learning classrooms. *Computers & Education*, 78: 227–236, 2014.
[8] Sehoya Cotner, Jessica Loper, JD Walker, and D Christopher Brooks. " it's not you, it's the room"âĂŤare the high-tech, active learning classrooms worth it? *Journal of College Science Teaching*, 42(6):82–88, 2013.
[9] Qiang Hao, Bradley Barnes, Ewan Wright, and Eunjung Kim. Effects of active learning environments and instructional methods in computer science education. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*, pages 934–939. ACM, 2018.
[10] Yehudit Judy Dori and John Belcher. How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *The journal of the learning sciences*, 14(2):243–279, 2005.
[11] Beth Simon, Michael Kohanfars, Jeff Lee, Karen Tamayo, and Quintin Cutts. Experience report: peer instruction in introductory computing. In *Proceedings of the 41st ACM technical symposium on Computer science education*, pages 341–345. ACM, 2010.
[12] Brenda Timmerman and Robert Lingard. Assessment of active learning with upper division computer science students. In *Frontiers in Education, 2003. FIE 2003 33rd Annual*, volume 3, pages S1D–7. IEEE, 2003.
[13] Hossein Hakimzadeh, Raman Adaikkalavan, and Robert Batzinger. Successful implementation of an active learning laboratory in computer science. In *Proceedings of the 39th annual ACM SIGUCCS conference on User services*, pages 83–86. ACM, 2011.
[14] Jon DH Gaffney, Evan Richards, Mary Bridget Kustusch, Lin Ding, and Robert J Beichner. Scaling up education reform. *Journal of College Science Teaching*, 37(5): 48, 2008.
[15] Catherine H Crouch and Eric Mazur. Peer instruction: Ten years of experience and results. *American journal of physics*, 69(9):970–977, 2001.
[16] Deborah Allen and Kimberly Tanner. Infusing active learning into the large-enrollment biology class: seven strategies, from the simple to complex. *Cell biology education*, 4(4):262–268, 2005.
[17] Diane Ebert-May, Carol Brewer, and Sylvester Allred. Innovation in large lectures: Teaching for active learning. *Bioscience*, 47(9):601–607, 1997.
[18] David J Nicol and James T Boyle. Peer instruction versus class-wide discussion in large classes: A comparison of two interaction methods in the wired classroom. *Studies in higher education*, 28(4):457–473, 2003.
[19] I Michele and Ralph Preszler. Introductory biology course reform: A tale of two courses. *International Journal for the Scholarship of Teaching and Learning*, 8(2):5, 2014.
[20] Leo Porter, Dennis Bouvier, Quintin Cutts, Scott Grissom, Cynthia Lee, Robert McCartney, Daniel Zingaro, and Beth Simon. A multi-institutional study of peer instruction in introductory computing. In *Proceedings of the 47th ACM Technical Symposium on Computing Science Education*, pages 358–363. ACM, 2016.

[21] Leo Porter, Saturnino Garcia, John Glick, Andrew Matusiewicz, and Cynthia Taylor. Peer instruction in computer science at small liberal arts colleges. In *Proceedings of the 18th ACM conference on Innovation and technology in computer science education*, pages 129–134. ACM, 2013.
[22] Daniel Zingaro and Leo Porter. Peer instruction in computing: The value of instructor intervention. *Computers & Education*, 71:87–96, 2014.
[23] Cynthia Bailey Lee, Saturnino Garcia, and Leo Porter. Can peer instruction be effective in upper-division computer science courses? *ACM Transactions on Computing Education (TOCE)*, 13(3):12, 2013.
[24] Leo Porter, Cynthia Bailey Lee, and Beth Simon. Halving fail rates using peer instruction: a study of four computer science courses. In *Proceeding of the 44th ACM technical symposium on Computer science education*, pages 177–182. ACM, 2013.
[25] Qiang Hao. *Online Help Seeking in Computer Science Education*. PhD thesis, University of Georgia, 2017.
[26] Soohyun Nam Liao, William G Griswold, and Leo Porter. Impact of class size on student evaluations for traditional and peer instruction classrooms. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*, pages 375–380. ACM, 2017.
[27] Sam Van Horne, Cecilia Murniati, Jon DH Gaffney, and Maggie Jesse. Promoting active learning in technology-infused tile classrooms at the university of iowa. *Journal of Learning Spaces*, 1(2):n2, 2012.
[28] Leo Porter, Cynthia Bailey Lee, Beth Simon, and Daniel Zingaro. Peer instruction: do students really learn from peer discussion in computing? In *Proceedings of the seventh international workshop on Computing education research*, pages 45–52. ACM, 2011.
[29] Andy Field. *Discovering statistics using SPSS*. Sage publications, 2009.
[30] Theresa A Beery, Dustin Shell, Gordon Gillespie, and Eileen Werdman. The impact of learning space on teaching behaviors. *Nurse education in practice*, 13 (5):382–387, 2013.