Student Buy-In to Active Learning in a College Science Course

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ABSTRACT

The benefits of introducing active learning in college science courses are well established, yet more needs to be understood about student buy-in to active learning and how that process of buy-in might relate to student outcomes. We test the exposure–persuasion–identification–commitment (EPIC) process model of buy-in, here applied to student (n = 245) engagement in an undergraduate science course featuring active learning. Student buy-in to active learning was positively associated with engagement in self-regulated learning and students' course performance. The positive associations among buy-in, self-regulated learning, and course performance suggest buy-in as a potentially important factor leading to student engagement and other student outcomes. These findings are particularly salient in course contexts featuring active learning, which encourage active student participation in the learning process.

INTRODUCTION

Research investigating undergraduate learning experiences in the science, technology, engineering, and mathematics (STEM) disciplines has focused on identifying teaching practices that improve learning outcomes and persistence among students (Estrada-Hollenbeck *et al*., 2010; Graham *et al*., 2013; Tanner, 2013; Eddy *et al*., 2015). In the fields of education and psychology, there is growing evidence of the benefits of active learning (Roediger and Pyc, 2012; Dunlosky *et al*., 2013; Chi and Wylie, 2014). While there is general consensus that active learning is effective as a method of engaging students, there is an ongoing debate as to students' preferences for active learning versus lecture formats (Walker *et al*., 2008; Welsh, 2012), benefits and perceptions of active learning for particular groups of students (Machemer and Crawford, 2007; Crossgrove and Curran, 2008), and the efficacy of specific active-learning pedagogies (Linn *et al*., 2015).

In the field of biology education research, active engagement in the learning process has been found to positively impact student outcomes, including test performance, course grades, and persistence (Braxton *et al*., 2008; Freeman *et al*., 2014). This has held true for women and students with lower grade point averages (Gross *et al*., 2015). Evidence of student engagement as a positive aspect of learning raises the question of how students become engaged. Relatively unstudied are the student-level mechanisms that contribute to this engagement. Currently, this area of research may be more beneficial to education efforts than additional studies that again replicate the comparative benefits of active learning (Dolan, 2015).

The current study seeks to test a model of buy-in applied to student engagement within active-learning contexts. We examine the extent to which students 1) are clearly *exposed* to active learning in the classroom, 2) are *persuaded* that active learning is beneficial to their education, 3) *identify* with these activities as compatible with

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their preferred way of learning, and 4) *commit* to engaging in active learning. We further relate buy-in to self-regulated learning behaviors known to be associated with positive student outcomes, such as increased exam performance.

Buy-In

In the psychology and education research literature the term “buy-in” remains undefined in a systematic way. Our conceptualization of student buy-in to active learning draws on decades of research spanning the literatures of motivation (Wigfield and Eccles, 2000; Pintrich, 2004), social-cognitive (Bandura, 1989; Richardson *et al*., 2012), and discipline-based education (Singer *et al*., 2012). Active learning provides students with opportunities to engage in the learning process, and students may decide to participate based on a series of judgments, including whether the activities are deemed as valuable to the learning process, are enjoyable, or allow for meaningful interaction with others (Yuretich, 2004; Eddy *et al*., 2015). Such judgments may be influenced by a multitude of factors, including students’ perceived ability to learn (Dweck and Master, 2008), instructor support (Micari and Pazos, 2012; Zumbrunn *et al*., 2014), classroom climate (Freeman *et al*., 2007), and prior experiences (Tanner, 2013).

The theoretical framework and preliminary data we present consider the role of buy-in and how it relates to student engagement in self-regulated learning and course performance. We start our coverage of this framework with the desired end result: student outcomes.

Student Outcomes

The use of active learning is increasingly considered to be associated with student engagement and improved outcomes in undergraduate STEM education (Freeman *et al*., 2014). Recent studies in biology education research have identified factors associated with increased student performance and ability to adjust self-regulated learning strategies in college-level classrooms featuring active learning. Eddy and Hogan (2014) examined the relationship between increased course structure (a core component of active learning) and student outcomes, identifying higher levels of student preparation and a more cohesive class environment as key mediators in this relationship. Similarly, Gross and colleagues (2015) examined student performance in a flipped-format upper-level biochemistry course for majors. These findings indicated upward of 12% gains in quality of student performance, which is consistent with Freeman *et al*.’s (2014) meta-analysis. Furthermore, the authors were also able to establish a link between active learning and student outcomes through shifts in student cohorts’ self-regulated learning strategies, such as preclass preparation and course engagement. Notable in each of these studies, results were either equal or more robust for students with lower grade point averages and groups traditionally underrepresented groups in the sciences (i.e., female and minority students; Eddy and Hogan, 2014; Gross *et al*., 2015). Research is now needed to understand how students engage in active-learning contexts.

Student Engagement in Self-Regulated Learning

Engagement is most often understood as a series of intentional actions involving cognitive, emotional, and behavioral elements (Fredricks *et al*., 2004). Engagement is a core component of behavioral research in the social sciences and impacts outcomes ranging from educational attainment, job satisfaction, and productivity (Kuh *et al*., 2008; Maslach and Leiter, 2008) to knowledge acquisition and use of problem-solving strategies (Hake, 1998). In educational contexts, the term “engagement” typically describes students’ contributions to the learning process, such as efforts to pay attention, participation in class activities, and actively thinking about course content (Wang and Eccles, 2012).

In this paper, we operationally define student engagement as *self-regulated learning* (Kahu, 2013), which describes strategies used by students to process information and construct knowledge, including critical thinking, behavioral control, and metacognition (e.g., planning and monitoring study habits). Self-regulated learning behavior has been found to be associated with self-efficacy, motivation, and academic achievement in college student samples (Young, 2005; DiBenedetto and Bembenutty, 2013; Mega *et al*., 2014). Successful students tend to be flexible in their use of self-regulated learning strategies (Zimmerman and Schunk, 2001), and this flexibility is influenced by factors such as level of motivation, desired grade, and course demands (Pintrich, 2004). Nevertheless, the ability to self-regulate learning is not uniform across students (Wolters and Hoops, 2015). One possible factor influencing the self-regulation process within active-learning contexts may be a lack of “buy-in” to course activities (e.g., Hunt *et al*., 2003).

Student Buy-In to Active Learning

“Buy-in” is a colloquial term that describes individuals’ feelings in relation to a new way of thinking or behaving. Buy-in has been described as reflecting elements of participation, support, and a sense of commitment to change, as well as a belief that such changes will have a positive impact on student learning (Education Commission of the States, 1999; Levin, 2000; Brazeal *et al*., 2016). Despite the prevalence of the term “buy-in” within teacher and student contexts, the education research literature has yet to focus on a standard definition of buy-in. Moreover, there is less research on student buy-in relative to self-regulated learning.

The introduction of progressive pedagogies like active learning in undergraduate science courses represents a growing appreciation of the importance of student learning experiences (Handelsman *et al*., 2007). In faculty development programs like the long-standing Summer Institutes on Scientific Teaching (Pfund *et al*., 2009) and similar initiatives, convincing instructors to move beyond the traditional lecture is achieved through an emphasis on the growing evidence that activities that capture student attention serve to motivate students throughout the learning process (Pintrich, 2003). Recent work has shown that faculty who embrace these practices are more likely to ultimately adopt and implement them in the classroom (Aragón *et al*., 2016). Faculty reported higher implementation of scientific teaching principles when they moved through this adoption process. In essence, this pedagogy adoption model represents faculty *buy-in* to activities that motivate students. Here, we use this model, adapting it for students.

In this paper, student buy-in is operationalized through the exposure–persuasion–identification–commitment (EPIC) model (see Aragón *et al*., 2016). This process of buy-in works in four steps: from 1) exposure to active learning, to 2) persuasion that these activities are good, to 3) identification that the activities are good for them personally, to 4) commitment to this way of learning. We seek to highlight the relationship among persuasion and identification, identifying student attitudes as a prominent driver of learning behavior. In this case, persuasion is hypothesized as necessary in order to impact identification *with* and subsequent commitment *to* engaging in active learning. We propose that this process of buy-in plays out in a systematic manner, with each stage dependent on attitudes and appraisals made during previous stages.

Summary

The positive effects of active learning on performance outcomes among postsecondary students of various ages, races/ethnicities, and majors are sufficiently established (for a detailed account of this research, see Freeman *et al.*, 2014). Nevertheless, less is known about the student-level mechanisms by which active learning yields such gains (although, see Eddy and Hogan, 2014; Gross *et al.*, 2015). This study represented an initial test of mechanisms promoting student engagement in undergraduate active-learning contexts by examining student buy-in to active learning. We sought to establish the components of buy-in that are related to self-regulated learning behaviors and, ultimately, course performance. We anticipated that students would report varied levels of buy-in to active learning and that these variations would account for subsequent relationships to self-regulated learning and course performance. We examined student buy-in as represented by progression through the EPIC model (Aragón *et al.*, 2016). The current study investigates the following research questions:

1. What is the nature of student buy-in to this active-learning classroom context?
2. To what extent is student buy-in associated with engagement in self-regulated learning behaviors and course performance?

METHODS

Context

The present study focused on a single section of Human Anatomy and Physiology, a one-semester 2000-level course with an enrollment of 363 students at the University of Connecticut, a large public university in the northeast United States. During the Fall semester, the second half of the course was taught by a teaching-track faculty member who used instructional practices consistent with the scientific teaching taxonomy (Couch *et al.*, 2015). "Scientific teaching" is a term used to represent a student-centered pedagogical approach that incorporates active learning, formative assessment, and inclusive teaching practices as core elements (Handelsman *et al.*, 2007). This particular professor (author X.C.) attended one of the Summer Institutes described earlier. This professor was trained in and used the practices of active-learning pedagogies (e.g., defining learning goals, formative assessment strategies) consistent with current developments in discipline-based educational research (DBER). The active-learning principles associated with scientific teaching encourage student engagement by, for example, calling upon students to think critically, participate in collaborative discussion, and consider ways they can best achieve learning objectives (Chen *et al.*, 2013). This instructor also self-reported a high level of scientific teaching pedagogy adoption on a census survey sent to all past Summer Institute participants from 2004 to 2014 (Aragón *et al.*, 2016).

TABLE 1. Student demographics (n = 245)

		Students (%)
Gender	Male	80 (33)
	Female	158 (64)
	Chose not to identify	7 (3)
Age	18–19	123 (50)
	20–21	103 (42)
	22–24	12 (5)
	25+	2 (1)
	Did not respond	5 (2)
Racial/ethnic group	Non-Hispanic white	155 (63)
	Asian/Pacific Islander	51 (21)
	Black or African American	14 (6)
	Hispanic/Latino	23 (9)
	Multiracial	8 (3)
Class	Sophomore	131 (54)
	Junior	72 (29)
	Senior	37 (15)
	Other	5 (2)
Course type	Major requirement	220 (90)
	General requirement	7 (3)
	Elective	14 (6)
	Did not respond	4 (1)

Participants

All students enrolled in the course were eligible for participation. Student participants included 245 students (67% of course enrollees; 64% female), with most (90%) enrolled in the course as part of a general or major credit requirement. A majority (54%) of participants were sophomores, although the course included juniors (29%) and seniors (15%), as well as five students who had completed baccalaureate degrees and returned to school for additional training in the sciences. A full accounting of participant demographics is presented in Table 1.

Procedure

Near the end of the Fall semester, an online survey was distributed to students via an emailed link using the Qualtrics survey software program. Students were offered nominal course credit for their participation (i.e., an additional two percentage points on one exam grade) and were given the option to opt out of the survey without penalty. This research was classified as exempt from institutional review board review.

Measures

Students' reported their level of buy-in to a discrete set of 16 empirically supported active-learning pedagogies detailed in the scientific teaching taxonomy (Couch *et al.*, 2015) and adoption process model (see Aragón *et al.*, 2016). Activities were selected for inclusion in the protocol based on clarity and relevance to the course. These were broken out along three domains: active learning (e.g., "I answered questions in class using a clicker or other polling method"), assessment (e.g., "I completed supporting activities like worksheets, problem sets, additional reading when assessments revealed a problem area"), and inclusivity (e.g., "I considered the contributions of diverse people and perspectives in the realm of scientific discovery").

For each learning pedagogy, students indicated their level of exposure: "I did this"; "I did not do this"; or "I did this but did not understand it." Students who indicated that they had engaged and understood any one of the 16 activities (i.e., indicated "I did this" on the exposure measure) were then prompted with a series of statements for each activity and asked to indicate their extent of involvement in each activity using a yes/no answering format. Statements included "I was convinced that this was good" (persuasion); "I did this because I believed it would contribute to my learning in a positive way" (identification); and "I am committed to embracing this as a way of learning" (commitment) (Supplemental Material).

An individual sum score was calculated for each of the remaining three EPIC categories (persuasion, identification, and commitment) by totaling "yes" responses to the 16 activity prompts. Sum scores thus ranged from 0 to 16 for persuasion, identification, and commitment. In addition, students endorsed two supplementary statements gauging their motivation for engaging in active-learning activities, namely, "I liked doing this as a way to learn" and "I did this because I had to." These additional items were not included in the computation of buy-in scores; responses were collected to inform item interpretation.

Student engagement in course activities via self-regulated learning behaviors was assessed using an abbreviated form of the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich *et al.*, 1993; Duncan and McKeachie, 2005). Self-regulated learning describes the extent to which students are proactive contributors to the course, both within and outside the classroom. Sample items included: "I try to work with other students from this class to complete the course assignments" and "I make sure that I keep up with the weekly readings and assignments for this course." Participants were asked to rate the extent to which 38 learning behaviors reflected their experiences while enrolled in their current course on a scale from 1, "Not at all true of me," to 7, "Very true of me." Subscales from the MSLQ used in the current study included: Elaboration, Organization, Critical Thinking, Metacognitive Self-Regulation, Time and Study Environment Management, and Peer Learning. Reliability was satisfactory ($\alpha = 0.87$) overall.

As a measure of student outcomes, students' final grades were provided by the instructor following the end of the semester. Final grades were computed based on a combination of in-class examinations, a lab component, and a final examination. The course included four 100-point in-class examinations. Each of the best three lecture exams accounted for 15% of the final grade. The lab component accounted for 25%, and a 100-point accumulative final exam accounted for 30% of the final grade. Each student was able to earn up to five extra points in each regular exam by completing active-learning assignments (e.g., concept maps, clicker questions, weekly assessment, exam wrapper).

Analyses

Our main analyses addressing each of the primary research questions involved a progression from within- to between-variable statistics tests. All analyses were executed using IBM SPSS 22.0 software. We first examined the percentage of students endorsing each phase of the EPIC framework. A total sum score was then computed for each student by aggregating dichotomous "yes/no" responses to each of the 16 exposure–persuasion–identification–commitment items. We conducted a series of one-way analyses of variance (ANOVAs) to examine potential group differences on the basis of gender, race/ethnicity, and school year within each variable. Bivariate relationships among each variable were then examined using linear regression as an initial test of the viability of the proposed model. Finally, a serial mediation model was fitted to the data.

RESULTS

Background Analyses

Table 2 offers a full accounting of student-reported buy-in to each activity. On average, students reported having completed approximately six activities (M = 6.27, SD = 3.26), because they were believed to contribute positively to learning, and reported liking an average of 5.6 (SD = 3.31) of the 16 total strategies as a way to learn. Students reported only completing activities "because I had to" to a lesser extent (M = 3.02, SD = 2.04). Overall student engagement in self-regulated learning was represented by a mean score of 3.91 out of 7 (SD = 0.62); the average course grade was 80.12 (SD = 11.93) on a 100-point scoring scale.

Tests of Group Differences

One-way ANOVAs were used to test potential group differences in the current sample for each study variable. In this course, male students reported significantly greater persuasion ($F(2,215) = 6.21$, $p = 0.002$) and commitment ($F(2,203) = 5.49$, $p = 0.005$) to active learning than their female counterparts, though no statistically significant difference was observed with respect to identification ($p = 0.85$). Further, no statistically significant difference was observed between male and female students with respect to engagement in self-regulated learning behaviors ($p = 0.10$). In addition to gender differences, we examined mean differences across all variables between grade levels: no statistically significant differences were observed. With respect to race/ethnicity, only final course grade, which was higher for white students (M = 81.6, SD = 10.91) than for underrepresented minority students (M = 76.5, SD = 12.95), was found to be statistically significant ($F(1,231) = 6.79$, $p = 0.01$).

EPIC Process Model

Before testing our full model of effects, we conducted a series of regression models incorporating buy-in and self-regulated learning as an initial test of the model's viability. Importantly, the persuasion ($b = 0.05$, SE = 0.01, $t = 4.15$, $p < 0.001$), identification ($b = 0.07$, SE = 0.01, $t = 5.67$, $p < 0.001$), and commitment ($b = 0.06$, SE = 0.01, $t = 4.25$, $p < 0.001$) elements of the EPIC framework were found to independently contribute to engagement in self-regulated learning. On the basis of these findings, we next fitted a serial mediation (Hayes, 2013) process model to the data to highlight the relative contribution of each step in the EPIC model to student engagement. Results are presented in Table 3 and Figure 1.

We tested the steps of the EPIC process model with serial mediation (Hayes, 2013), which allowed for tests of mediation pathways with more than one mediator working sequentially through each step while considering all previous steps in the model. For example, serial mediation first estimates the total and direct effects of exposure to identification through persuasion. A

TABLE 2. Student-reported buy-in as represented by endorsement of EPIC items

	n	% Students reporting exposure who endorsed:		
In this course…	Exposure	Persuasion	Identification	Committed
1. I answered questions in class using a clicker or other polling method.	234	45	56	32
2. I adjusted my thought process when solving problems or answering questions.	219	51	59	49
3. I applied knowledge of other subjects.	217	45	63	48
4. I reflected on the effectiveness of my study habits.	211	50	69	47
5. I related scientific concepts to everyday phenomena or human experiences.	189	44	69	44
6. I completed in-class activities (like think–pair–/share discussions, problem sets, case studies) in a group of two or more.	179	42	58	34
7. I identified clear learning goals (what I was expected to know and be able to do) based upon my instructor's materials.	178	59	75	37
8. I designed and conducted experiments in the lecture portion of this course.	170	31	33	21
9. I worked with other students in diverse groups.	164	48	49	35
10. I developed hypotheses and then made predictions based on my hypotheses.	161	40	45	29
11. I completed supporting activities when assessments revealed a problem area.	159	55	72	42
12. I considered the contributions of diverse people and perspectives in the realm of scientific discovery.	152	50	48	40
13. I provided feedback to my classmates on projects, assessments, or other activities.	144	39	44	29
14. I presented my scientific ideas in writing.	97	31	34	26
15. I provided feedback to my instructor on this course's structure and content.	82	50	51	29
16. I read and evaluated scientific literature.	54	44	41	31

statistically significant pathway would suggest that exposure led to persuasion, which in turn led to identification. Next estimated was the path of persuasion to commitment through identification while the model controlled for the effects of the variables in the previous mediation, which in this case would be exposure. A statistically significant pathway at this step of the model suggested that persuasion led to identification (over and above the effects of exposure described earlier), which in turn led to commitment. The serial mediation worked through all steps of the proposed model in a similar manner. At any point, the statistical pathway could fail to find relationships that provide effects over and above previous steps in the model, and the serial mediation would not indicate a significant pathway. Therefore, a significant pathway indicates that each step of the model is a unique contributor to the outcome variable and that the model provides a statistical account of this process.

Serial mediation analyses did reveal a significant pathway from exposure to engagement via persuasion, identification,

TABLE 3. Serial mediation model of the process of engagement in active learning

	Model	Persuasion	Identification	Commitment	Engagement
1	Exposure	0.70***			
2	Exposure		0.39***		
	Persuasion		0.52***		
3	Exposure			0.08	
	Persuasion			0.51***	
	Identification			0.57***	
4	Exposure				0.05*
	Persuasion				–0.01
	Identification				0.04*
	Commitment				0.06***
r^2		0.26	0.44	0.53	0.19
Constant		–2.17	0.12	–0.28	3.79
SE		0.91	0.69	0.73	0.19

*$p < 0.05$.
*** $p < 0.001$.

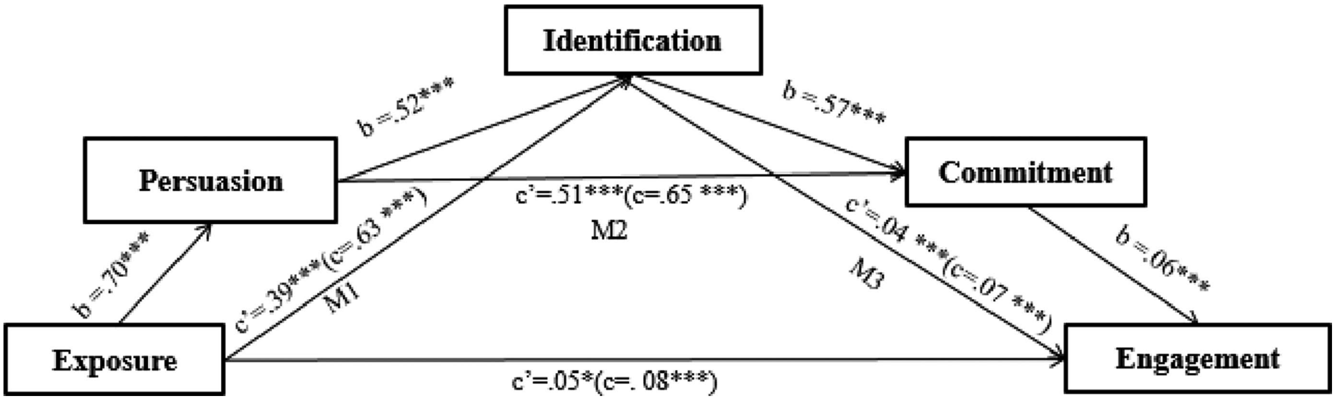

FIGURE 1. Serial mediation model depicting process of student buy-in and engagement. *b*, unstandardized coefficients showing relationship between variables; *c*, direct path between predictor and outcome variables; *c'*, path from predictor to outcome variables controlling for the proposed mediator. Indirect paths are pathways from predictors through mediators to outcome variables. When c' is smaller than c, it suggests that some of the variability in the outcome variable is explained by the indirect path. Exposure predicts identification via persuasion (M1), persuasion predicts commitment via identification (M2), and identification predicts engagement via commitment (M3). A serial mediated pathway beginning from exposure through persuasion, identification, and commitment to predict engagement is significant: LLCI = 0.009; ULCI = 0.089. A full serial mediation model was tested; paths from exposure to commitment and persuasion to engagement have been omitted for clarity. Lines M1–M3 represent mediated relationships. *, *p* < 0.001.**

and commitment. The lower and upper limits of the confidence interval for the exposure→engagement pathway did not cross zero ($b = 0.05$, lower level confidence interval [LLCI] = 0.009, upper level confidence interval [ULCI] = 0.089), indicating a statistically significant pathway. There was a main effect of each step in the EPIC process. Exposure to active-learning principles in this course significantly predicted the likelihood that students would be persuaded of the value of these practices ($b = 0.70$, SE = 0.08, $t = 8.63$, $p < 0.001$). Persuasion, in turn, was found to significantly impact identification ($b = 0.52$, SE = 0.05, $t = 10.65$, $p < 0.001$), and identification to predict commitment ($b = 0.57$, SE = 0.06, $t = 9.12$, $p < 0.001$). Serial mediation accounts for each step in a pathway to account for all prior stages in a model; in this case, we found a significant main effect for commitment on engagement and an indirect impact of commitment on engagement accounting for exposure, persuasion, and identification. These results indicate that persuasion, identification, and commitment are each an important component of buy-in, while higher levels of buy-in were found to positively predict self-regulated learning.

Engagement in self-regulated learning was subsequently found to impact students' course performance, as a statistically significant relationship (controlling for gender) was found between self-regulated learning and final grade ($\beta = 0.29$, SE = 1.06, $t = 4.68$, $p < 0.001$). Results indicate that exposure to scientific teaching principles in the classroom, in conjunction with persuasion that these principles benefit student learning, an identification with scientific teaching as compatible with an individual student's way of learning, and a commitment to participating in these learning behaviors in future courses are each associated with student outcomes relevant to course performance.

DISCUSSION

We provided support for a process model depicting student buy-in to active learning in an undergraduate science course. The EPIC model was found to contribute significantly to engagement in active learning, with exposure found to impact engagement via persuasion, identification, and commitment. We presented a statistically significant serial mediation model indicating the role of each stage impacting subsequent stages. Importantly, persuasion, identification, and commitment were each found to directly and indirectly contribute to the likelihood of student engagement in self-regulated learning. These results provided support for our hypothesized model of a multiphase process of student buy-in linking exposure to active learning with student performance outcomes.

One of the primary concerns for any instructor introducing an activity into his or her classroom is the nature of student response: Will the activity lead to a stimulating discussion that unearths new insight into course material (as envisioned by the instructor during the design of the activity), or will it fail to resonate as interesting and relevant, falling flat due to lack of student interest (Seidel and Tanner, 2013)? Though an instructor may foresee educational value in implementing active-learning exercises (e.g., short writing exercises, small-group activities, clicker questions), there is no known guarantee that students will share this view. It is equally plausible that, within a class, some students will respond more positively than others (Kearney *et al.*, 1991). From an instructor perspective, recognizing the likelihood of the variation in student response is an important first step in providing an educational experience that benefits all types of learners. From there, instructors may target areas of student disinterest, discontent, or doubt by adjusting the frequency and type of active learning introduced in the classroom, thus maximizing the impact of these activities on student learning. This study sought to inform these types of instructional decisions by specifying the nature of students' attitudinal and behavioral responses to active learning.

The goal of this study was to investigate student buy-in to active learning in the classroom and its relation to student outcomes. We targeted student perceptions of active-learning experiences, establishing buy-in as a viable explanation for the consistent link between active learning and enhanced learning outcomes in the sciences established elsewhere (Armbruster *et al.*, 2009; Freeman *et al.*, 2014; Connell *et al.*, 2016). Our findings revealed that students who reported more substantial buy-in to active learning were more likely to engage in the types of self-regulated learning behaviors that often lead to academic success. Our model extends earlier work on student perceptions within undergraduate courses (Tinto, 2015) by examining elements of student response to active learning: whether students are persuaded of the value of these practices, believe they will ultimately benefit as learners, and wish to continue these practices in future courses.

Active learning stands in contrast to traditional lecture-based course formats by introducing a participatory expectation into the classroom. Students are invited to engage in the learning process and construct their knowledge by involving themselves in activities that emphasize collaboration, interaction, and experimentation. Our conceptualization of buy-in functions as an operational definition of the student response to this invitation and a proxy for many of the student-level factors (e.g., motivation, instructor perceptions, academic self-concept) explored in other literatures (Kim and Sax, 2014; Zumbrunn *et al.*, 2014; Linn *et al.*, 2015) that contribute to student success.

By virtue of the fact that student buy-in was found not to be uniform across students in this study, we were able to demonstrate and measure the range of student experiences that occurred within the classroom setting for this particular course. Some students believed that active learning contributed to their learning process, and wished to continue using it in the future. Others failed to distinguish or remained otherwise unconvinced of the merits of these practices. Despite significant efforts on the part of the instructor to implement active-learning activities throughout the course, student response to these practices varied. Though students reported mixed perceptions of active learning in the classroom, buy-in to active learning was nevertheless significantly associated with each of the student outcomes of interest in this study.

Serial mediation analyses revealed that student buy-in to active learning was significantly associated with engagement in self-regulated learning behavior. To the extent that students made a commitment to participate in active-learning activities, they were more likely to actively evaluate and self-assess their understanding of course materials and their learning strategies. In association with student buy-in, student engagement played a statistically significant role in students' performance in this course. Students who bought into active learning were more likely to achieve higher course grades than those who did not. This statistical significance underlies the multifaceted nature of buy-in as a concept and its potential to explain a range of course-relevant outcomes.

These results are meaningful in representing student responses regarding current active-learning practices common within undergraduate STEM classrooms. Student experiences in courses required for science majors are important in impacting scientific thinking and career decisions, among other outcomes (Wang and Degol, 2013; Brownell *et al.*, 2015). Poor course experiences may impact the choice of one's major, the likelihood of graduating, and the decision to pursue graduate training (Seymour *et al.*, 2004). In contrast, positive course experiences have the potential to inspire the growth and development of the next generation of scientists. Science educators should continue to cultivate an appreciation and understanding of students' undergraduate course experiences to meet the needs of all learners. These findings reaffirm the variability of student experiences in undergraduate courses and the need to account for these differences by providing a range of learning activities to encourage student engagement.

Although not explicitly tested in this manuscript, any interpretation of individuals' responses to the introduction of new ideas is indebted to the seminal work of Rogers (2010) and other theorists of the diffusion of innovation. Innovation theory predicts the likelihood that and rate at which a new idea will be adopted or rejected based on a number of factors, including individual characteristics, organizational context, and the features of the innovation itself (Tornatzky and Klein, 1982). Rogers and others focus on elements of awareness and persuasion as the drivers of these decisions.

The assumption in the field of DBER is that the introduction of an innovation such as active learning into the classroom will benefit students, largely due to its capacity to actively engage students in the learning process (e.g., Gross *et al.*, 2015). The remaining question is *why* active learning serves to engage students; diffusion of innovation theory would suggest that students decide whether to engage in active learning on the basis of a series of appraisals, including the characteristics and expected value of active learning. In some instances, Rogers (2010) posits that individuals may bypass appraisals in the persuasion stage and instead decide to adopt the innovation on a limited basis before deciding on its utility.

The EPIC process model was not intended to replace or compete with Rogers' (2010) perspective: rather, we sought to build on the work of Aragón and colleagues (2016), and to deepen our understanding of individual perceptions and behavior in innovative educational settings. The EPIC model was developed independently of Roger's work, relying upon constructs developed in research investigations in social and organizational psychology of: exposure, including aspects of communication, memory, salience, and accessibility (e.g., Eagly and Chaiken, 1998; Eagly *et al.*, 1999); persuasion, including theories of descriptive norms (Cialdini *et al.*, 1991) and attitude change (stages of change model; for a review, see Norcross *et al.*, 2011); identity, including self-theory (Kuhn, 1964), individual self (Brewer and Gardner, 1996), and self-efficacy (e.g., Ajzen, 1991); and commitment, including theories of attitude strength (e.g., Krosnick and Petty, 1995) and goal strength (e.g., Gollwitzer, 1993). Interestingly, the EPIC model and innovation theory independently converged on substantially overlapping conceptualizations of these processes. Because of these consistencies, the EPIC model might aptly contribute to innovation theory research as well by providing a straightforward application of similar principles within a sample of undergraduate science students.

Limitations

Given the role of self-regulated learning and engagement in predicting a constellation of student outcomes demonstrated elsewhere (Fredricks *et al.*, 2004; Young, 2005; Mega *et al.*, 2014), we sought to define buy-in as an antecedent of engagement. Though we were not testing a causal model, results from this study provide preliminary support for the process of student buy-in as a potentially important contributor to engagement. As an individual difference measure, buy-in is valuable in capturing the diversity of student course experiences. Buy-in may also emerge as an area of focus for instructors seeking to improve student outcomes such as course performance and retention. Careful study of the process by which students engage in self-regulated learning can provide insight into strategies for successfully implementing active learning and other progressive pedagogies in ways that serve to meet the needs of diverse student populations across a range of educational contexts (Estrada-Hollenbeck *et al*., 2010; Eddy and Hogan, 2014).

Implications

The findings presented here reaffirm the relationship among active learning, student engagement, and performance outcomes while suggesting a new avenue for research in understanding student mechanisms that contribute to these relationships. While the interpretive scope of these results are limited by the cross-sectional nature of the data from a sample of students in a single course, they nonetheless provide insight into student experiences within a required course common among undergraduate science majors in the United States. These findings suggest the potential for a linear model depicting the process by which students construct knowledge and understanding within a course featuring active learning.

Future Directions

As the field of DBER continues to move forward in understanding teaching and learning in the information age, future studies within the STEM disciplines can move toward examining the elements of student classroom experiences that most contribute to buy-in, such as student–teacher relationships, cultural and gender-inclusive practices, and student perceptions of course content and learning activities. By examining these relationships for particular subsets of students (e.g., students from groups traditionally underrepresented in the sciences), researchers may identify elements of active learning that contribute to a narrowing of the achievement gap on college campuses. In addition, research is needed to investigate ways that course experiences impact student outcomes over time, including meaningful effects on critical thinking (Brownell *et al*., 2015), degree completion, the formation of ties to the scientific community, and attainment of graduate degrees in the sciences (Graham *et al*., 2013).

While these findings are encouraging, they represent only a first step in explaining the myriad student-level factors influencing engagement and performance in college courses. Earlier findings suggest that individual difference measures such as students' perceived ability to learn (Dweck and Master, 2008) and prior exposure to active learning (Tanner, 2013) may impact their course experiences. Classroom contextual factors such as course structure and quality of student interactions may play a central role in impacting student learning experiences in active learning contexts that encourage high degree collaboration, as in other learning contexts (Eddy and Hogan, 2014; Connell *et al.*, 2016). Finally, there is reason to believe that instructor characteristics, including level of support and quality of interactions with students may be of particular interest in this context (Micari and Pazos, 2012; Zumbrunn *et al*., 2014). Future studies should explore the confluence of student-, classroom-, and instructor-level influences that serve to meaningfully impact student buy-in, engagement, and performance outcomes. Additional research will be important in elucidating the strength and direction of these potential relationships across a wide range of educational contexts and building a case for causal inference.

CONCLUSION

While there is strong empirical evidence to support the use of active learning in college science classrooms to improve learning outcomes, the elements of student experiences that produce these effects are less well understood. The findings presented here suggest that student learning may benefit from buy-in to active learning, as these attitudes surrounding buy-in impact engagement in self-regulated learning and course performance. Though buy-in is a well-worn term across a range of research literatures in the social sciences, we are only beginning to understand the impact of student buy-in within undergraduate educational contexts and the resultant impact of this buy-in on performance and other outcomes.

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REFERENCES

Ajzen I (1991). The theory of planned behavior. Organ Behav Hum Decis Process 50, 179–211.

Aragón OR, Dovidio JF, Graham MJ (2016). Colorblind and multicultural ideologies are associated with faculty adoption of inclusive teaching practices. J Divers High Educ, doi: 10.1037/dhe0000026.

Armbruster P, Patel M, Johnson E, Weiss M (2009). Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology. CBE Life Sci Educ 8, 203–213.

Bandura A (1989). Human agency in social cognitive theory. Am Psychol 44, 1175.

Braxton JM, Jones WA, Hirschy AS, Hartley HV III (2008). The role of active learning in college student persistence. New Dir Teach Learn 2008, 71–83.

Brazeal KR, Brown TL, Couch BA (2016). Characterizing student preceptions and buy-in toward common formative assessment techniques. CBE Life Sci Educ 15, ar73.

Brewer MB, Gardner W (1996). Who is this "we"? Levels of collective identity and self representations. J Pers Soc Psychol 71, 83–93.

Brownell SE, Hekmat-Scafe DS, Singla V, Seawell PC, Imam JFC, Eddy SL, Stearns T, Cyert MS (2015). A high-enrollment course-based undergraduate research experience improves student conceptions of scientific thinking and ability to interpret data. CBE Life Sci Educ 14, ar21.

Chen X, Kimball K, Frederick J, Graham MJ (2013). Training TAs in scientific teaching for the human physiology and anatomy laboratory. Adv Physiol Educ 37, 436–439.

Chi MT, Wylie R (2014). The ICAP framework: linking cognitive engagement to active learning outcomes. Educ Psychol 49, 219–243.

Cialdini RB, Kallgren CA, Reno RR (1991). A focus theory of normative conduct: a theoretical refinement and reevaluation of the role of norms in human behavior. Adv Exp Soc Psychol 24, 201–234.

Connell G, Donovon D, Chambers C (2016). Increasing the use of student-centered pedagogies from moderate to high improves student learning and attitudes about biology. CBE Life Sci Educ 15, ar3.

Couch BA, Brown TL, Schelpat TJ, Graham MJ, Knight JK (2015). Scientific teaching: defining a taxonomy of observable practices. CBE Life Sci Educ 14, ar9.

Crossgrove K, Curran KL (2008). Using clickers in nonmajors- and majors-level biology courses: student opinion, learning, and long-term retention of course material. CBE Life Sci Educ 7, 146–154.

DiBenedetto MK, Bembenutty H (2013). Within the pipeline: self-regulated learning, self-efficacy, and socialization among college students in science courses. Learn Individ Differ 23, 218–224.

Dolan EL (2015). Biology education research 2.0. CBE Life Sci Educ 14, ed1.

Duncan TG, McKeachie WJ (2005). The making of the motivated strategies for learning questionnaire. Educ Psychol 40, 117–128.

Dunlosky J, Rawson KA, Marsh EJ, Nathan MJ, Willingham DT (2013). Improving students' learning with effective learning techniques: promising directions from cognitive and educational psychology. Psychol Sci Public Interest 14, 4–58.

Dweck CS, Master A (2008). Self-theories motivate self-regulated learning. In: Motivation and Self-Regulated Learning: Theory, Research, and Applications, ed. DH Schunk and BJ Zimmerman, Erlbaum, 31–51.

Eagly AH, Chaiken S (1998). Attitude structure and function. In: Handbook of Social Psychology, vol. 1, 4th ed., ed. DT Gilbert, ST Fiske, and G Lindzey, Boston: McGraw-Hill, 269–322.

Eagly AH, Chen S, Chaiken S, Shaw-Barnes K (1999). The impact of attitudes on memory: an affair to remember. Psychol Bull 125, 64–89.

Eddy SL, Brownell SE, Thummaphan P, Lan M-C, Wenderoth MP (2015). Caution, student experience may vary: social identities impact a student's experience in peer discussions. CBE Life Sci Educ 14, ar45.

Eddy SL, Hogan KA (2014). Getting under the hood: how and for whom does increasing course structure work? CBE Life Sci Educ 13, 453–468.

Education Commission of the States (1999). Comprehensive School Reform: Five Lessons from the Field, Denver, CO. http://files.eric.ed.gov/fulltext/ED439514.pdf (accessed 5 February 2015).

Estrada-Hollenbeck M, Woodcock A, Hernandez PR, Schultz P (2010). Toward a model of social influence that explains minority student integration into the scientific community. J Educ Psychol 103, 206.

Fredricks JA, Blumenfeld PC, Paris AH (2004). School engagement: potential of the concept, state of the evidence. Rev Educ Res 74, 59–109.

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP (2014). Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci USA 111, 8410–8415.

Freeman S, O'Connor E, Parks JW, Cunningham M, Hurley D, Haak D, Dirks C, Wenderoth MP (2007). Prescribed active learning increases performance in introductory biology. CBE Life Sci Educ 6, 132–139.

Gollwitzer PM (1993). Goal achievement: the role of intentions. Eur Rev Soc Psychol 4, 141–185.

Graham MJ, Frederick J, Byars-Winston A, Hunter AB, Handelsman J (2013). Increasing persistence of college students in STEM. Science 341, 1455–1456.

Gross D, Pietri ES, Anderson G, Moyano-Camihort K, Graham MJ (2015). Increased preclass preparation underlies student outcome improvement in the flipped classroom. CBE Life Sci Educ 14, ar36.

Hake RR (1998). Interactive-engagement versus traditional methods: a six-thousand- student survey of mechanics test data for introductory physics courses. Am J Physics 66, 64–74.

Handelsman J, Miller S, Pfund C (2007). Scientific Teaching, New York: Macmillan.

Hayes A (2013). Introduction to Mediation, Moderation, and Conditional Process Analysis, New York: Guilford.

Hunt DP, Haidet P, Coverdale JH, Richards B (2003). The effect of using team learning in an evidence-based medicine course for medical students. Teach Learn Med 15, 131–139.

Kahu ER (2013). Framing student engagement in higher education. Stud High Educ 38, 758–773.

Kearney P, Plax TG, Burroughs NF (1991). An attributional analysis of college students' resistance decisions. Commun Educ 40, 325–342.

Kim YK, Sax LJ (2014). The effects of student–faculty interaction on academic self-concept: does academic major matter? Res High Educ 55, 780–809.

Krosnick JA, Petty RE (1995). Attitude strength: an overview. Attitude Strength: Antecedents and Consequences, 1st ed., Mahwah, NJ: Erlbaum, 1–24.

Kuh GD, Cruce TM, Shoup R, Kinzie J, Gonyea RM (2008). Unmasking the effects of student engagement on first-year college grades and persistence. J High Educ 79, 540–563.

Kuhn MH (1964). Major trends in symbolic interaction theory in the past twenty-five years. Sociol Q 5, 61–68.

Levin B (2000). Putting students at the centre in education reform. J Educ Change 1, 155–172.

Linn MC, Palmer E, Baranger A, Gerard E, Stone E (2015). Undergraduate research experiences: impacts and opportunities. Science 347, 1261757.

Machemer PL, Crawford P (2007). Student perceptions of active learning in a large cross-disciplinary classroom. Active Learn High Educ 8, 9–30.

Maslach C, Leiter MP (2008). Early predictors of job burnout and engagement. J Appl Psychol 93, 498.

Mega C, Ronconi L, De Beni R (2014). What makes a good student? How emotions, self-regulated learning, and motivation contribute to academic achievement. J Educ Psychol 106, 121.

Micari M, Pazos P (2012). Connecting to the professor: impact of the student–faculty relationship in a highly challenging course. Coll Teach 60, 41–47.

Norcross JC, Krebs PM, Prochaska JO (2011). Stages of change. J Clin Psychol 67, 143–154.

Pfund C, Miller S, Brenner K, Bruns P, Chang A, Ebert-May D, Fagen AP, Gentile J, Gossens S, Khan IM, Labov JB (2009). Summer institute to improve university science teaching. Science 324, 470.

Pintrich PR (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. J Educ Psychol 95, 667.

Pintrich PR (2004). A conceptual framework for assessing motivation and self- regulated learning in college students. Educ Neuropsychol Rev 16, 385–407.

Pintrich PR, Smith DA, García T, McKeachie WJ (1993). Reliability and predictive validity of the Motivated Strategies for Learning Questionnaire (MSLQ). Educ Psychol Meas 53, 801–813.

Richardson M, Abraham C, Bond R (2012). Psychological correlates of university students' academic performance: a systematic review and meta-analysis. Psychol Bull 138, 353.

Roediger HL, Pyc MA (2012). Inexpensive techniques to improve education: applying cognitive psychology to enhance educational practice. J Appl Res Mem Cogn 1, 242–248.

Rogers EM (2010). Diffusion of Innovations, Chicago: Simon and Schuster.

Seidel SB, Tanner KD (2013). "What if students revolt?" Considering student resistance: origins, options, and opportunities for investigation. CBE Life Sci Educ 12, 586–595.

Seymour E, Hunter AB, Laursen SL, DeAntoni T (2004). Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. Sci Educ 88, 493–534.

Singer SR, Nielsen NR, Schweingruber HA (2012). Discipline Based Education Research, Washington, DC: National Academies Press.

Tanner KD (2013). Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity. CBE Life Sci Educ 12, 322–331.

Tinto V (2015). Through the eyes of students. J Coll Stud Ret Res Theory Pract, doi: 10.1177/1521025115621917.

Tornatzky LG, Klein KJ (1982). Innovation characteristics and innovation adoption-implementation: a meta-analysis of findings. IEEE Trans Eng Manage EM-29, 28–45.

Walker J, Cotner SH, Baepler PM, Decker MD (2008). A delicate balance: integrating active learning into a large lecture course. CBE Life Sci Educ 7, 361–367.

Wang M, Eccles J (2012). Adolescent behavioral, emotional, and cognitive engagement trajectories in school and their differential relations to educational success. J Res Adolesc 22, 31–39.

Wang MT, Degol J (2013). Motivational pathways to STEM career choices: using expectancy–value perspective to understand individual and gender differences in STEM fields. Dev Rev 33, 304–340.

Welsh AJ (2012). Exploring undergraduates' perceptions of the use of active learning techniques in science lectures. J Coll Sci Teach 42, 80–87.

Wigfield A, Eccles JS (2000). Expectancy–value theory of achievement motivation. Contemp Educ Psychol 25, 68–81.

Wolters CA, Hoops LD (2015). Self-Regulated Learning Interventions with At-Risk Youth: Enhancing Adaptability, Performance, and Well-Being, ed. T Cleary, Washington, DC: American Psychological Association, 67–68.

Young MR (2005). The motivational effects of the classroom environment in facilitating self-regulated learning. J Mark Educ 27, 25–40.

Yuretich RF (2004). Science classes. J Sci Teach 33, 40–45.

Zimmerman BJ, Schunk DH (2001). Self-Regulated Learning and Academic Achievement: Theoretical Perspectives, New York: Routledge.

Zumbrunn S, McKim C, Buhs E, Hawley LR (2014). Support, belonging, motivation, and engagement in the college classroom: a mixed method study. Instr Sci 42, 661–684.