Findings and Critique of an Extracurricular Program in the Science of Learning to Improve Educational Outcomes for Engineering Students

Thomas J. Van Hoof Stephen J. Walsh Jacob Missal Daniel D. Burkey
University of Connecticut

Abstract

The science of learning (learning science) is an emerging interdisciplinary field that concerns itself with how the brain learns and remembers important information. The authors describe an innovative extracurricular program that introduced first-year undergraduate students in engineering to learning science, specifically the biological steps in the learning process and study strategies consistent with that process. The evaluation of the first two years of the program included data about attendance, satisfaction, grade point average, retention, and learning approach. This article describes the program and its evaluation findings, and the authors offer a critique in light of expert opinion and relevant research in order to improve program evaluation, recruitment, retention, and possibly effectiveness.

Keywords: Science of learning, learning science, STEM outcomes, co-curricular programs, higher education

Introduction

Current and prospective collegiate students often perceive engineering as one of the more challenging majors to pursue. A study by the National Center for Educational Statistics (NCES) showed that while non-science, technology, engineering, and mathematics (non-STEM) students had higher attrition rates from baccalaureate programs than STEM students (56%-62% versus 48%, respectively), the reasons for student attrition from STEM majors could be specific and unique to the challenges of students pursuing STEM (Chen, 2013, pp. 4-5). For students that switched from a STEM to a non-STEM major, the data showed that student performance in STEM classes, the challenge and rigor of those classes, and the number, intensity, and type of the classes were all contributing factors to students' decision to switch (Chen, 2013, pp. 5-6). Also correlated with leaving STEM majors was the total number of failing grades and course withdrawals on students' academic records (Chen, 2013, pp. 5-6). For students that withdrew completely from college after leaving a STEM program, overall struggles with collegiate-level work was a prime factor, but so were difficulties with STEM courses as evidenced by lower grades in those courses compared to non-STEM courses and higher failure and withdrawal rates from STEM courses (Chen, 2013, pp. 5-6).

Underrepresented engineering students may experience the above-described challenges at higher rates, as identity and cultural issues compound the existing obstacles to success. Indeed, over the course of the last 30 years, the engineering workforce has remained stubbornly dominated by white males, with non-white and non-male engineers growing from 9% to only 13% (Eastman, Christman, Zion, & Yerrick, 2017, p. 885; Landivar, 2013, pp. 2-21). Both of these disappointing outcomes (i.e., STEM attrition and low underrepresented minority workforce participation) are, at least in part, attributable to failures in the pedagogical approach of engineering educators (Borrego, Froyd, & Hall, 2010, p. 185). Despite many decades of research, one of the dominant methods of curriculum delivery in engineering is the lecture, with problem-sets that are highly dependent upon mastery of higher-level mathematics (Borrego et al., 2010, p. 185; Marra, Rodgers, Shen, & Bogue, 2012, pp. 8-9; Wirt et al., 2001, p. 79).

Lee and Matusovich note that the engineering education community has invested significant efforts in studying curricular changes and instructional practices designed to improve student academic success, but that *co-curricular* support, such as mentoring, tutoring, and other non-curricular-but-complementary-interventions, has received much less attention (2016, p. 407). While the literature does report the impact of co-curricular engineering programs on undergraduate research experiences (Carter, Ro, Alcott, & Lattuca, 2016), leadership programs (Athreya & Kalkhoff, 2010), academic engagement (Wilson et al., 2014), and learning communities (Maltby, Brooks, Horton, & Morgan, 2016), a review did not locate any studies that specifically measure the impact of coaching or training of students in the learning-science strategies described in this article.

Building on Tinto's model on institutional departure (1994 and 2012), Lee and Matusovich (2016) offer a conceptual model of co-curricular support that illustrates how students' interactions with both the academic and the social elements of a university program contribute to their persistence. Lee and Matusovich distinguish three different input *types* in their model: *programs, activities*, and *services*. Programs are connected events that require students to participate regularly. Whereas, activities are briefer experiences that do not require ongoing participation. Finally, services are continuously available resources that students can take advantage of at-will. Some interventions may be distinct, while others may incorporate elements of multiple types, depending on the specific intervention. Most closely aligned with Lee and Matusovich's program type, the extracurricular activity described in this article is relatively unique in that it describes a program-within-a-program, that is, a co-curricular program within a learning community; although, some student-participants approached the program as an activity, by attending only briefly. Lee and Matusovich also identified six outputs of their model: academic performance, faculty/staff interactions, extracurricular involvement, peer-group interactions, professional development, and special circumstances. The program described in this article touches on virtually all of these outputs even though their model did not inform the program.

In fall 2015, under a grant to the University of Connecticut (university) to improve STEM education, the School of Engineering (school) had an opportunity to begin a student-focused, voluntary, multi-year, extracurricular program to help incoming students in one of the school's learning communities understand and develop habits consistent with the emerging interdisciplinary field of learning science. The purpose of the program was to improve important educational outcomes for a relatively diverse set of engineering students from the very outset of matriculation. The extracurricular program, named Engineering's Lifelong Learning Program (program), had its basis in two 6-week pilots in the School of Nursing conducted by one (TVH) of the authors as a result of his educational scholarship with health care professionals (Van Hoof & Doyle, 2018). This article briefly describes the educational program, including two years of outcomes data, and critiques the program from the perspective of relevant literature. The authors believe that such a critique will be helpful to the school in its ongoing efforts to improve the program and to guide others who may be considering conceptually similar student-centered approaches.

Though a full treatment of learning science is beyond the scope of this article, learning science, which concerns itself with what happens in the brain when learning occurs (Van Hoof & Doyle, 2018, p. 1), reflects a variety of related fields (e.g., cognitive psychology and neuroscience) that one expert collectively refers to as "the learning sciences" (Sawyer, 2016, pp. 1-20). While deeper discussions about the biology of learning and the research underlying the evidence certainly occurred during the program, it focused on three basic learning steps (i.e., encoding, consolidation, and retrieval) and four evidence-based, learning-science strategies (i.e., distributed learning, retrieval practice, interleaving, and elaboration) (Van Hoof & Doyle, 2018, pp. 2-5). For content, the program relied significantly on several learning-science books (Brown, Roediger, & McDaniel, 2014; Carey, 2014; Doyle & Zakrajsek, 2013; Oakley, 2014), three authors of which served as guest-discussants in the program. The program chose content from these books as starting places for discussions, as the authors, many learning-science researchers themselves, described information in relatable ways to first-year college students. The program also developed a set of brief podcasts on the subject as part of the curriculum.

Description of the Innovation

This article includes information about the program's first two academic years, 2015-2016 and 2016-2017. Following a recruitment effort that hinged largely on communication during orientation activities, the program consisted of a series of regular one-hour meetings (weekly during the first semester and biweekly for the remaining three) with coordinated pre-activities (readings or podcasts about learning science) and post-activities (change commitments in study or related habits, such as sleep and exercise). As per the students' choice, the program met on Sunday evenings in a community room of the hall in which the learning community resided. As incentives, food and refreshments from a popular restaurant were always available at the meetings, and students received all program materials at no cost. Each meeting followed a consistent agenda that included: (1) debriefing on change commitments promised at a prior meeting; (2) discussion of readings or podcasts and their relevance to study habits; (3) an activity, reading, or didactic that built on the pre-activity; and, (4) reflection and sharing of new or modified change commitments.

Two faculty members (one representing the discipline of engineering and the other the evidence on learning science) consistently attended the sessions and facilitated the agenda. Occasionally, the meeting also included a guest-discussant, who was either a practicing engineer (to discuss continuing professional development habits), faculty member (to discuss relevant research), or a book author (to discuss their learning-science work). Students generated questions throughout each year for the book author, who attended one of the final sessions. During the first year of the program, only freshmen participants attended the sessions. During the second year, a limited number of new freshmen from the same learning community joined the program. Throughout the two years, the program remained a voluntary activity, with no consequence for lack of attendance, preparation, or participation. The outcome data in this article reflect only the student cohort that began in the fall of 2015.

Methodology

The university's institutional review board (IRB) approved the program's evaluation, including the collection, analysis, and dissemination of session attendance and overall grade point average (GPA), satisfaction with the program, retention (in an engineering major), and learning approach. The source of attendance data was students themselves, who signed an attendance sheet available at each session. At the end of each semester, students had the option of responding anonymously to a survey about their satisfaction with the program through a five-item (ranging from "extremely dissatisfied" to "extremely satisfied") Likert-style question that asked, "With this semester's activities in mind, which item best describes your overall satisfaction with Engineering's Lifelong Learning Program?" Students were also the source of information about the learning approach, i.e., deep and surface approaches reflecting learning motive and strategy, for which the program used a modified version of the revised two-factor Study Process Questionnaire (study process questionnaire) (Biggs, Kember, & Leung, 2001; Kemppainen, Sticklen, Oakley, & Chung, 2015). The university's Office of Institutional Research and Effectiveness provided students' demographic information and data on overall GPA (each semester) and retention (each year).

For more information about the study process questionnaire, it is a 20-item tool that has two main scales (deep and surface), with total point values for each ranging 10-50, inclusive (Biggs et al., 2001). As the names imply, the "deep" approach to learning scale reflects the frequency of more effective learning habits (what educators want to see increasing), and the "surface" approach scale reflects the frequency of less effective learning habits (what educators want to see decreasing). Each time students completed the study process questionnaire, the program asked them to keep a specific and recent STEM course (e.g., Foundations of Engineering) in mind. The course changed with each administration, as no single course spanned beyond a semester.

The authors used Excel 2016 (Microsoft, Redmond WA) for univariate and bivariate analyses, STATA Version 15.1 (StataCorp LLC, College Station TX) for calculating confidence intervals, and IBM SPSS 25 (IBM, Armonk NY) for estimating and testing regression. The authors expressed attendance as a proportion of sessions attended by the 33 participants each semester, with the confidence intervals accounting for the fact that attendance events are "clustered" within individuals during a specific semester. In calculating the average overall GPA, the denominator changed across the four semesters (33, 31, 30, and 29, respectively), as some students took a leave of absence or left the university. In estimating trends in GPA over time, statistical tests accounted for repeated measures within program participants. For program satisfaction, authors combined responses on the two highest Likert-scale options - extremely satisfied and relatively satisfied - with only the first two assessments generating a response from five or more participants. The program used five as the minimum cell size to protect student confidentiality. Data about retention were only available at the end of each academic year, and the denominator changed from 31 in year one to 29 in year two. Finally, for learning approach, the program calculated each student's deep and surface approach to learning scales, although sufficient data (i.e., ≥ 5 responses) were available only at baseline and at the end of the first two semesters.

Results

Univariate Analysis

Of the 101 first year engineering students living in the learning community at the start of fall of 2015, 33 (32.7%) accepted an invitation to join the program. Of these participants, 18 (54.6%) were female and 25 (75.8%) were non-Hispanic White. In total, 19 (57.6%) self-identified as underrepresented minority by way of female gender and/or racial/ethnic minority status (i.e., racial/ethnic minority background other than non-Hispanic Asian American). Over the four consecutive semesters of the program, attendance rates were 38.4%, 20.3%, 13.9%, and 10.6%, respectively (Table 1). Average overall GPA was 3.03, 2.98, 3.11, and 3.18 across the four semesters. For the first two semesters, all respondents (100%) reported being satisfied with the program, and retention in engineering as a major at the end of each program-year was 93.9% and 87.8%, respectively. With regard to approaches to learning, the deep approach was 30.7 at baseline, 31.4 at the end of the first semester, and 33.0 at the end of the second semester. Whereas, the surface approach to learning was 21.0 at baseline, and 22.2 and 25.5 at the end of the first and second semesters, respectively.

Bivariate Analysis: Relationship of Attendance and GPA

In order to examine the association of attendance and GPA, the authors placed students into three groups: *frequent* attendees (five students who participated in one or more sessions in each of the four semesters), *sometimes* attendees (21 students who participated in one or more

Outcome Variable Expressed as mean (SD) or proportion (95% CI)*	Semester and Number of Program Sessions across Two Academic Years				
	Baseline	*Fall 2015 (12 weekly sessions)*	*Spring 2016 (7 biweekly sessions)*	*Fall 2016 (7 biweekly sessions)*	*Spring 2017 (8 biweekly sessions)*
Session Attendance**	N/A*	38.4% (27.0-51.2)	20.3% (11.4-33.5)	13.9% (6.4-27.6)	10.6% (4.2-24.5)
Semester Grade Point Average***	N/A	3.03 (0.69)	2.98 (0.79)	3.11 (0.80)	3.18 (0.71)
Satisfaction with Program****	N/A	100%	100%	N/A	N/A
Retention in Engineering Program*****	N/A	N/A	93.9% (79.8-99.3)	N/A	87.8% (71.8-96.6.)
Learning Approach:******					
Deep:	30.7 (5.1)	31.4 (6.4)	33.0 (4.8)	N/A	N/A
Surface:	21.0 (6.4)	22.2 (5.5)	25.5 (6.3)	N/A	N/A

Table 1. Educational Outcomes by Semester for Engineering's Lifelong Learning Program's Participants

***SD = standard deviation, CI = confidence interval, and N/A = not applicable or not available**

****Proportion representing the number of sessions attended by the 33 participants over the course of the semester divided by the total number of opportunities to attend that semester. The CIs account for the fact that attendance patterns are clustered within individuals during a specific semester.**

*****The denominator changed across the four semesters (33, 31, 30, and 29, respectively), given that some students took a leave of absence or left the university.**

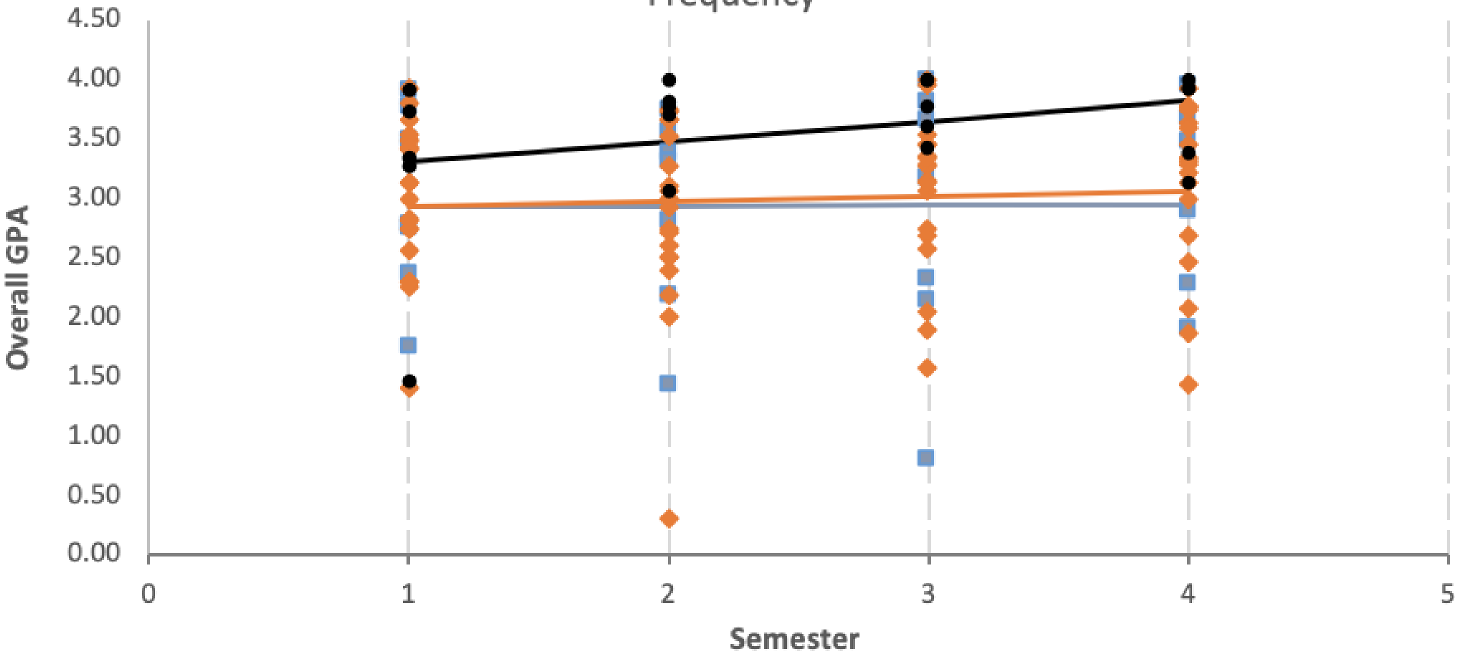
******Student self-report as either "extremely satisfied" or "relatively satisfied" based on a five-point Likert scale. The program received an inadequate response (<5) during the last two semesters, so results are not available.**

*******Retention (remaining in an engineering major) was only available at the end of each academic year, and the denominator changed each year (31 and 29, respectively).**

********At the beginning of Fall 2015 (as a baseline) and at the end of each semester, the program asked students to complete the validated revised two-factor Study Process Questionnaire, which has two distinct scales, a deep approach to learning and surface approach to learning. See text for additional information. The program received an inadequate response (<5) during the last two semesters, so results are not available.**

sessions in at least one but in no more than three semesters), and never attendees (seven students who enrolled but never attended a session in any semester). Though not statistically significant ($p = 0.32$) after accounting for the fact that GPAs are not independent over time within individuals, frequent attendees had an average GPA of 3.42 (CI = 2.85-3.99) across the four semesters compared to sometimes attendees with an average GPA of 2.98 (CI = 2.70-3.26) and never attendees with an average GPA of 2.91 (CI = 2.43-3.39). In comparing slopes of changes in GPA between attendance categories across the four semesters (Figure), the results were again not statistically significant ($p = 0.17$), although the GPA of frequent attendees increased by 0.17 (CI = -0.01 - +0.36) on average per semester, compared to an increase of sometimes attendees by 0.03 (CI = -0.07 - +0.12) and to a decrease among never attendees by 0.06 (CI = -0.22 - +0.10).

Figure: Overall Grade Point Average (GPA) by Semester* for Engineering's Lifelong Learning Program Participants by Attendance Frequency**



*Semester 1 = Fall 2015; 2 = Spring 2016; 3 = Fall 2016; and 4 = Spring 2017
The **black line represents *frequent* attendees, the orange line represents *sometimes* attendees, and the blue line represents *never* attendees (see text for full explanation). The slope of changes in the overall GPA across the four semesters were not significant (p = 0.17); although, the GPA of frequent attendees increased, on average and per semester, by 0.17 (CI = -0.01 - +0.36) compared to an increase of sometimes attendees by 0.03 (CI = -0.07 - +0.12) and to a decrease among never attendees by 0.06 (CI = -0.22 - +0.10).

Bivariate Analysis: Relationship of Attendance and Learning Approach

Nine students completed the study process questionnaire at baseline and at the end of spring 2016 after two semesters of the program. These students represented a roughly equal mix of frequent attendees and sometimes attendees. The numbers were too small to compare meaningfully the two sub-groups, but in looking at the changes of the nine students as a group, the average deep approach score was 31.89 (SD = 5.39) at baseline and 34.00 (SD = 4.24) in spring 2016 for an increase in the mean difference of 2.11 (p = .051; CI = -0.01 - +4.23). The average surface approach score was 21.56 (SD = 8.85) at baseline and 24.67 (SD = 6.58) in spring 2016 for an increase in the mean difference of 3.11 (p = 0.07; CI = -0.34 - +6.56).

Discussion

General Comments

With a relatively large group (101 freshmen) in the learning community at the start of the program, the authors anticipated having conditions for a natural experiment, with sizable subgroups (30-40) with varying rates of involvement available for comparison; however, this was not the case. The program recruited only 33 students, with only 26 coming to one or more sessions, and with session attendance declining steadily (from 38.4% to only 10.6%) across four semesters. Despite challenges with recruitment and retention, the program did have a diverse group of students participate in the program, and they (albeit those who continued) reported being satisfied with the program. Furthermore, although not statistically significant (p = 0.17), the GPA slope of frequent attendees increased, on average, by 0.17 points per semester, comparing favorably to the GPA trends of sometimes attendees and never attendees. End-of-year retention in engineering was relatively high at 93.9% and 87.8%, but in the absence of any comparison data, the authors are unable to interpret these findings. The mixed findings with learning approach, with deep and surface approaches both increasing over the first year, suffers from a similar problem, i.e., no comparison for context. In summary, additional evaluation with a larger sample size and a control group is necessary to evaluate the potential impact of this extracurricular activity on important educational outcomes.

Although this would not have overcome challenges with sample size and control-group absence, the program would have benefitted from a conceptual model such as Lee and Matusovich's model of co-curricular support (2016) providing proactive guidance. While the program did include many of their model's program-type interventions (e.g., mentoring program, first year seminar, professional seminar, activity cluster, scholar program, and student leaders), the program could have considered linkages with other school and university interventions, such as the summer bridge program and the undergraduate research program. Moreover, considering the model's metrics of short-term (e.g., academic integration) and medium-term outcomes (e.g., intentions) would have improved the program's formative and summative evaluation efforts. In retrospect, the program should have utilized a model to develop a logic plan to improve planning, evaluation, and implementation. We focus the remainder of the discussion on opportunities for improving recruitment and retention, and possibly program effectiveness, in light of expert opinion and other research.

Improving Program Recruitment

Although the authors marketed the program through open house and email announcements, the major recruitment activity for the program was a 60-minute meeting with the learning community during freshmen orientation. An unexpected and untimely change in the university's orientation schedule resulted in many members of the learning community missing the recruitment meeting, at which students had the opportunity to listen to a carefully planned learning-science overview, learn about the program, and consent to participate as per the IRB-approved protocol. In the authors' opinion, this recruitment challenge resulted in far fewer participants starting the program than expected. In retrospect, recruitment efforts would have been more widespread, perhaps with additional meetings (online and in-person) planned in the learning community and with visits to first-year engineering courses. Although the program sought to reach students as close to the start of their first semester as possible, when students may be most open to new learning habits (Leamnson, 1999, p. 34), allowing students to join during the semester, perhaps after their first set of exams or after the first semester, might have increased participation. Having said this, such flexibility would have required a rapid change in the study protocol, and that might not have been possible. Moreover, joining later might have decreased the cohesiveness of the group, thereby adversely affecting retention.

One additional strategy that might have resulted in a larger participant group would have been recruiting students from more than one learning community, or inviting engineering students living outside of any learning community. The disadvantage of the latter approach is that the program would have lacked some learning community supports, such as community-specific first-year-experience courses. The authors believed that offering the program within the residence hall of the learning community, making it easy for members to attend regardless of the weather, likely improved recruitment and retention. Nonetheless, expanding recruitment efforts remains an untested strategy that might enhance interest.

Improving Program Retention

The program steadily lost participants in the cohort as the program progressed. Through a survey, key informant interviews, or a focus group, understanding attrition and infrequent attendance would have been an important addition to the evaluation plan. Such assessment might have allowed us to make adjustments that would have decreased attrition. Another adjustment that might have increased program retention would be having more diversity reflected in program faculty. While the two faculty-facilitators were enthusiastic and experienced educators, they were both white males. Having the facilitators reflect the diversity of the group, even with the addition of peer mentors (Dennehy & Dasgupta, 2017), might have increased the comfort level of underrepresented participants, increasing the longevity of their participation. Finally, the commitment to the program was open-ended. Not only might this have discouraged some students from joining, it might also have led to students leaving prematurely. Asking students to commit to a semester at a time, as a minimum, and offering program content that was consistent with that timeframe, or even embedding the program content within a required course (Doyle & Hooper, 1997), might have led to students remaining in the program longer. Similarly, offering some type of recognition for completing each semester – perhaps a certificate or a course credit - might be an additional incentive.

Improving Program Effectiveness

In addition to increasing the diversity of faculty facilitators as previously mentioned, two other interventions would build upon, and could potentially improve, the program. Given that approximately half of the program's participants were female, incorporating female peer mentors might increase the effectiveness of the program for women. Dennehy and Dasgupta (2017, p. 1) reported that female peer mentors, available early in college, increased women's retention in engineering, among other important outcomes and associated factors (e.g., self-efficacy). An extracurricular activity like the one described in this article, with regular informal meetings spanning multiple semesters, might lend itself well in supporting mentor-mentee relationships. In a qualitative study of near-peer mentoring in the physical sciences, Zaniewski and Reinholz (2016, p. 10) recommend placing mentoring in the context of a community, with informal, food-centric meetings.

Nearly one-quarter of program participants reported a race/ethnicity other than non-Hispanic white. As such, incorporating a "lay theory intervention" (Yeager et al., 2016, p. E3341) as part of a recruitment session during orientation might be an appropriate way to support students with minority backgrounds. Lay theory interventions work by preparing students for common challenges in the transition to college, and by preventing students from interpreting those challenges to mean that they do not belong or that they cannot be successful (Yeager et al., 2016, p. E3341). Yeager and colleagues (2016) demonstrated that a one-time, online, pre-matriculation lay theory intervention – grounded in social belonging, growth mindset, or both – significantly improved first-year full-time enrollment among disadvantaged students at a four-year public university. Although, a more recent study by Oreopoulos and Petronijevic (2019), who implemented a similar mindset intervention among college students enrolled in a first-year economics course, did not find improvements in academic performance, even among students at higher risk of attrition. Despite these inconsistent findings, even if students choose not to participate in the program, a lay theory intervention at the start of the program might enhance students' success in engineering.

Conclusion

This article describes an innovative extracurricular program designed to impart learning-science evidence and strategies in support of an important set of educational outcomes. While a small set of diverse undergraduates in engineering were satisfied and participated actively, and while trends in overall GPA appear promising, the small sample size and lack of a control prevent the authors from commenting on the program's effectiveness. Through a critique of the program, the authors offer suggestions for improving evaluation, recruitment, and retention, and possibly for enhancing program effectiveness. Additional research is necessary to determine whether and how the emerging interdisciplinary field of learning science can benefit incoming undergraduate students in engineering.

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Thomas J. Van Hoof holds a Doctor of Medicine with a specialty in Psychiatry and a Doctor of Education degree focused on educational administration. He is the Director of Teaching and Learning in the School of Nursing, an Assistant Director of Faculty Development in the Center for Excellence in Teaching & Learning, and an Associate Professor in the Schools of Nursing and Medicine at the University of Connecticut. In addition to the science of learning, his research focuses on the use of educational interventions to change clinician behavior and to improve patient outcomes.

Stephen J. Walsh holds a Master of Science in Theology, a Master of Science in Applied Mathematics, and a Doctor of Science in Biostatistics. He is an Associate Professor in the School of Nursing at the University of Connecticut. He provides statistical consultation to faculty and student researchers within the school. His research focuses on secondary analysis of existing data.

Jacob Missal holds a bachelor's degree in Actuarial Science and Finance from the University of Connecticut. He works in the property and casualty insurance industry and has an interest in analyzing data in support of educational projects that improve teaching and learning.

Daniel D. Burkey holds a Master of Science in Chemical Engineering Practice and a PhD in Chemical Engineering. He is a Professor-in-Residence in Chemical & Biomolecular Engineering, the Associate Dean for Undergraduate Engineering and Diversity in the School of Engineering, and University Teaching Fellow. His research focuses on the use of game-based and game-inspired educational interventions to help improve student learning and engagement, as well as the professional formation of engineering students, with a special emphasis on ethical and moral reasoning in the profession.