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Article

Context Matters: Influence of Undergraduates' Approaches, Experiences, and Expectations on the LA Model in Large Enrollment Science Courses

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Abstract: The Learning Assistant (LA) model was designed to facilitate the innovative use of active learning in large lecture courses by training and integrating undergraduate near-peer instructors called Learning Assistants (LAs). We analyze the LA model in the context of the course learning activities, their influence on student outcomes, and students' expectations for the course. We used results from a large-scale survey to model expectations, course activities, and outputs in the form of course satisfaction and final grades, and drew from interviews, classroom observations, and student focus groups to make sense of the model results. Quantitative results revealed a small positive effect of LAs on final grade when only LAs were input into the statistical model. However, when the influence of students' perceptions of their professor, their teaching fellow (TF), and their own study habits were included, the effect of LAs was mitigated. Qualitative results showed that while undergraduates reported that they felt more comfortable asking LAs questions about course material, many still focused on grades over conceptual understanding. LAs championed small group work more than their teaching partners, but the effectiveness of the LAs to encourage group work was linked to the TF's approach to teaching. Results suggest that the expectations of the students, teaching staff, and the course activities and assessments can impact the effectiveness of the LA model.

Keywords: Undergraduate students, Introductory biology, Introductory chemistry, Introductory physics, Required courses, Peer teaching, group work, Course transformation

1. Introduction

Many undergraduate students in introductory science courses are faced with large, lecture-based courses with little opportunity for personalized instruction (Stains et al., 2018; Armstrong, Chang, & Brickman, 2007; Wood, 2009). These courses often serve as a barrier for students, rather than a gateway to continuing in STEM majors (Gasiewski et al., 2012; Sadler & Tai, 2001; Tai, Sadler, & Loehr, 2005). Despite programs and initiatives designed to improve the environment, most of these large enrollment courses have been slow to change (Wieman, Perkins, & Gilbert, 2010).

The Learning Assistant (LA) model was designed to address the challenges students and teachers face in these large courses (Otero, 2015). The LA model is an initiative to improve STEM education by employing undergraduate students (LAs) to assist with course instruction. LAs work both in large lecture courses and smaller discussion sections (recitations) or laboratory sessions that are often led by the graduate teaching assistants or fellows (TFs). A feature of the LA program that distinguishes it from traditional undergraduate peer mentoring is that LAs are introduced to pedagogical concepts in a seminar course, typically staffed by an institution's school of education. The course slightly varies by institution, but in general, lessons are centered around discussion of readings that address seminal concepts of research-based teaching and learning. The final essential component of the LA experience is weekly meetings with professors and TAs for lesson planning (Thompson et al. 2013).

This study explores the first three years of the implementation of the LA model in introductory science courses at a large research university. The goal of this study is to examine how the LA model affects students' experiences, learning activities, and outcomes through a mixed-methods approach using the Biggs' 3P theoretical framework for student learning (Biggs, 1989). We frame the study with these three questions:

(1) How, if at all, does the LA model influence outcomes in the course (grades, perceptions of lab/ discussion, satisfaction)?
(2) How do students' approaches, experiences, and expectations for the course impact the effectiveness of the LAs in these courses?
(3) How do LAs perceive their role in the course and what challenges do they encounter when trying to enact that role?

This study highlights the perspectives of the LAs and the undergraduate students they worked with in LA-supported courses during the first three years of LA program implementation to gain a better understanding of how LAs impact the course process and course outcomes in the form of final grades and course satisfaction. These findings build on recently published work detailing how to improve an institutional LA program using participants' perceptions (Campbell et al. 2019). Additionally, we uncover some potential caveats to previous findings regarding the impact of LA support on failure rates (Alzen et al., 2018) and student satisfaction (Talbot et al., 2015). The LA model is cross-disciplinary, but much of the relevant published research (discussed below) is rooted in Discipline Based Education Research. In this study, we apply a conceptual framework used in higher education for a broader look at the impact of the LA program.

1.1. Conceptual Framework

Biggs' 3P framework for student learning considers how three "ps", presage, process, and product influence undergraduate learning approaches to the course (Biggs, 1989). According to the 3P framework, undergraduates' characteristics and expectations (presage) interact with the course environment and activities (process), and that student and course attributes interact to influence learning outcomes (product). Similar to the LA model, Biggs' 3P Framework recommends moving from a teacher-centric course to a learner-centric course. When university courses have a clear connection between the teaching and learning activities, the intended learning outcomes, and the assessment tasks, the course is said to be in constructive alignment (CA) (Biggs, 2003; Biggs & Tang, 2007; Wang et al., 2013). A model for student learning within the Biggs 3P framework in large introductory college courses is summarized in Fig. 1.

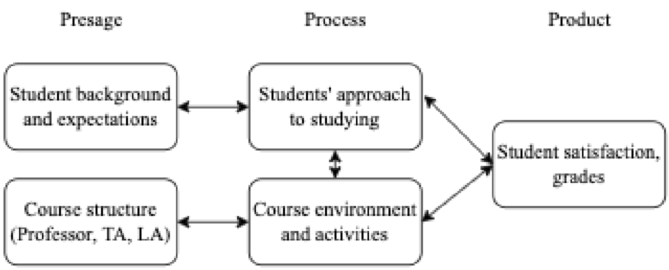

Fig. 1. Biggs' Framework for Student Learning in Undergraduate Courses

The 3P framework suggests an interrelationship between the structure of the class and students' initial conceptions (presage), the learning activities (process), and the assessment of learning outcomes (product). Course activities are established before the course (presage) and are also enacted during the course process. Instructors create a culture in how they spend time during class, the types of assignments they give to students, and how student knowledge is assessed. When innovative programs are introduced into undergraduate courses, they both influence the course and are influenced by the existing ecosystem of the course (Seymour 2002). Rather than simply investigating the impact of the LA model on student outcomes, this study connects students' perceptions and expectations and direct observations of the course in progress to understand how the LA model and the course interact.

1.2. Significance and Roadmap

This study contributes to the literature by using a model for creating courses in constructive alignment (the Biggs framework) to analyze a model of how to foster student success (the LA model). Unifying these two perspectives allows us to explore the impact of the LA model on the course, and the impact of the undergraduate and course structure on the LA model. First, we provide background on the existing literature on the LA model and describe how this study contributes to that body of knowledge. We describe the theoretical framework for understanding university course environments and students' expectations for those environments. Finally, we use a mixed methods approach to explore the impact of the LA model on students' experiences and outcomes in six large enrollment undergraduate courses that are using the LA model.

1.3 Learning Assistants and the Learning Assistant Model

With increasing evidence that active learning is more effective than lecture-based instruction, professors of large introductory STEM courses have been shifting away from a solely lecture-based approach in favor of more active learning (Freeman et al., 2007, Wieman, 2015). This shift from passive lecture-based instruction to active learning is sometimes referred to as “course transformation” (Chasteen, Perkin, Beale, 2011). In transforming their courses, introductory course professors have incorporated active learning strategies such as Peer Instruction (Mazur, 1997) and Just in Time Learning (Novak, 2011). With a focus on conceptual understanding and collaborative work, the LA model aligns with the movement toward active learning.

The LA model was designed to improve STEM education by providing pedagogical training and teaching experience to undergraduate students (Otero et al. 2006; Otero 2015). The program is notable for positioning itself as a model for other universities and for investing effort in sharing resources to support instructors at institutions aiming to establish their own LA programs. For example, specific guidelines for transforming courses to integrate LAs, the syllabus for the LA pedagogy course, and a curated list of published research on the model are shared via the LA Alliance website. Additionally, the LA Alliance hosts annual conferences and regional workshops to share programmatic experiences and support new programs.

Adding LAs to a classroom can dramatically improve the student-to-instructor ratio, which facilitates evidence-based teaching methods, especially collaborative learning (Otero 2010). LAs’ proximity in age and experience can also be valuable assets. As undergraduates who recently took the course, LAs share similar experiences with students in the course. They are often able to explain concepts in familiar terms and understand the challenges of taking the course, a concept called “social and cognitive congruence” (Lockspeiser et al., 2007).

One of the core goals of the model is to engage faculty in Disciplined-Based Educational Research (Singer et al., 2012). Simply inserting LAs into an existing course with no other pedagogical changes is not in the spirit of the LA model. Instead, it is suggested that instructors transform their course to incorporate more active learning and include LAs as a central part of course design. To ensure that instructors are committed to this notion, some programs require instructors to apply to include LAs in their course with detailed information about how they will change their course to ensure that LAs are used as an essential piece of the curriculum (Otero 2015). In this study, we examine some of the factors that instructors should consider when preparing to include LA support in their courses.

A number of studies have investigated the programmatic outcomes of the LA model as well as the impact on student outcomes (reviewed by Barrasso and Spilios 2021). Students in LA-transformed courses have improved learning gains as measured by concept inventory scores (Herrara et al. 2018), greater course satisfaction and improved attitudes toward science (Talbot et al. 2015), and better performance on exam questions that require higher order cognitive skills (Sellami et al. 2017). In addition, LAs reduce the rate of course failure and withdrawal (DFW) in large introductory courses (Alzen et al. 2018), and the reduced DFW rate is observed in all student demographics but is greatest among men of color, although traditional inequities still exist (Van Dusen and Nissen 2020). The LA model also provides a valuable experience for the LAs themselves. LAs perform similarly to graduate students on concept inventories after their first semester as LAs (Otero et al. 2010), and the LA experience fosters the development of strong professional identities (Close et al. 2016; Nadelson and Finnegan 2014).

2. Materials and Methods

This study is an integrated mixed methods approach to explore the effect of the LA model on the overall course climate and the association between students' perceptions, study habits, and course grades. We selected a multistage evaluation mixed method design to explore undergraduate’s perceptions of the large introductory classes and their LAs, generate hypotheses about the effect of the program on students’ perceptions, and then test those hypotheses across different classes (Johnson & Onwuegbuzie 2004; Creswell 2014). The study involved an abductive cycle of moving from qualitative to quantitative data collection with each round of data collection informing the subsequent round of data collection characteristic of an embedded sampling strategy, as shown in Fig. 2 (Fetters, Curry & Creswell 2013). The waves of data collection in this multistage evaluation study are detailed in Fig. 2 (Creswell 2014). The pilot study was reviewed by the IRB under protocol IRB 2729x, and the full study was reviewed by the IRB under protocol 3164 E.

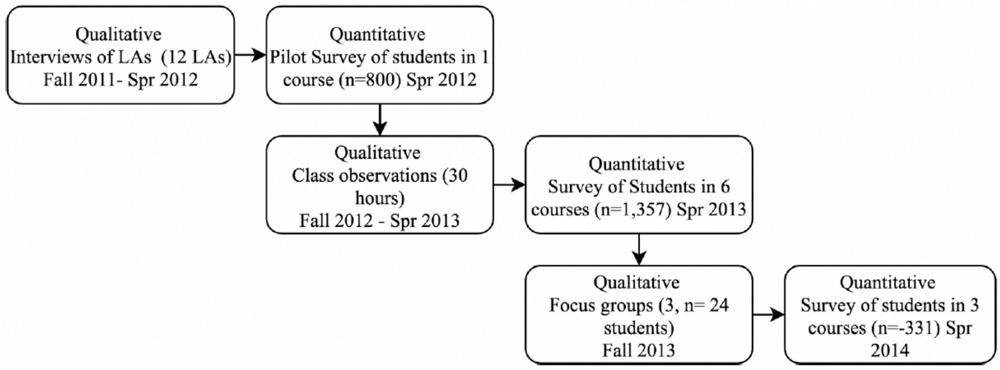

Fig. 2. Multistage evaluation study design

The theoretical model of the Biggs 3P model of tertiary education informed the types of data gathered in the quantitative part of the study. Presage variables in the survey included student backgrounds such as the number of courses taken, reasons for taking the course, and future plans. Process variables included course structure questions that gathered students' perceptions of the professor, Teaching Fellow, Learning Assistant, and the effectiveness of the small group sessions on learning. Product variables included undergraduates' satisfaction with the small group session co-led by the LA, overall course satisfaction, and final grades.

The design included a qualitative set of interviews with LAs, a review of the literature to build the theoretical model, development of the survey instrument, two years of quantitative data collection, field notes from 30 hours of classroom observations, and data from 3 focus groups. At each stage in the study, data were reviewed and analyzed to inform the next data collection step. For example, the interviews with the LAs about their interactions with students in their classes informed the questions in the pilot survey. The results of the pilot survey prompted questions about the enactment of roles by the LA and TF during a discussion or lab section and guided the classroom observations. The results of the first year of the survey prompted the focus groups. As this study was conceived as a mixed method approach, both methodology and results are presented in an integrated fashion.

2.1. Qualitative Data Collection: Interviews and Written Reflections with LAs

The LA program began at this university in the introductory chemistry course during the spring semester of 2011. The undergraduate students taking chemistry in the 2010-2011 academic year had a unique perspective; they did not have a LA in the fall of 2010, but did have one in the spring of 2011, and then some became an LA in the fall of 2011. In Fall 2011, LAs witnessed the benefits of having a LA, and also the challenges of starting this type of a program in a large course. Between Fall 2011 and Spring 2012, a series of 20 semi-structured interviews were conducted with 14 LAs. Through these interviews, we learned more about why students wanted to be an LA, which often involved their experience in the spring of 2011. We also learned what it was like to be an LA, and how that affected their overall experience at the university. All interviews were audio recorded, transcribed, and analyzed using HyperResearch, a qualitative data management tool.

Writing weekly teaching reflections is one part of the required education course all LAs take. These reflections were gathered with consent from the students during the year 2012–2013 and were analyzed for recurring themes in HyperResearch using Braun & Clarke's (2006) thematic approach. In their reflections, the LAs wrote about their motivation for becoming an LA, their experiences as an LA, and the effect of being an LA on their overall experience at the university. Some of these themes also emerged during the interviews. All names in this study were replaced by pseudonyms.

2.2 Understanding the Undergraduates' Perspectives on their LAs

The first online survey of students in classes with LAs was piloted in Spring 2012 in Introductory Biology. Initially, the survey focused on students' perceptions of their LAs and TAs in the small group discussion sections and laboratory courses.

2.2.1. Classroom Observations

To gain a better understanding of the working environment for the LAs, we observed 13 LAs working in discussion sections in the introductory chemistry class two times each during the Fall of 2012 (26 hours) and 4 LAs working in laboratory sessions in the introductory biology class in Spring 2013 once (8 hours during the 2-hour laboratory sessions). A total of 34 hours of observations were recorded through field notes; no audio or video recording was used. There were three goals for the classroom observations: (1) to observe how the LAs interacted with the students, (2) to gauge how much the LAs used the material from the class during their teaching, and (3) to understand how the LAs and graduate Teaching Fellows (TFs) worked together in the classroom. The observer took extensive notes on the classroom discussion and the flow of the class such as the movement of the LA and graduate TF during the class.

Focus Groups

In order to determine students' perceptions, study approaches, and strategies for success in these large-enrollment, required courses, we convened three focus groups of students. The focus group participants were recruited through an e-mail announcement distributed to all students in the class by the course professors; focus group volunteers responded directly to the first author. A total of 17 students participated in the focus groups; three students participated in the first group, six participated in the second, and eight participated in the third group. The focus group participants were self-selected; nevertheless, students from six of the eight classes that were included in the survey sample in April of 2013 participated in the groups. Each focus group took approximately one hour, were audio recorded and transcribed, and was analyzed using HyperResearch.

Quantitative Survey

All surveys were conducted online. The surveys had four parts: a set of single-item measures to gather information on students' frequency of use and satisfaction with resources in the class (TFs, LAs, tutoring centers), and a series of multiple-item measures designed to gather information for the structural equation model (SEM), questions designed to gather demographic information about the students, and two open response questions. The multiple item measures included course satisfaction ($\alpha = 0.81$, 4 items), whether students used a group study strategy (4 items, $\alpha = 0.83$), undergraduate students' perceptions of the professor ($\alpha = 0.84$), Teaching Assistant (7 items, $\alpha = 0.93$), and Learning Assistant (8 items, $\alpha = 0.93$), and the value of the small group session either as a discussion section or laboratory. A full list of the constructs in the survey is included in Table 1.

Table 1. Names and definitions for the variables in the model

Factor name	Factor definition
Number of courses taken in high school	The number of related courses taken in high school.
Group study strategy	A measure of whether students indicate they prefer to work in groups to study for exams and complete assignments, and how much they believe they learn better through discussing topics with others.
Perceived effectiveness of professor	A measure of students' perceptions of how well the professor's lectures and demonstrations help their learning, how well emailing their professor helps their learning, and the student's overall satisfaction with their professor.
Perceived effectiveness of TF	A measure of how much their Teaching Fellow (TF) is perceived by students as helpful, whether the TF can explain difficult topics clearly, and whether the TF can help students think about course topics in ways they can understand.
Individual attention	A measure of the student's perception of how much the TF and LA talk with them individually and whether the TF and LA make a great effort to help their students.

Table 1. *cont.*

Perceived effectiveness of LA	A measure of how much their Learning Assistant (LA) is perceived by students as helpful, whether the LA can explain difficult topics clearly, and whether the LA can help students think about course topics in ways they can understand.
Course satisfaction	A measure of how much students believe they understand the basic and complex concepts presented in the course, whether students expect to do well, and whether students are satisfied with the course workload, tests, and their own learning in the course.
Lab/ discussion useful	A measure of how effective the laboratory or discussion is in helping students learn the material, improve students' confidence in their knowledge, and succeed in the course.
Final grade	The final grade in the course on a score from 0-100 points.

Data from six classes that took the survey in 2013 and three classes that took the survey in 2014 are included in this study (Table 2). In total, 1,688 online surveys were gathered between 2013 and 2014. During data cleaning and preparation, students co-enrolled in multiple introductory courses (i.e. biology and chemistry) were flagged and only one survey was selected for inclusion in the data set. The final data set used for analysis included 895 of the 1,688 online surveys collected, with the difference, accounted for by eliminating incomplete surveys and duplicate surveys from the same students who took the survey in different classes.

Table 2. Total number of responses by class in the final data set

	Number	Percent
Biology	315	35.2
Chemistry	334	37.3
Engineering	8	0.9
Neuroscience	26	2.9
Physics	145	15.6
Physics E& M	72	8.0
Total	895	100

The sample included 60% female and 32% male (7% missing); the ethnicity of the students was 10% Hispanic, 79% non-Hispanic (11% missing), and reported race was 53% white, 23% Asian, 4% Black/ African American, with 16% of respondents choosing not to disclose their race.

3. Results

We begin by sharing the results of the quantitative part of the study to uncover the effect of the LA model on course outcomes (or product, in the Biggs' model). To understand these findings and place them in a larger context, we consider the qualitative interviews, reflections, focus groups, and classroom observations. For simplicity, we refer to the smaller group session (either discussion section or lab) as the lab.

3.1. Product: How, if at All, does the LA Model Influence Outcomes in the Course?

Following Biggs' 3P framework, the independent variables included in the model are students' study habits and the course structure of TA, professor, LA, group discussion (process), and student background represented by the number of courses taken in the topic (presage) and the dependent variables are course satisfaction and final grade (products). The final sample size for the structural equation model was n= 895, which is a sufficient number of observations to fit an SEM (Kline, 2011). Theoretically justified modification indices were incorporated into the model to improve model fit, as detailed in Appendix A. Full information maximum likelihood (FIML) is the estimator; FIML was selected for the analysis for its ability to perform well even with missing and non-normal data (Enders 2001). FIML fixes the first item on each of the constructs and then estimates the intercept and variance

(Kline 2011). The summary of parsimony and fit statistics are provided in Table 3. R studio and the model estimation package LAVAAN were used to create and analyze the models (Rosseel 2012).

Table 3. Model Fit Statistics

Model (variables)	n-free parameters	Chi Sq	df	p-value	RMSEA	CFI	SRMR
M1 (LA)	21	4107.43	14	0.00	0.06	0.99	0.20
M2 (M1 + TF, professor, study approaches)	72	1085.87	180	0.00	0.08	0.92	0.06
M3 (M2 + satisfaction, perception of small group section)	125	1277.88	435	0.00	0.06	0.95	0.06

To present the results we fit a set of three models, starting with the simplest model (regression), and adding more variables to account for complex relationships (structural equation model). These models are summarized in Table 4.

Table 4. Three models showing the effect of the LAs only compared with the other parts of the course

Parameters	Model 1 (LA only)	Model 2 (LA TF Professor Group study)	Model 3 (Model 2+ Satisfaction Background Lab Useful)
Direct effects			
LA--> Final grade	0.67 (0.04)	0.56 (0.50)	0.24 (0.45)
TF--> Final grade		-0.56 (0.53)	0.17 (0.55)
Professor --> Final grade		4.46*** (0.48)	0.52 (0.64)
Group study --> Final grade		-3.2*** (0.63)	-0.55 (0.65)
Course satisfaction --> Final grade			10.15*** (1.07)
Courses taken --> Final grade			-0.71 (0.45)
Lab useful --> Final grade			-2.26*** (0.59)
LA --> Lab useful			0.11*** (0.03)
TF --> Lab useful			0.51*** (0.04)
Group study --> Lab useful			0.33*** (0.04)
LA --> satisfaction			0.05* (0.03)
TF --> satisfaction			0.05* (0.03)
Group study --> satisfaction			-0.18*** (0.040)

Table 4. *cont.*

Professor --> satisfaction			0.41*** (0.03)
Courses taken --> satisfaction			0.07*** (0.03)
Covariances			
Group study <--> Professor		0.56	0.18
Group study <--> TF		0.09	0.33
Group study <--> LA		0.08	0.12
Professor <--> TF		0.18	
Professor <--> LA		0.09	
TF <--> LA		0.33	0.33
TF <--> Professor			0.18
Variances			
Final grade	128.11	107.13	80.02
LA		0.86	0.87
Group study		0.56	0.55
Professor		0.92	0.9
TF		0.83	0.84
Course satisfaction			0.24
Lab Useful			0.46
Courses taken			0.8
Indirect and total effects	Estimate	SE	P(>z)
LA through Lab useful	-0.25	0.09	0.009
LA through Course satisfaction	0.47	0.27	0.074
Total	0.47	0.48	0.33

Note: ***$p<0.001$

Model 1 is a simple regression to test whether there was a relationship between final grade and perception of the LA. The results of the regression indicated that there is a positive but small and non-significant effect of the LA on final grade (Beta = 0.67, p=0.16). However, the theoretical model suggests that LAs are only one part of the course. Model 2 adds the impact of TF, professor, and students' study approaches in the course. When considering these factors, the effect of the LA on final grade remains positive, but is smaller and still not at a level of statistical significance (0.56, p=0.26). Other factors such as professor (4.46, p=0.00) and study habits (-3.2 p=0.00) explain some of the variances, while TF (-0.56, p=0.28) also explains some of the variances, but not at a statistically significant level. This model suggests that the effect of the LAs is positive, but is mediated through professors', students' study habits, and their TF.

Model 3 includes student satisfaction and perception of the usefulness of the small group session. Once those factors are included, the direct effect of the LA on the final grade (0.24, p=0.59) is further absorbed by the other variables. Course satisfaction (10.15, p=0.00) has a strong and statistically significant predictor of the final grade, while the perception of the lab as useful (-2.26, p=0.00) is a statistically significant predictor of Final grade in the negative direction. The other factors considered, including past courses taken (0.71, p=0.12), professor (0.52, p=0.42), TF (0.17, 0.59) and students' study habits (-0.55, p=0.40) do not reach statistical significance. Model 3 also shows that the LA has an indirect effect on the final grade based on whether students perceive their lab as useful (-0.25, p=0.09) and their course satisfaction (0.47, p=0.074), although neither of these is statistically significant. Model 3 suggests that in addition to a small positive direct effect, the LAs also have an indirect effect on final grades through the course. While the theoretical model is not supported fully, results show that LAs do have a small and detectable relationship with the final grade that is mediated by whether undergraduates in the course perceived the lab as useful and their satisfaction in the course.

3.2. Presage: Student Motivation and Perception of Course Success is Linked to Grades 3.

Students' rationale for taking a course guides whether they take a surface approach (motivated by grades) or a deep approach to their learning in the course (Biggs, 1989). When asked whether they were taking the course for personal interest on the survey, for a future career, or to fulfill a requirement, students indicated that they took the course because it was required and important for a future career. They were neutral about their interest in the course.

During the focus groups, students were asked, "What does it mean to be successful in these courses?" Students' responses to this question most often included references to earning a good grade. Emily, a neuroscience major, described how she aimed to get good grades in her chemistry class. She explained:

> I also think success for me depends on the course. Like in chemistry, I hated chemistry. I was going to get through this. It was just a prerequisite. So for me, it was only about the grade. I just want to go through here, get a good grade that I'm happy with, and that's it.

Early in the class, students recognized that their exam scores contribute the most to their final grade, so they became keenly interested in the topics and problems that could appear on the exams. During the focus groups, an undergraduate named Amanda recounted hearing the professor speak about the course grading scheme.

> At the beginning of the course, Professor Smith said that the exam is important, but it's not everything. But then the thing is, if you look at it, each exam is like 10 percent of your grade and the final is a huge chunk in itself. So each exam isn't worth much, but if you plug them all together, it's the majority of your grade.

Other students echoed this sentiment, equating doing well with good grades. In their interviews and written reflections, the LAs also described how students prioritized grades over deep learning. Don, an LA for physics, said, "Most students are taking physics because they have to for medical school. They have the mindset of, "I just need a good grade." Arthur, another physics LA, explained that his students "…are motivated because they need to get good grades… But they're motivated towards getting the grade itself rather than getting motivated to learn the subject." In addition to being a theme in the LA reflections, all 12 LAs discussed this theme during the interviews.

The focus on grades rather than learning was in direct contrast to the LAs' main directive of learning for mastery of the material. In fact, LAs are not supposed to be involved with any aspects of grading for the course. In the teaching reflections, the LAs described how their students' concerns about grades in the course made their students more concerned about getting the right answer than learning how to work through the problem. In particular, LAs noted how the students in the course "don't see the point of taking the time to run through each step" and were "more concerned about solving the problems rather than truly understanding the implications of a particular problem." LAs observed students memorizing formulas and applying them without understanding the rationale behind them. During her interview, Melinda, a chemistry LA, explained, "I notice that when I teach that they just want to know the answer. But it's more important for them to understand so they can apply and continue."

Students' concern with "the right answer" was even more urgent when it came to exams. During week 4, students received their first exam back during the discussion section. In his reflection for that week, William, a chemistry LA, wrote:

> Many of the students were more concerned about the exam [than the discussion packet] and were asking me questions such as 'How did you do on the first exam?' and 'How do they scale this exam?'. The atmosphere was very stressful and anxious and I noticed that many of the students were not as responsive to my help.

William noticed that the focus on exam performance continued throughout the course. In his week 7 reflection, he wished his students would just "step out of the 'Will this be on the exam?' mentality".

In addition to exams, students also completed online assignments, lab reports, and weekly quizzes for these courses. However, students still focused on exam scores. When asked how he determined his grade during the course, Rick, a student, answered flatly, "I just look at my exam grades, essentially." The focus on grades in general and exam performance, in particular, made exams a frequent and recurring topic; it was mentioned by 10 of the 15 focus group participants during the three focus groups. Students gave a high priority to studying for the exams, and always sought out ways of studying for the exams more effectively.

3.3. Process: Students Adjust Studying Habits to Match their Perceptions of Course Assessment

Rick, Amanda, Rebecca, and Jessica described how they used the weekly discussion packets to study for the chemistry exam. The students noted that "the exam most closely resembles the discussion packets", Rick made problem-solving his key strategy for exam study. Amanda also reviewed for exams by "doing discussion packets I left halfway [finished] in previous weeks."

Students also discussed whether they studied with others or by themselves. Rick preferred to study alone for exams, explaining, "Since exams are a measure of individual knowledge, I always study on my own. Because that's how I do best on exams, just from my own knowledge." Michelle agreed the best way to study for the exams was to do problems by herself. She stated,

> Yeah, since I think for chemistry or problem-based sciences…it's really hard to work in a group because the test is going to be questions. To get the questions, you need to do the problems and the discussion [packets] or in the book or something. That's not really a group activity.

Michelle's comment reinforces the idea that performance on the test is an important focus for her, and that she viewed the exam as a measure of individual performance.

In the focus groups, Lisa and Jessica jointly described group study sessions that took place twice a week in the common rooms of one of the largest dormitories on campus. Jessica explained that she participates in study groups in order to "have that extra cemented understanding of the help that you get from explaining it to someone. That's how people talk about how you learn by teaching. I really subscribe to that. I love that". Lisa's study group formed during introductory chemistry in her first year, but continues to meet for her sophomore neuroscience class. She describes the group as "chaotic, but in the best way possible". Lisa continued,

> The one thing I really, really love about my study group is that everybody brings something else to the table. Everyone has a slightly different perspective. So there's always one of us in the corner going, wait, that doesn't look right. Does that not look right to you? Then we're kind of like that totally doesn't look right. Then we go, 'Matthew, that does not look right.' Then you tell him why it's not right…Yeah, study groups are like 60 percent of my success at [this university].

Lisa's description of her group parallels the descriptions of group work offered by the LAs in their teaching reflections, where students' varying perspectives allow them to facilitate each other's learning. This suggests that having the professor, TA, or LA share some of the benefits of working together with other students could potentially make more students receptive to working together during class.

Many of these large enrollment courses adjust the grades of the students in the class based on the mean score for the test, a technique sometimes called grading on a curve or curving the class. Such a technique could discourage students from helping each other because helping another student could increase the mean for the exam. Students were asked whether other students at the university would refuse to help each other in order to lower the overall mean for the test. In each focus group, the students maintained that the competition between students did not prevent them from helping each other. In fact, Michelle explained how she believed that the difficulty of the tests encouraged students to study together.

> These tests are so hard that even [for] the best students there are still some areas they don't understand. They need help from other people. That's why everyone helps each other because you need to help yourself.

Part of the value students found in the small group discussion sections was in helping them do well on the quizzes and the exams. The laboratory or discussion sections helped students with exams because that is where the students learned how to solve problems similar to the ones on the exams. Joanne described how her discussion section impacted her course performance in the discussion:

> I loved my discussion section. My LAs are fabulous. I think that I consistently do well in discussion quizzes because it will be "here's the topic that we're going to handle and here's how we're going to handle it". So we solve these problems. And we just learned the approach they want us to use, the type of math they want us to use. I do very well. And also as a result of going to discussions directly, I think, I have consistently beaten the chemistry average by a large margin.

3.4. Process: LAs Champion Group Work, but are Influenced by the TF's Teaching Strategy

3.4.1 Presage: Student Motivation and Perception of Course Success are Linked to Grades 3

The LA interviews, reflections, and classroom observations suggest that LAs were the primary champions of collaborative learning, and some TF regarded the group work part of the class as the LAs' domain. Classes often started with a short quiz, then the TF would introduce the experiment for the day (in the laboratory) or a type of problem to be solved (in discussion). Then there would be time for the students to work together in groups either on their experiments (in the lab) or on the discussion packet (in discussion). The LAs encouraged students to work together, recommending that they turn their desks to face each other, compare problem-solving strategies, and explain their solutions to others in the group who had not yet solved them. The TF played a secondary role, standing at the front of the classroom, walking along the periphery, or sometimes even correcting quizzes.

The theme of LAs championing group work was also apparent in LA interviews and written reflections, where encouraging group work was mentioned 44 times by 17 different individuals. Victoria, who was an LA for chemistry, explained that working together enabled students to actively engage in the material.

> So, I know the LAs, encourage people to work in groups…We hand out the discussion packets and say, 'OK, get into small groups. Then usually if people are working by themselves, we will try to encourage them to just join a small group. That way if they have questions, they can try and feed off each other's ideas and figure it out together versus us just giving people the answers.

The LAs noticed that encouraging group work prompted students to learn from each other. In her LA teaching reflection, Gina wrote about how a group grappled with a difficult problem without her help; each student "knew how to address different parts of the same problem, so that together they were able to solve the problem, and to explain concepts to each other." Kristina noted that students would identify problems that their peers had during the problem-solving process and suggest alternative ways of approaching the problem. We observed students learning from each other during the classroom observations, but fostering this type of interaction took a great deal of reinforcement from the TF or the LA. When the TF and the LA both created an environment that expected – and rewarded – group work, we saw that students participated in collective problem-solving.

What types of factors influenced whether and how the undergraduate students engaged in group work? We gained insight into the factors during direct observations of the LAs at work. Below we provide two examples: one environment conducive to group work, and one environment that was detrimental to group work.

3.4.2. An Environment Conducive to Group Work

This description is of one classroom observation where the TF was supportive of the LA's attempts to encourage group problem-solving. Eight minutes into the discussion section, the TF introduced the day's discussion packet by telling the entire class: "[LA name] and I want to make sure you understand these. [LA name] and I will make sure you are on the right track." When the TF asked the students to get into groups, all twenty-two students in the class turned their desks towards each other to form five clear groups, labeled in Figure 3. Both the TF and the LA circulated to ask the students questions, but the TF walked a central path through the groups, and the LA wove in and out of the groups in a more sinuous fashion.

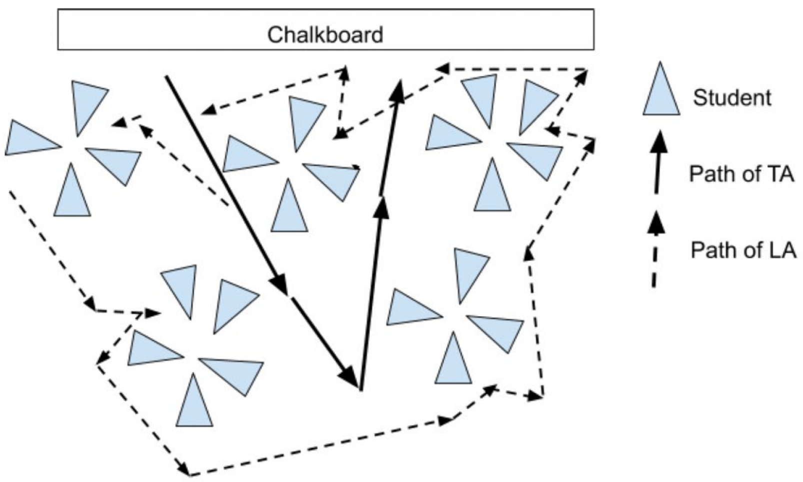

Fig. 3. Diagram of student seating patterns and LA and TF walking patterns in a class conducive to group work

The group formation allowed the LA to engage with each of the five groups at least once during the class. The LA was not shy about interacting with groups. At one point, the LA drew a diagram on the board as part of her explanation for group 5. Then the

LA said, “How about you guys work on that?” and told them she would check back in later. While talking to group 2, the LA asked a group member about a problem, and a group member gave the LA the correct numeric answer. The LA challenged the group member for an additional explanation because “Numbers don’t tell you everything…so you have to tell me what it means.” The TF also walked around the room but kept his arms crossed and only engaged with students who asked him questions first. At the end of the class, the LA and TF had a brief conversation with the entire class after the LA pointed out one problem that was likely to be on the exam. The TF agreed with the LA’s observation, saying “Oh yes, that problem has ‘professor’ written all over it.” The way the TF helped answer questions during the group work and brought the LA into his introduction demonstrated a respect for the LA’s role in the class.

3.4.3. An Environment Detrimental to Group Work

In observation of a different discussion section, the TF did not try to promote group work, which hindered the effectiveness of the LA. The TF opened the class with a nine-minute discussion of the day’s topics and the LA passed out the worksheet. The TF did not prompt the students to get into groups. Although the LA quickly suggested that the students could work together on the problems, the students did not move their chairs, resulting in a suboptimal classroom set-up as shown in Fig. 4.

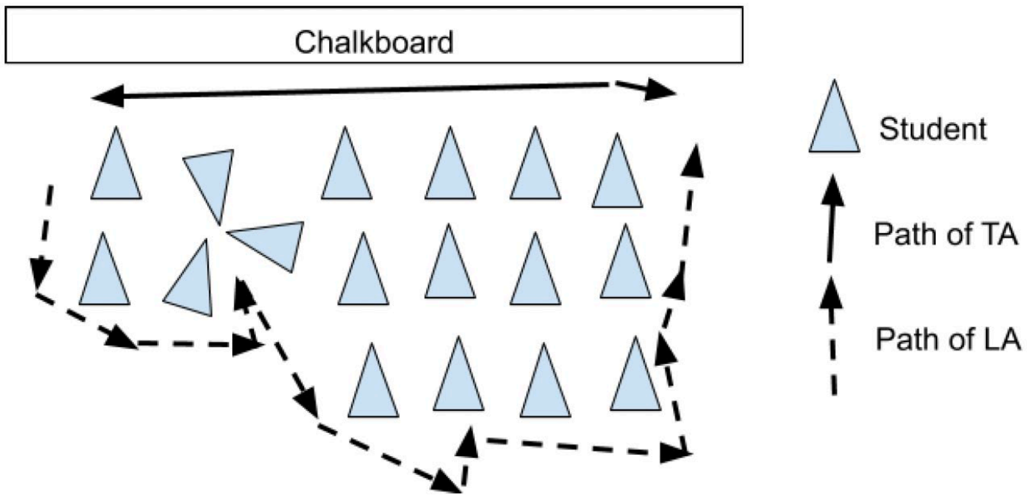

Fig. 4. Diagram of student seating patterns and LA and TF walking patterns in a class detrimental to group work

The LA first worked with a student at the front of the class, then spent some time with the students from group 1. The LA asked direct questions such as “What’s your y axis” and probing questions such as “Do you see that you do it that way?”, and “Why don’t you think it’s right? What did you do”? Meanwhile, the TF answered some students’ questions from the front of the room, and then walked around the class checking students’ papers and stating “Good, it looks like everyone is getting the right answers.” Twenty-seven minutes into the fifty-minute class, the TF brought the group back together to review some of the questions by doing them on the board. The TF solicited answers from the full class using direct questions such as “What is the intercept here?” and “So what does the rate tell you?” During the TF-led class discussion, the LA sat on the left side of the class, watching the students. The LA noticed that one student raised his hand during the full group work, but his question was not answered during class. As the students packed up, the LA approached the student to see if he still had a question. When the same TF/LA pair was observed later in the semester, a student described to the LA how he was not working on solving the problems because he was waiting “for the TF to give us all of the answers.” Since the TF had established this pattern of giving all of the students the answers, the undergraduate students in the class had little incentive to work on the problems, which made for a challenging environment for the LA.

These two examples were selected to illustrate how the classroom environment, established primarily by the TF, is critical to the effectiveness of the LA. Many of the observations included elements that were both enabling and challenging to the LAs. The observations also indicate that encouraging group work and answering questions were often considered to be the domain of the LA. When TFs and LAs both prioritized group work, students were more receptive to teaming up and working together.

3.4.4. Challenges of Group Work

A lack of support for problem-solving through group work creates a very challenging environment for the LA. However, some LAs noticed that, even when there was verbal support for group work from their TFs, the groups were not always as effective as they could be. In his teaching reflection, an LA noticed, “The groups always change from week to week, so maybe a way to try and alleviate that is to have them sit in regular groups, and so they will be more comfortable with each other.” In many of these courses, group work is informal; students are not given guidelines for how to work with other students in the course, and they are not graded on how they work with other students. In a course where students are concerned about their grades and trying to learn the material as efficiently as possible, struggling through problems with other peers who are also novices may not seem like an efficient way to learn. Implementing group work in this informal fashion may limit how seriously students take group work and limit its effectiveness.

3.5. Process: LAs Provide Value through Answering Questions and Sharing Perspectives

Additional evidence about the LAs’ role comes from the student focus groups and surveys (Table 2). These data give us insight into how students perceive the role of LAs. Students reported using their TAs and LAs as resources with equal frequency and regarded both TAs and LAs as equally helpful, yet they are more satisfied with their LAs than their TAs. Students were asked an open-ended question in the survey: “If you have any specific comments you would like to include about your Learning Assistant please share them here.” A total of 280 undergraduate students responded to the open-ended question. 82% of students (230 out of 280) provided positive comments about their LAs while 18% of students (50 out of 280) wrote negative comments about the LAs. The comments are included in Table 5.

Table 5. Students’ positive and negative open-ended comments about LAs

Positive comments	Frequency	Sample quote
Helpful	76	My LA was engaging, helpful and understanding….
Generally positive	48	I loved my LAs. They made a big difference to me.
Explains topics well	43	In her passion for the material and ability to explain concepts in simple terms, my LA was inspiring.
Dedicated/ available outside of class	25	My LA was very knowledgeable and went out of her way to make sure we understood the material and had access to her if we needed help on weekends.
Provided practical advice	21	provided great hints on what to study for on the tests as well as advice about next year class choices.
Negative comments	**Frequency of mention**	**Sample quote**

Table 5. *cont.*

Not knowledgeable/ uncertain	20	Removed and seemed unsure about things.
Not enough interaction	11	My LA stood in the front of the room and didn't talk. I don't think she knew our names and she didn't seem too enthused to be there.
Unhelpful	6	He never made an effort to help out anyone, and if he did, it was cryptic and never seemed like it was actually worth my time to actually ask him anything.
Did not use LAs	6	Did not much interact with the LA; did so much more with the TA. No knock on the LA, I just didn't have as many opportunities to interact with the LA.
LA limited by the TA	3	My LA was heavily limited by the TA. If she was given more of a chance she could have performed adequately.

Students appreciated LAs who interacted with them in the class by walking around, checking in on groups, and asking questions. Alternatively, LAs who did not interact often with students in the class or were aloof were viewed negatively. The students noticed when the TF and the LA did not work well together during the laboratory or discussion time. However, some LAs were able to counterbalance that by meeting with students and helping them outside of class time. The students recognized and appreciated the LAs who put effort into helping them learn the material. One student explained,

> It is really helpful having someone who recently took the course try to explain how to go about certain types of more difficult problems because they know what we're going through and how we're thinking. They can relate to us, which makes it easier for them to explain challenging ideas or problems. Also, they can offer helpful advice about studying and succeeding in the course.

They valued the perspective of someone who had recently learned the material, had been successful in the class, and could explain the concepts in an understandable way.

These themes were further validated by our coding of open-ended responses to the survey. The top three positive ways students described their LAs were "helpful", "knowledgeable" and able to "explain topics well." Students valued their LAs for their understanding of the course content and their ability to help explain topics in the course in a "concise and straightforward manner" using "terms I can easily understand." Conversely, students were not satisfied when their LA was not willing to help or seemed uncertain of the material. Language barriers also inhibited the effectiveness of the LAs to explain topics clearly, as noted in Table 5.

Students' appreciation of LAs extended beyond content knowledge. In the open-ended question mentioned above, twenty-one students referenced the practical advice they received from their LAs. This advice included specific tips and strategies for how to solve problems in class or helpful hints about how to perform certain laboratory techniques. Students also valued the advice their LAs shared about what courses to take the following semester, and how to find a research internship. This advice was unique to the LAs since the TFs often came from other undergraduate institutions and were not familiar with those aspects of the university.

Thirty-four students described how their LAs were approachable and respectful of all types of questions in the open-ended comments. The LAs did not make students feel uncomfortable about asking questions and were rarely condescending to students. The LAs treated their questions respectfully, without judgment, and did not make them "feel dumb" for asking a question. Students appreciated that their LAs cared about their progress in the course. Although caring was only mentioned in 15 open-ended comments, it seemed to be especially important to some students to have an LA who cared about them. One student explained "[The LAs] make me feel like someone truly cares about my progress in this course, which is something I sincerely appreciate. I don't feel like I am struggling alone."

4. Discussion

We explore the outcome of initiating an LA program in six introductory STEM courses at a large university using Biggs' 3P framework for university-level courses. The Biggs framework explores how students' approaches to the course are influenced by the course structure, their experiences, and their background in the material. The LA model supports the process of conceptual understanding through group problem solving as an approach toward mastering the materials in the course. Results of this study suggest that LAs enact their goal and support models of course change. However, students' expectations and experiences for the course and instructors' teaching strategies may influence LA effectiveness. In discussing the findings, we will share some of the factors that instructors should consider when transforming their courses to include LA support.

LAs perceived their role as facilitators of group work and felt ineffective when their students did not value the knowledge they gained from working together. Even though professors followed the LA program requirements through weekly meetings with LAs and incorporated more active learning into the courses, the course learning objectives, and student activities were not aligned with the assessment tasks in the course (Biggs 1989). Similar to the engineering program described in Borrego & Cutler (2010), the LA model's goals of conceptual understanding and collaborative work conflicted with students' expectations for a competitive course and with the assessment strategy of individual exams.

The lack of support from the TFs on collaboration and conceptual understanding combined with the LA's limited influence on grading also affected the success of the LA model. Course instructors should ensure that TFs and LAs all understand the course learning objectives, and provide clear guidelines about how to create environments of mutual support and respect. This situation could be addressed by increasing training for the TAs, which could benefit student learning, and allowing seasoned undergraduate instructors to take a larger role in leading and assessing students, thus having more influence on student outcomes (Wheeler, Maeng & Chiu, 2017).

The quantitative results show a small, positive effect of the LA on the final grade. Students appreciate their LAs for helping them understand the concepts and for reasons beyond the course. Students perceive the LAs do not have a strong impact on the course grading and perceive that LAs do not affect their final grades directly. Not surprisingly, there is a strong relationship between course satisfaction and final grade. The survey results and interviews with the LAs and the focus groups confirm that relationship – these courses are required, so students' focus is on the grades. The classroom observations show a strong impact on how the TF integrates the LA into the small group session. This strong dependence on the TF demonstrates how the expectations and process of the course influence the effectiveness of the LA model implementation.

The final quantitative model suggests that students' ongoing perceptions of the course, as demonstrated by satisfaction and perceived usefulness of the small group session, have a two-way interaction with the approach to the course. The LA model emphasizes using small group discussion as an important approach to learning. However, the final model indicates that students who take a group study approach to the course are less satisfied with the course. This finding is congruent with Biggs' framework of a two-way interaction between students' approaches to the course and course outcomes. When considering the results of the focus groups, students who appreciate studying in groups and the grouping in discussion sections (the LA model) are not rewarded by the assessment tasks in the course. In Biggs' framework, the assessment tasks and the course learning objectives are not in constructive alignment. Since students are focused on grades, and grades hinge on individual exam scores, it makes sense that the approach espoused by the LA model only has a small effect.

These data provide a clear story of how students approach these large enrollment courses such as introductory Biology, Chemistry, and Physics. The story that emerges is that in these types of required courses many students are motivated by grades, rather than mastery of the subject matter. As a result, students measure success in the course through course grades. Students quickly discern that exam scores are the most important predictor of grades. However, exams are essentially an assessment of individual performance, and often reward a "surface approach" to learning (Biggs, 1989). Students valued the small group sessions because the sessions showed them how to do the problems that will appear on the exams. However, the LAs' focus on working in groups and understanding the problem conceptually contradicted the students' goal of learning one correct way to obtain the right answer. Returning to the 3P framework, this mismatch is an example of constructive misalignment between course activities and assessment activities (Biggs, 2003). Students in the focus groups made it clear that their goal of getting a good grade in the course was linked to being able to solve problems on their own, and they tailored their efforts accordingly.

In addition to increasing the teacher-to-student ratio, we also found evidence that LAs exhibited social and cognitive congruence with the students in their classes (Lockspeiser et al., 2008). Students appreciated LAs' ability to explain concepts in understandable language and remember what it was like to be learning the material for the first time. They also valued the LAs' perspectives on university life beyond the course such as research internships and balancing course schedules. Although these held great value for students, they did not relate to the final grade in the course. Recognizing the LAs for their perspectives as "expert novices" in the material could help instructors and TFs find ways to introduce LAs to the students in the course, and to better incorporate LAs into the small group sessions.

We explore how students' perceptions of and experiences in the course influence their approaches to the coursework and their learning outcomes in the course. Understanding students' experiences is essential to enabling course change (Biggs 1989, 1996). Students' perceptions of courses are significantly influenced by the other students in the course (Bowman & Seifert 2011), and students' approach to course activities is influenced by their perceptions. In the growing research around LA programs, this study contributes information about students' and LAs' perspectives on their learning processes, their perceptions of the processes in the course, the wide range of activities students can use to address the learning, and the outcome that students attend to most – their final grade for the course.

5. Conclusion and Implications

The infusion of LAs into large enrollment introductory courses is one of many innovations designed to transform these courses from passive to active learning environments (Wieman, 2014; Froyd 2008; Handlesman et al., 2004; Wood, 2009). Yet the addition of these LAs and an emphasis on collaborative problem solving and understanding content over "the right answer" did not in itself redirect student expectations away from achieving the highest possible final grade on the exams. Final course grades were strongly related to students' satisfaction with the course structure. Students who were satisfied with the workload, assignments, and grading policies appeared to be more satisfied with the professor and had higher final grades in the course. Students who studied in groups outside of class were more satisfied with the small group sessions, valued the efforts of the TFs and the LAs who ran those sessions, yet tended to receive lower final grades. The TFs and LAs could be helping the students who are most at risk by providing opportunities for them to actively engage with the material in the course. However, the course structure may favor students who study alone and perform better on the assessments, which focused on exams taken by individual students. Students' satisfaction with their LAs appears to be based on the support and encouragement provided by the LAs, more than on the effect LAs may have had on their grades.

The movement for course transformation in college science courses requires a focus on what students should learn, on assessing whether students are learning and supporting students' learning through evidence-based teaching practices (Chasteen et al., 2011). Although course transformation is presented as a systematic procedure (Science Education Initiatives, 2014), changing educational practices at the university level is a complex process that is influenced by context (Seymour, 2002). In this study, the infusion of LAs into science courses enabled more active and cooperative learning in the small group sessions. However, course processes, including the teaching strategies used by the TF partnered with the LA, the assessment structure for the course, and students' focus on performance goals over learning goals, reduced some of the effects the LA model had on the larger course. Professors who are moving towards course transformation should consider the importance of student expectations and perceptions on their study habits, the impact of TFs on the LAs' effectiveness, and the alignment between course assessment strategies and stated learning objectives. The results of this study are a reminder that any innovation occurs within the context of the learning environment, and understanding that context is a critical step in enabling change.

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Appendix A: Description of model revisions for EFA, CFA, measurement, and structural models

This appendix provides a detailed description of each step of the exploratory, confirmatory factor analyses, as well as the measurement and structural models. The structural models were then used in the final analysis. First, we split the data set into two halves using a random number generator. We first test the theoretically established relationships between the survey items through exploratory factor analysis (EFA), and then confirm those relationships through confirmatory factor analysis (CFA). The measurement and structural models include the entire sample from the 2013 survey (n= 854). In each model fitting process, we present the modification indices for possible ways to improve fit in ways that are supported theoretically.

Excessive fitting in factor analysis and structural equation modeling has been criticized. To avoid these potential pitfalls, we have used the split half sampling approach for the EFA to CFA. We have purposefully avoided overfitting the model, and only adjusted fit on the “with” statements (linking residuals) rather than on the “by” statements (for the proposed model). we also explicitly state each modification step in this document and demonstrate how the modifications are theoretically justified.

1. Exploratory factor analysis (EFA)

All of the items included in the model already have theoretical associations with the factors to be measured. The purpose of doing an EFA is to ensure that there are no additional relationships between items that the researcher may not have detected. This is distinct from CFA in that all relationships between the factors and the items are tested in EFA, whereas CFA restricts the items to load onto fewer preidentified factors.

The table contained 449 cases, of those 436 were included in the EFA as 12 cases had missing variables and thus were excluded by MPlus. The robust maximum likelihood (MLR) estimator was used to account for potential nonnormality of data, with geomin, oblique rotation.

Table A1 summarizes the EFA results for 4,5 and 6 factors.

Table A1. Exploratory factor analysis results (n=436)

Factors	BIC	RMSEA	CFI	TLI	SRMR	X2
4	26335.45	0.10	0.89	0.83	0.05	680.41*
5	26131.30	0.07	0.93	0.88	0.03	627.22*
6	26051.54	0.07	0.95	0.92	0.02	447.03*

A scree plot and parallel plot were also analyzed as an alternate measure of evaluating the number of factors. The parallel plot crossed between 5 and 6 factors. Although the TLI for 5 factors was low, and the BIC continued to drop between 5 and 6 factors, theoretically, the 5 factor model was more justifiable. In particular, each factor in the 5 factor model addressed one particular part of the course, such as the description of group study, satisfaction, and the Learning Assistant, graduate Teaching Fellow, or the professor. In the 6 factor model, items about frequency of asking the LA and the TF created a two item factor. In order to create the simplest model to describe this system, we selected the 5 factor model.

Table A2. Rotated pattern matric for five factors

		Group study	TF	Satisfaction	LA	Professor
Q14_1RM	I studied for exams best alone	**0.643***	-0.029	-0.205*	-0.045	-0.029
Q14_2M1	I learn the topic better when I can discuss it with someone	**0.691***	-0.015	0.055	0.008	0.007
Q14_3M1	I usually did homework with other students from the class	**0.573***	-0.092	-0.027	0.032	-0.056
Q14_4M1	I find the groupwork in class very helpful for learning the material	**0.602***	0.133	-0.019	0.029	0.144*
Q14_5RM	I don’t learn much from working with others	**0.721***	0.015	0.080	-0.033	0.006

Table A2. *cont.*

Q15_1M2	I understand the basic concepts taught in this course	-0.044	-0.014	**0.787***	-0.064	0.030
Q15_2M2	I understand the most complex material taught in this course	0.020	-0.029	**0.832***	0.058	-0.057
Q15_4M2	I expect to do well in this class.	-0.013	-0.019	**0.726***	-0.069	-0.003
Q26_1M2	Satisfaction with the workload for this course	-0.066	0.053	**0.496***	0.038	0.172*
Q26_2M2	Satisfaction with my learning of the material as a result of this course	0.121*	0.075	**0.515***	0.027	0.271*
Q24_1M3	My TF shared advice about how to approach particular topics in this class	-0.005	**0.924***	-0.010	-0.017	0.029
Q24_2M3	My TF framed difficult concepts in ways I could understand	0.019	**0.844***	0.015	0.042	-0.004
Q24_3M3	My TF helped me think about topics in this course in a way that made sense to me.	-0.010	**0.961***	0.005	0.013	-0.003
Q24_4M3	My TF understood my perspective as someone who has learned this material before.	-0.050	**0.909***	0.026	-0.002	0.002
Q28_8	Satisfaction with the TF	0.031	**0.779***	0.013	-0.027	-0.053
Q21_4	How often I ask a TF	0.202*	**0.372***	-0.091	0.061	0.024
Q35_1M4	My LA shared advice about how to approach particular topics in this class	-0.014	0.014	-0.043	**0.914***	-0.023
Q35_2M4	My LA framed difficult concepts in ways that I could understand	0.005	0.000	0.018	**0.925***	-0.022
Q35_3M4	My LA helped me think about topics in this course in a way that made sense to me.	0.028	0.004	0.056	**0.934***	-0.033

Table A2. *cont.*

Q35_4M4	My LA understood my perspective as someone	-0.044	0.006	0.002	**0.865***	0.043
	who has learned this material before.					
Q21_5	How often I ask an LA	0.195*	0.110	-0.084	**0.416***	0.055
Q26_9	Satisfaction with the LA	-0.006	-0.038	0.017	**0.797***	0.027
Q18_1M7	How well professor's lectures allow me to learn	-0.009	-0.026	0.014	-0.010	**0.863***
Q18_2M7	How well demonstrations by the professor allow me to lean	0.024	-0.015	0.011	-0.008	**0.838***
Q26_7	Satisfaction with the course professor	-0.032	0.015	0.006	0.002	**0.525***

After the number of factors was established using EFA, a confirmatory factor analysis (CFA) was completed for the independent items. The CFA was based on the second split half of the sample (n=416). The model terminated normally (max log likelihood value for unrestricted H1 model= -11525.21)

After each analysis step, the model fit parameters were reviewed, and modification indices and theoretical justifications were consulted to adjust the model fit. Model fit values for each test of the model are provided in the summary table, with descriptions of each modification described in the subsequent tables. The initial model, summarized in CFA1, has marginally acceptable fit. The RMSEA is above 0.08 and the SRMR is 0.07, both the CFI and TLI hover around the "acceptable" cutoff value of 0.90, as shown in table A3.

Table A3. Confirmatory factor analysis summary of results

step	BIC	X2	df.	p	RMSEA	CFI	TLI	SRMR
CFA1	24441.76	792.8	265	p<0.00	0.07	0.89	0.88	0.06
CFA2	24115.44	481.001	261	p<0.00	0.05	0.96	0.95	0.06

The modification between, CFA1 and CFA2, is summarized in Table C4.

Table A4. CFA modification 1

Step	Items	MI	Item 1	Item 2
1	Q21_5 with Q21_4	130.97	Frequency asking TF	Frequency asking LA
2	Q15_2M2 with Q15_1M2	59.21	I understand the most complex material presented by the professor in the course	I understand the basic concepts in the course
3	Q35_4 with A24_4	45.73	My LA understood my perspective as someone who has learned this material before	My TF understood my perspective as someone who has learned this material before

4	Q26_9 with Q26_8	43.96	Satisfaction with the LA	Satisfaction with the TF

All three pairs in the first modification are links between the TF and the LA. Since the TF is in charge of the small group session, the TF has a great influence on the LA. The TF influences how much time is spent on group work, so can influence how much time the LA talks individually with students, and helps students with understanding the material, which impacts satisfaction and frequency of asking the TF and LA. The first modification resulted in an improvement in model fit in CFA2, so that CFI (0.96) and TLI (0.95) are above the cutoff value of 0.90 indicating acceptable fit, while the RMSEA dropped to 0.05 and SRMR remained at 0.06. Results are presented in table A5.

Table A5. Measurement model summary of results (n=854)

ID	BIC	X2	df	p	RMSEA	CFI	TLI	SRMR
M1	58878.33	1134.11	386	p<0.00	0.05	0.95	0.94	0.06
M2	58878.58	1101.81	385	p<0.00	0.05	0.95	0.94	0.06

The measurement model included the entire data set (n=854) and added the outcome variables. The first model had good fit, although modification indices indicated two relationships that could improve the model fit. The only new adjustment to the model was to link students' perception of increased confidence and understanding resulting from attending the laboratory/ discussion section (MI=37.53). This link was both theoretically justified and as the dependent variables were not present in the CFA, the model was adjusted. The items and specific MI are included in Table A6.

Table A6. Measurement model modification 1

ID	Items	MI	Item 1	Item 2
4	Q37_4 with Q37_3	37.53	Attending laboratory/ discussion made me more confidence about my knowledge of the topics covered in this course	Attending laboratory allowed me to better understand the material covered in this course.

The adjustment resulted in M2 with an RMSEA value of 0.05, a CFI of 0.95, a TLI of 0.94, and an SRMR of 0.06.

The final step is to add the directional relationships between the variables to create the structural model. Table A7 details relationships that were used for the structural model. The influence of gender, and race were not significant, and not included in the final model.

Table A7. Relationships for initial structural model

Satisfaction on	Number of courses taken in high school Group study Perceived effectiveness of professor Perceived effectiveness of TF Usefulness of lab/ discussion group
Usefulness of Lab/ Discussion group	Individualized attention Perceived effectiveness of LA Perceived effectiveness of TF Group study
Final grade	Satisfaction Number of courses taken in high school Group study Perceived effectiveness of professor Usefulness of Lab/ discussion group

The initial structural model S1 fit the data well, with an RMSEA of 0.04, a CFI or 0.95, a TLI of 0.94, and an SRMR of 0.06 (n=797).

References

1. Allison, P. D. (2002). *Missing Data*. Thousand Oaks, CA: Sage.
2. Alzen, J. L., Langdon, L. S., & Otero, V. K. (2018). A logistic regression investigation of the relationship between the Learning As sistant model and failure rates in introductory STEM courses. *International Journal of STEM Education*. https://doi.org/10.1186/s405 94-018-0152-1
3. Anderson, W. A., Banerjee, U., Drennan, C. L., Elgin, S. C. R., Epstein, I. R., Handelsman, J., et al. (2011). Changingthe culture o f science education at research universities. *Educate*, *10*, 12.
4. Armstrong, N., Chang, S. M., & Brickman, M. (2007). Cooperative learning in industrial-sized biology classes. *CBE Life Sciences Education*. https://doi.org/10.1187/cbe.06-11-0200
5. Authors. (2013). Investigating the effect of peer teachers on learning environments in large STEM courses. In *National Association of Research in Science Teaching (NARST)*. San Juan, Puerto Rico.
6. Barrasso, A. P., & Spilios, K. E. (2021). A scoping review of literature assessing the impact of the learning assistant model. *Interna tional Journal of STEM Education*, *8*(1), 1–18.
7. Barattucci, M., Pagliaro, S., Cafagna, D., & Bosetto, D. (2017). An examination of the applicability of Biggs' 3P learning process model to Italian university. *Journal of E-Learning and Knowledge Society*. https://doi.org/10.20368/1971-8829/1277
8. Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education*, *32*(3), 347–364. https://doi.org/10.1007/BF0 0138871
9. Biggs, J. B. (1989). Approaches to the enhancement of tertiary teaching. *Higher Education Research & Development*. https://doi.org/ 10.1080/0729436890080102
10. Borrego, M., & Cutler, S. (2010). Constructive alignment of interdisciplinary graduate curriculum in engineering and science: An an alysis of successful IGERT proposals. *Journal of Engineering Education*, *99*(4), 355-369.
11. Bowman, N. A., & Seifert, T. (2011). Can college students accurately assess what affects their learning and development? *Journal of College Student Development*, *52*(3), 270.
12. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*. https://doi.org/10.1191/ 1478088706qp063oa
13. Chasteen, S. V, Perkins, K. K., Beale, P. D., Pollock, S. J., & Wieman, C. E. (2011). A thoughtful approach to nstruction: Course t ransformation for the rest of us. *Journal of College Science Teaching*, *40*(4), 24–30. Retrieved from http://www.eric.ed.gov/ERICWe bPortal/detail?accno=EJ921529
14. Clinton, V. (2014). The relationship between students' preferred approaches to learning and behaviors during learning: An examinati on of the process stage of the 3P model. *Instructional Science*, *42*(5), 817–837. https://doi.org/10.1007/s11251-013-9308-z
15. Close, E. W., Conn, J., & Close, H. G. (2016). Becoming physics people: Development of integrated physics identity through the L earning Assistant experience. *Physical Review Physics Education Research*, *12*(1), 1–18. https://doi.org/10.1103/PhysRevPhysEducRes. 12.010109
16. Cohen, J. W. (1988). *Statistical power for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.
17. Cohen, J. W. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155
18. Creswell, J. W. (2014). *A concise introduction to mixed methods research*. Sage Publications.
19. Enders, Craig K. (2001). The impact of nonnormality on full information maximum-likelihood estimation for structural equation mo dels with missing data. *Psychological Methods, 6*(4), 352-370.
20. Evans, B. C., Coon, D. W., & Ume, E. (2011). Use of theoretical frameworks as a pragmatic guide for mixed methods studies: A methodological necessity? *Journal of Mixed Methods Research*. https://doi.org/10.1177/1558689811412972
21. Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs - Principles and practices. *Health Services Research*. https://doi.org/10.1111/1475-6773.12117
22. Fielding, N. G. (2012). Triangulation and Mixed Methods Designs: Data Integration With New Research Technologies. *Journal of Mixed Methods Research*. https://doi.org/10.1177/1558689812437101
23. Freeman, S., O'Connor, E., Parks, J., Cunningham, M., Hurley, D., Haak, D., et al. (2007). Prescribed active learning increases perf ormance in introductory biology. *CBE - Life Sciences Education*, *6*(132–139).
24. Froyd, J. (2008). White Paper on Promising Practices in Undergraduate STEM Education. In N. R. Council (Ed.). Retrieved from ht tp://www7.nationalacademies.org/bose/Froyd_Promising_Practices_CommissionedPaper.pdf.

25. Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (2012). From Gatekeeping to Engagement: A Multicont extual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses. *Research in Higher Education*. http s://doi.org/10.1007/s11162-011-9247-y
26. Gilbert, J. K. (2008). Visualization: Theory and practice in science education. In M. . N. Gilbert, J.K.; Reiner (Ed.) (pp. 3–24). Spri nger London.
27. Gray, K. E., Webb, D. C., & Otero, V. K. (2016). Effects of the learning assistant model on teacher practice. *Physical Review Phys ics Education Research*. https://doi.org/10.1103/PhysRevPhysEducRes.12.020126
28. Grindstaff, K., & Richmond, G. (2008). Learners' perceptions of the role of peers in a research experience: Implications for the app renticeship process, scientific inquiry, and collaborative work. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.2 0196
29. Hamilton, J., & Tee, S. (2009). Extending the Biggs 3P teaching and learning model: A structural equation modeling approach. In *Proceedings of the International Conference on Electronic Business (ICEB)*.
30. Handlesman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., et al. (2004). Scientific teaching. *Science*, *304*(567 0), 521–522.
31. Herrera, X., Nissen, J. M., & Van Dusen, B. (2018). Student Outcomes Across Collaborative-Learning Environments. In *Physics Ed ucation Research Conference*. Washington DC.
32. Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational R esearcher*. https://doi.org/10.3102/0013189X033007014
33. Kline, Rex B. (2011). Principles and practice of structural equation modeling. New York :Guilford Press.
34. Lockspeiser, Tai, O'Sullivan, P., Teherani, A., & Muller, J. (2008). Understanding the experience of being taught by peers: the valu e of social and cognitive congruence. *Advances in Health Sciences Education, 13*(3), 361-372. doi: 10.1007/s10459-006-9049-8
35. Ludvigsson, J. F. (2003). Biggs' teaching for quality learning at university. *Journal of Pediatric Gastroenterology and Nutrition*. htt ps://doi.org/10.1097/00005176-200304000-00028
36. Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.
37. Nadelson, L. S., & Finnegan, J. (2014). Path less traveled: Fostering STEM majors' professional identity development through enga gement as STEM Learning Assistants. *Journal of Higher Education Theory & Practice*, *14*(5), 29–40 http://search.ebscohost.com/logi n.aspx?direct=true&db=eue&AN=100405018&site=ehost-live. Accessed 14 Jan 2020
38. Novak, G. M. (2011). Just-in-time teaching. *New Directions for Teaching and Learning*. https://doi.org/10.1002/tl.469
39. Novak, G., Patterson, E., Garvrin, A., & Christian, W. (1999). *Just-in-time teaching: {Blending} active learning with web technolog y*. Upper Saddle River, NJ: Prentice Hall.
40. Otero, V. K. (2015). *Nationally scaled model for leveraging course transformation with physics teacher preparation*.
41. Otero, V., Pollock, S., & Finkelstein, N. (2010). A physics department's role in preparing physics teachers: {The} {Colorado} learn ing assistant model. *American Journal of Physics*, *78*(11), 1218–1224. https://doi.org/10.1119/1.3471291
42. Otero, V., Pollock, S., McCray, R., & Finkelstein, N. (2006). Who is responsible for preparing science teachers? *Science*, *313*(5786), 445–446. https://doi.org/10.1126/science.1129648
43. Rosário, P., Almeida, L., Soares, S., Núñez, J. C., González-Pienda, J. A., & Rubio, M. (2005). The academic learning viewed fro m the perspective of John Biggs' «3P model». *Psicothema*.
44. Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http:// www.jstatsoft.org/v48/i02/
45. Sadler, P. M., & Tai, R. H. (2001). Success in introductory college physics: {The} role of high school preparation. *Science Educati on*, *85*(2), 111–136. https://doi.org/10.1002/1098-237x(200103)85:2<111::aid-sce20>3.0.co;2-o
46. Science Education Initiatives. (2014). *Course {Transformation} {Guide}*. Boulder, CO and Vancouver, BC.
47. Sellami, N., Shaked, S., Laski, F. A., Eagan, K. M., & Sanders, E. R. (2017). Implementation of a learning assistant program impro ves student performance on higher-order assessments. *CBE Life Sciences Education*. https://doi.org/10.1187/cbe.16-12-0341
48. Seymour, E. (2002). Tracking the processes of change in {US} undergraduate education in science, mathematics, engineering, and t echnology. *Science Education*, *86*(1), 79–105.
49. Singer, S. R., Nielsen, N. R., & Schweingruber, H. A. (2012). Discipline-based education research. *Washington, DC: The National Academies*.
50. Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., et al. (2018). Anatomy of STEM teachi ng in North American universities. *Science*. https://doi.org/10.1126/science.aap8892
51. Tai, R. H., Sadler, P. M., & Loehr, J. F. (2005). Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.20082

52. Talbot, R. M., Hartley, L M., Marzetta, K., & Wee, B. S. (2015). Transforming Undergraduate Science Education With Learning A ssistants: Student Satisfaction in Large-Enrollment Courses. *Journal of College Science Teaching*.
53. Thompson, M., Garik, P., Moser, A., Hammond, N., Jariwala, E. M., Spilios, K., et al. (2013). Investigating the effect of peer teach ers on learning environments in large {STEM} courses.
54. Van Dusen, B., & Nissen, J. (2020). Associations between learning assistants, passing introductory physics, and equity: A quantitati ve critical race theory investigation. *Physical Review Physics Education Research*, *16*(1), 010117.
55. Walsh, A. (2007). An exploration of Biggs' constructive alignment in the context of work-based learning. *Assessment and Evaluatio n in Higher Education*. https://doi.org/10.1080/02602930600848309
56. Wheeler, L. B., Maeng, J. L., Chiu, J. L., & Bell, R. L. (2017). Do teaching assistants matter? Investigating relationships between t eaching assistants and student outcomes in undergraduate science laboratory classes. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21373
57. Wieman, C.(2014). Large scale comparison of STEM teaching methods sends clear message. *Proceedings of the National Academy of Sciences. 111* (20) 8319–8320 DOI: 10.1073/pnas.1407304111
58. Wood, W. B. (2009). Innovations in biology teaching and why we need them. *Annual Review of Cell and Developmental Biology*, *25*, 93–112. https://doi.org/10.1146/annurev.cellbio.24.110707.175306
59. Yin, R. K. (2014). *Case study research: Design and methods*. Sage publications.