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Kevin P. O'Halloran
Georgia Gwinnett College, kohallor@ggc.edu

Sairam Tangirala
Georgia Gwinnett College, stangira@ggc.edu

Fengjie Sun
Georgia Gwinnett College, fsun@ggc.edu

Leonard E. Anagho
Georgia Gwinnett College, lanagho@ggc.edu

Gerald Agbegha
Georgia Gwinnett College, gagbegha@ggc.edu

See next page for additional authors

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An Experiential Report on the Thayer Method of Teaching across College-Level Chemistry, Biology, Math, and Physics Courses

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Authors

Kevin P. O'Halloran, Sairam Tangirala, Fengjie Sun, Leonard E. Anagho, Gerald Agbegha, Clay Runck, David Roth, and Amy H. Erickson

AN EXPERIENTIAL REPORT ON THE THAYER METHOD OF TEACHING ACROSS COLLEGE-LEVEL CHEMISTRY, BIOLOGY, MATH, AND PHYSICS COURSES

Kevin P. O'Halloran*, Sairam Tangirala, Fengjie Sun, Leonard E. Anagho, Gerald Agbegha, Clay Runck, David Roth, and Amy H. Erickson
School of Science and Technology, Georgia Gwinnett College,
Lawrenceville, Georgia, 30043
*Corresponding author: kohallor@ggc.edu

ABSTRACT

The Thayer method of instruction is a little-known active learning technique that dates back to 1817 at the U.S. Military Academy. Here we describe the implementation and statistical evaluation of an adaptation of the Thayer method in a variety of college science and math courses. All courses had five characteristics in common: (i) students were given a daily reading schedule and instructed to prepare before class, (ii) each class started with a question and answer session, (iii) class time minimized the use of lecture, (iv) class time maximized the use of active learning, and (v) students were frequently quizzed. A total of 51 sections across chemistry, biology, math, and physics taught by eight professors involving 542 students were used. Students were surveyed at the beginning and the end of the semester on their attitudes toward teaching methods using a 5-point Likert scale. The data were analyzed using the nonparametric Wilcoxon rank-sum test. The results show three outcomes: (i) students prefer the modified Thayer method over a traditional lecture method, (ii) students report feeling more encouraged to stay in college, and (iii) students report no difference in the amount of time that they spend on reading or working on problems. These three results are encouraging amid efforts to educate and retain STEM students. The modified Thayer method should be considered by those using or seeking to use an active learning technique.

Keywords: Thayer method, active learning, interdisciplinary

INTRODUCTION

Active learning approaches in higher education science courses have become increasingly popular especially since the 1990s. Evidence suggests that active learning approaches decrease the achievement gap in science, technology, engineering, and math (STEM) courses (Haak et al. 2011). Consequently, these methods are receiving increasing academic attention. The Thayer method of instruction is a form of active learning (Stiefel and Blackman 1994; Ertwine and Palladino 1987). Many science professors have been adopting active learning forms of teaching over the last few decades but are surprised to learn that the Thayer method was developed over 200 years ago in 1817 at the U.S. Military Academy by Sylvanus Thayer (Shell 2002). This teaching method emphasizes student preparation prior to class, daily work for students at the blackboards, frequent quizzing, and small class sizes. Its history (Shell 2002) and implementation (Paredes et al. 2010) have been reported, and it is commonly used at the U.S. Military Academy today but is relatively rare elsewhere. Several faculty members at Georgia Gwinnett College use the method because of their previous experiences from teaching at the U.S. Military Academy or through collaboration with colleagues who teach this way. The Thayer method has been shown to be useful in biochemistry (Stiefel and Blackman 1994), English (Gibson 2007), and in one study was shown to increase the completion rate of a 2-semester organic chemistry course with lab sequence to over 90% (Pursell et al. 2012). Despite these positive results, no study describes the Thayer method's uniform implementation across different disciplines. We therefore sought to expand the use of this teaching method with a study that spans across STEM disciplines at Georgia Gwinnett College. Large scale pedagogical studies with uniform implementation across multiple professors and disciplines are lacking in the literature. The goal of this study was to develop and describe a teaching method that is applicable across science and math disciplines and evaluate its effect on student opinions.

For the goal of producing more STEM graduates, recent policies in the U.S. have focused on attempting to reduce students' attrition in STEM subjects in college. It has been argued that a small percentage increase in STEM retention could be a cost-efficient method to substantially increase the supply of STEM students to workers (Ehrenberg 2010; PCAST 2012). Along the same line, in 2009, the Obama administration began a campaign titled *Educate to Innovate* for improving the participation and proficiency of U.S. students in STEM areas. The campaign titled *Let Everyone Dream* was launched during the White House Science Fair in 2015 to expand STEM opportunities for underrepresented youth. A study estimated that a total of 56% of college students who declared a STEM major in their first year left those fields over the next six years (Chen 2009, 2013). A student's personal decision to leave a STEM field is likely to arise from a number of factors. A main cause is the style of teaching, as Watkins and Mazur (2013) determined that students in a physics course with a lecture format switched out of STEM majors nearly twice as much as students in an active learning method called *peer supplemental instruction*. Gianquinto (2009) concluded that the type of instruction students receive is the biggest obstacle to degree completion. He suggested that faculty limit lecturing to 10–15 min, which is what we have done with our adaptation of the Thayer method of teaching.

To address these issues of STEM student retention and performance, a number of active learning techniques have been employed elsewhere. The most similar one to the Thayer method of teaching is *just-in-time teaching* where students must complete pre-class assignments while class time is devoted to active learning and adapted to the students' needs. The goals of just-in-time teaching are essentially the same as the Thayer method: to encourage preparation for class, maximize the effectiveness of class time, and increase student motivation to learn. Just-in-time teaching was developed in 1999 (Novak et al. 1999) and has many positive outcomes, including increased student learning in physics (Formica et al. 2000). The key difference between just-in-time teaching and the Thayer method is that the latter pre-dates computers so graded pre-class assignments were not used. Concerning other types of active learning, Dranea et al. (2014) presented an evaluation of peer-led small groups at a research university over a 10-year period across disciplines. Their data suggested that peer-lead groups increased participants' grades in five of the seven courses and in the retention rate in the four courses that require students to take a course sequence. Cotner et al. (2013) compared student performance in traditional and active learning classrooms in a large, introductory biology course using the same syllabus, course goals, exams, and instructor. Using ACT scores as predictive, the authors found that students in the active learning classroom outperformed expectations, whereas those in the traditional classroom did not. Those authors' results provide confirmation that these active learning environments positively affected student learning. Their data suggest that creating active learning spaces in science courses may improve student performance. Many educators today believe that particular attention should be paid to student motivation to stay in college. We therefore sought to investigate this question by asking the students directly about their intent to stay in college and taking the responses at face value.

METHODOLOGY

Research Plan

Our adaptation of the Thayer method was implemented primarily in introductory (freshman) level courses. Fall 2012 was used as a preparation semester to test the research survey design and also so that the participating faculty who were not familiar with the teaching method could practice using the method. In the following semester, spring 2013, the authors began formal data collection and continued to spring 2014 for a total of three semesters. The participating faculty members and sections used are given in Table I.

Table I. Summary of courses implemented. See the title page for full names of faculty members.

Faculty member	Courses	Total sections
O'Halloran	Principles of chemistry I, II	8
Anagho	Survey of chemistry I, II; Organic chemistry I	9
Sun	Principles of biology II	8
Runck	Principles of biology II	5
Agbegha	College algebra	7
Roth	College algebra	4
Erickson	Statistics	3
Tangirala	Introduction to physics I	7
Total		**51**

All eight participating STEM faculty members volunteered to participate in this study and adopted a consistent set of course attributes based on the Thayer method. To achieve consistency, the five course attributes used in all classes were as follows:

1. Students were given a detailed schedule containing homework and class topics for every class of the semester. This differs from a traditional course schedule which typically lists topics by week, rather than by class period.
2. Each class started with a question and answer session on the reading and homework assigned for that class.

3. Class time minimized the use of lecture. Typically, one-third of class time or less was devoted to lecture.
4. Class time maximized the use of active learning: board work or small group discussions in every class.
5. Students were quizzed frequently (every week except in physics in which they were quizzed every two weeks).

These five components above constituted our adaptation of the Thayer method for this study. These particular components may not necessarily be the same as those adopted by other faculty who use the Thayer method because it may be modified to match a particular faculty member's teaching style. The use of several faculty members and courses in this study greatly reduces possible statistical effects due to any individual faculty member's teaching style. Classes were similar in class size, composition, and offered a variety of times throughout the day. The student demographics in the School of Science and Technology at Georgia Gwinnett College are 67% full time and 33% part time; 57% female and 43% male; 33% African American, 18% Hispanic, 4% multi-racial, 28% white, 14% Asian, and 3% unknown or other. Since a major component of the Thayer method is active learning, several student whiteboards were used in all classrooms for this project.

Teaching Methods

Students were provided a reading assignment and suggested problems on the schedule. This is different from a traditional method because students read and did homework before the material is covered in class. Students often ran into some difficulties in solving these problems, so faculty would ask them at the beginning of class for questions. This allowed the professor to answer those questions and also tailor their short lecture that followed to meet student needs and explain potential pitfalls. The lecture part of class was minimized in order to allow for maximum time for the active learning that followed. Students then worked at the boards on assigned problems in groups, and the professor visited each group to answer questions and discuss the material with the groups. This differs from a traditional teaching method in that 1) it places more emphasis on the student to work before class, 2) class begins with question and answer, and 3) most of class is spent with students working at the whiteboards. The material covered in the course, including homework and exams, was the same as what is usually covered in each respective course. These aspects are very similar to just-in-time teaching but without an online feedback system. The similarities between the two methods are a focus and plan for students to prepare before class, and class time devoted to instructor feedback in real time. Therefore, the Thayer method could be considered a low-tech version of just-in-time teaching for those who do not use online homework or feedback systems for whatever reason.

Additional Teaching Methods for Biology

For quantitative biology topics such as problems in Mendelian genetics (e.g., Punnett squares and probabilities, pedigree analysis) and population genetics (e.g., Hardy-Weinberg equilibrium), the modified Thayer method was used. For conceptual topics, in order to keep in line with the tradition of the Thayer method, other active learning techniques were adopted. For example, student groups were assigned to different types of plant life cycles that they worked on collaboratively to draw on a whiteboard. The instructor reviewed the life cycle for accuracy, and then the student group presented their solution to the rest of the class for review and feedback. In another example, each student group was assigned the same *behavioral content objective* to solve. Content objectives were the basis of quiz or test questions. An example of one type of behavioral content objective involving the use of a figure was "Use a labeled figure to show the basic features of a biogeochemical cycle." Each group presented their solution, i.e., labeled figure, to the class for critiquing with the goal being to develop one best solution for the content objective. A similar process can be used to solve content objectives in the form of a six-sentence or less short answer. An example of a short-answer content objective was "Describe the relationship between chromosomes and inheritance." For some biology topics, like natural selection and ecology, more mini-lectures were used.

Survey Design

Students were asked to complete a 3 min, paper-based, self-administered survey on the first day of the semester (pre-survey) and at the end of the semester (post-survey). The response options used a 5-point Likert scale: strongly agree, agree, no opinion, disagree, and strongly disagree. Likert scales were originally proposed as psychometric scales, which is commonly involved in research measuring attitudes using questionnaires given in a survey format (Likert 1932). Likert scales are often called summative scales because item responses to the questionnaire could be summed for analysis. Due to its effectiveness, the Likert scale has been popularly applied in various disciplines to investigate attitudes (Alsharif and Henriksen 2009; Barry et al. 2015; Bowskill et al. 2014; Jacob et al. 201; Kable et al. 2015).

The pre-survey contained 15 questions to gauge student attitudes toward traditional lecture and active learning styles of teaching, the use of whiteboards in class, and the five components of the course design mentioned in the research plan section. The post-survey contained the same questions as above with six additional questions regarding student attitudes of the active learning method experienced in the course. The surveys were designed to adhere to the best practices of American Association of Public Opinion Research (2020). The students were asked to give informed consent by completing a waiver produced by the college Institutional Review Board that explained the purpose of the survey. Only data from students who completed a waiver were used. Since the lecture method is not our preferred teaching method, we did not use a pure lecture method for our courses. The comparison that we asked students to make is to other courses that use the lecture method. To guard against potential threats to statistical validity, the surveys were designed as follows:

- Survey completion was anonymous and voluntary by the students.
- The pre-survey and post-survey had an identical format, and identical wording was used for questions comparing the modified Thayer method to the traditional lecture method.
- Surveys were designed to be short to eliminate possible survey fatigue.
- Surveys were collected by eight different faculty members to eliminate possible instructor-dependent effects.

Analysis Methods

Since the 5-point Likert scale produces ordinal data (ranked from *strongly agree* to *strongly disagree*) rather than continuous data, the nonparametric method Wilcoxon rank-sum test was used to compare pre-survey and post-survey data (Rosner 2006). That is the desired test for opinion surveys with ranked options (DeLuca and Lari 2013). The test has greater efficiency and is more robust than *t* tests on data with non-normal distributions, and it works well even with small samples (Conover 1980). The Wilcoxon rank-sum test ranks and compares ordinal data from two independent data sets rather than comparing the averages and standard deviations of each. This was used to compare pre-survey and post-survey responses since the surveys were anonymous and we did not know which pre-survey form matched with which post-survey form. The null hypothesis was that the modified Thayer method has no effect on student responses compared to the traditional lecture format used in other courses.

RESULTS

In spring 2013 there were 146 completed pre-surveys and 135 completed post-surveys. In fall 2013 there were 246 completed pre-surveys and 197 completed post-surveys. In spring 2014 there were 264 completed pre-surveys and 210 completed post-surveys. That is a total of 656 pre-surveys and 542 post-surveys. Selected questions from post-surveys are presented in bar chart format in Figures 1–5. The bar charts conveniently show the spread and skew for responses to each question.

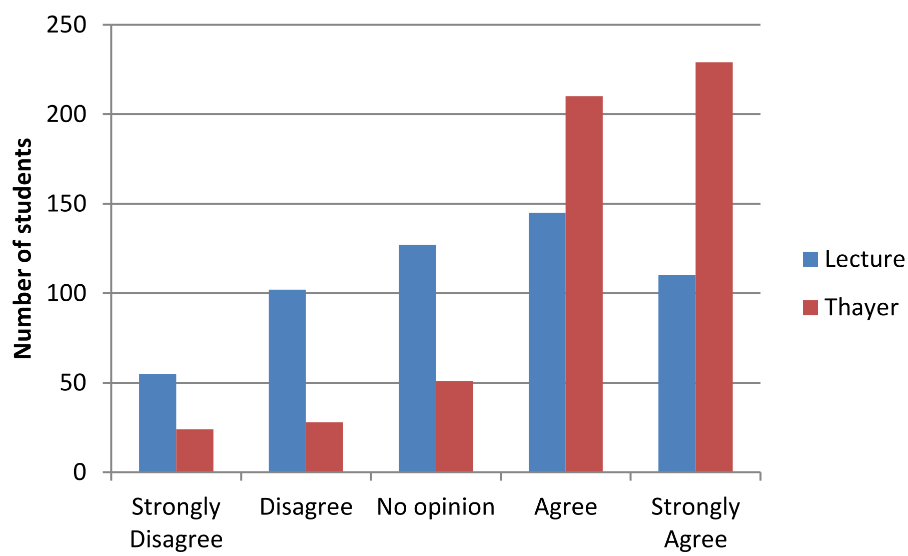

Figure 1. Teaching method preference. Student responses to the question "I enjoy class taught in this format".

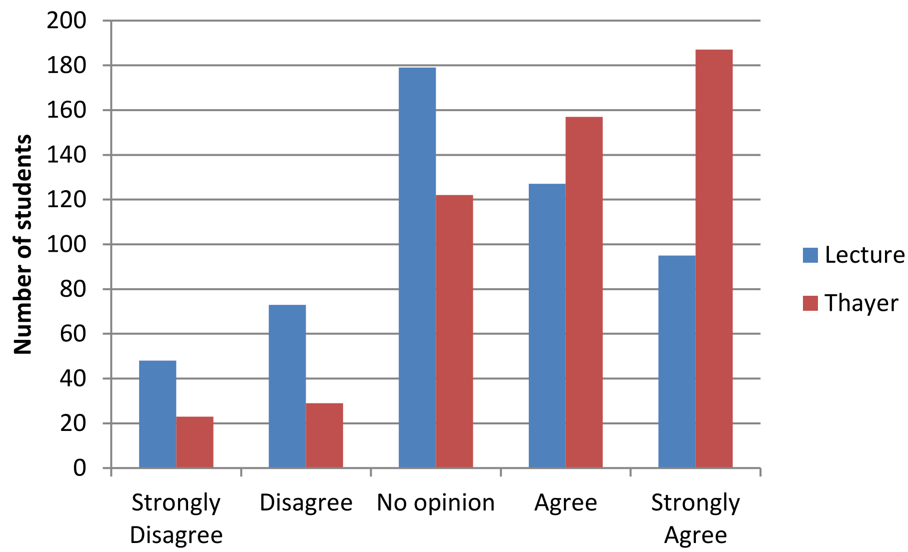

Figure 2. College retention. Student responses to the question "Courses in this format encourage me to stay in college".

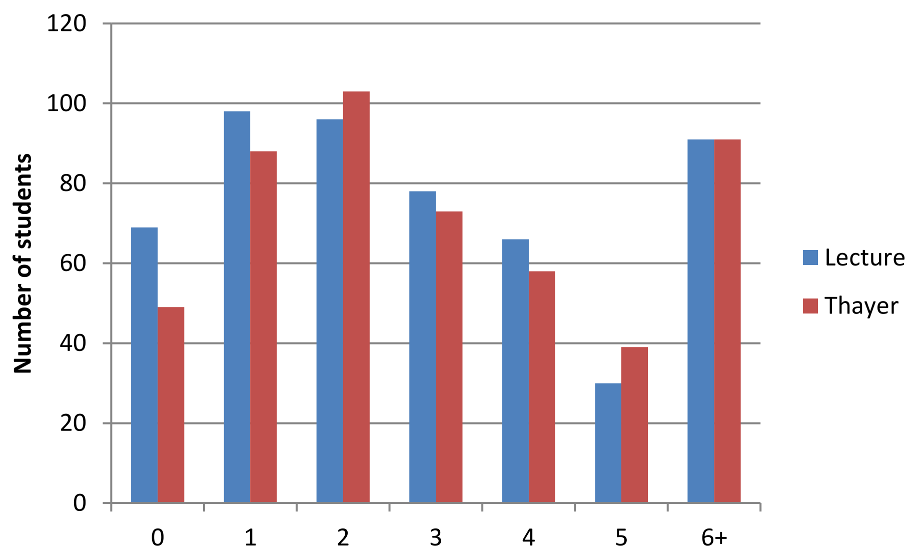

Figure 3. Hours spent reading the book. Student responses to the question "How many hours per week do you spend reading the book?"

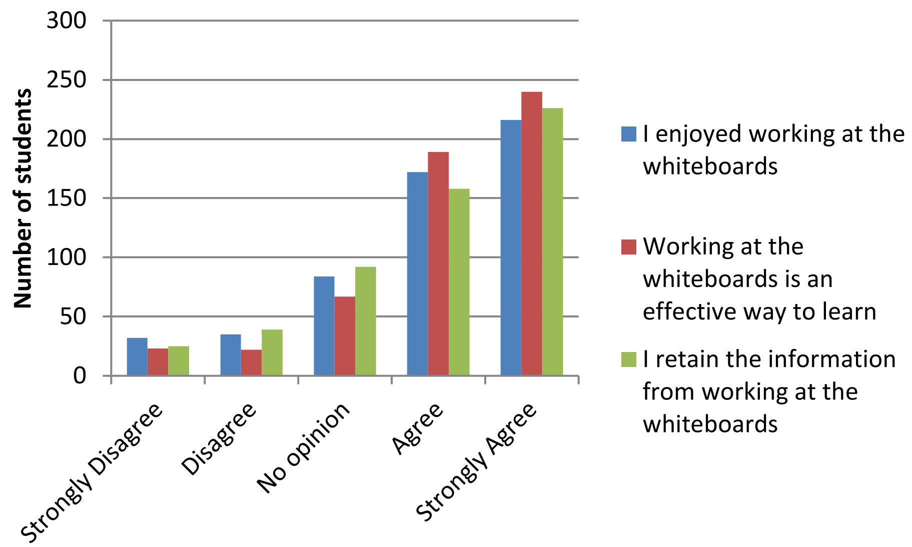

Figure 4. Attitudes on whiteboard use. Student responses to the questions about whiteboard use.

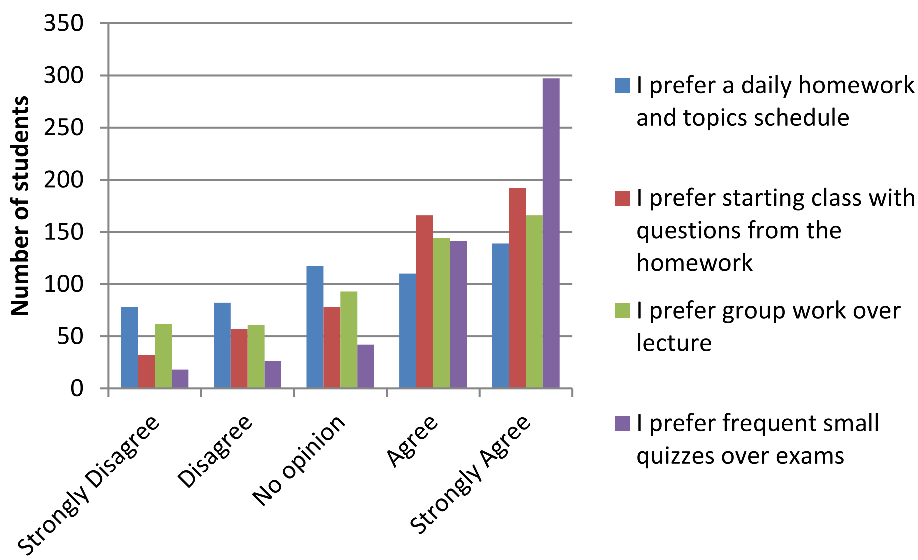

Figure 5. Attitudes on the modified Thayer method. Student responses to the questions about the components of the course.

The responses for all questions are summarized in Table II. To determine if implementation of the modified Thayer method affected students' responses, hypothesis testing was done to compare post-survey responses. While customary testing is done at the $\alpha = 0.05$ significance level, we chose a higher level of significance at the $\alpha = 0.005$ level based on the suggestion by Benjamin et al. (2018) for researchers to raise statistical standards. Student responses to the Thayer versus traditional lecture questions in the post-surveys were compared and the results are presented in Table III.

Table II. A summary of responses for all questions

Question	Pre-survey average	Post-survey average
For other courses taught in a TRADITIONAL LECTURE format		
I enjoy class taught in this format	3.31	3.28
I learn a lot in a class taught in this format	3.45	3.41
I prepare for class a lot in this format	3.37	3.22
I retain the information	3.51	3.38
How many hours per week do you spend reading the book?	4.21	3.50
How many hours per week do you spend working problems?	4.61	4.04
Courses in this format encourage me to stay in college	3.37	3.28
For this course taught in an ACTIVE LEARNING format		
I enjoyed class taught in this format	N/A	4.09
I learned a lot in this class taught in this format	N/A	4.06
I prepared for class a lot in this format	N/A	3.86
I retain the information	N/A	4.05
How many hours per week do you spend reading the book?	N/A	3.44
How many hours per week do you spend working problems?	N/A	4.10
Courses in this format encourage me to stay in college	N/A	3.88
Working at the whiteboards		
I enjoy working at the whiteboards	3.80	3.94
Working at the whiteboards is an effective way to learn	4.00	4.11
I retain information longer by working at the whiteboards than by lecture	3.81	3.97
General course design		
I prefer a daily class and homework schedule rather than a weekly schedule	3.28	3.29
I prefer starting class with questions from the reading and homework rather than lecture	3.62	3.82
I prefer group work over lecture	3.37	3.55
I prefer frequent small exams rather than fewer large exams	4.09	4.28

Table III. Hypothesis testing of the modified Thayer method vs. traditional lecture method in the post-surveys.

Question	Significance
I enjoy class taught in this format	$p < 0.005$
I learn a lot in a class taught in this format	$p < 0.005$
I prepare for class a lot in this format	$p < 0.005$
I retain the information	$p < 0.005$
How many hours per week do you spend reading the book?	$p = 0.986$
How many hours per week do you spend working problems?	$p = 0.0899$
Courses in this format encourage me to stay in college	$p < 0.005$

DISCUSSION

For five of the seven questions, the responses were significantly higher for the modified Thayer method than the traditional lecture method (Table III; $p < 0.005$). This result indicates that students rated the modified Thayer method more positively. The two questions where the data were indistinguishable ($p > 0.005$) were regarding the number of hours that students spent reading the textbook and solving problems outside of class. This result indicates that students reported no significant difference in time spent outside of class. The Hawthorne effect is when subjects modify their behavior when they know that they are being studied. The observed effects here are not likely due to unwanted effects like information feedback or the Hawthorne effect because the experimental design consciously avoided introducing any incentive or bias for the students' responses, which were anonymous, voluntary, carried no grade component, and we gave no indication to the students our preference or any anticipated outcome (Parsons 1974). The novelty effect is when students respond more positively to new technology or methods. We also do not expect these results to be due to the novelty effect as well because our students are exposed to other active learning strategies in several other courses at our college (Linder and Whitehurst 1973). We also tested the questions regarding the modified Thayer method versus the traditional lecture method across pre-surveys and post-surveys and reached the same significance results as above (data not shown).

There is a clear visual difference between the modified Thayer and traditional lecture teaching methods (Figures 1 and 2). There was no significant difference between the two teaching methods on the amount of time that students reported reading the book (Figure 3) or working on problems. Three questions were posed to the students about working at the whiteboards: if they enjoyed it, if they thought it was an effective way to learn, and if they retained the information (Figure 4). All three questions were rated highly by the students as either *agree* or *strongly agree*. Four questions were posed to the students about the five components of the course design that all faculty members adopted: a daily homework and topics schedule, a Q&A session at the beginning of class, group work rather than lecture, and frequent small quizzes rather than large exams (Figure 5). Students strongly favored three of these elements but showed no apparent preference for a daily homework and topics schedule. A comparison of the pre-survey to post-survey responses of the lecture method was made to see if students responded to questions about the traditional lecture method differently after experiencing the modified Thayer method. This comparison showed no significant differences in pre-survey and post-survey responses about the traditional lecture method ($p = 0.701$). This result indicates that students answered the post-survey questions on the traditional lecture method consistently.

The survey allowed students to provide comments about their opinions of both teaching methods. All of the comments received are organized and presented in Table IV. We have categorized these comments into positive, neutral and negative categories. These were enlightening because they captured some sentiments that are not able to be measured by Likert question responses. The number and emphasis of positive comments outweighed the number and emphasis of negative comments for the modified Thayer method. The reverse was observed for the traditional lecture method.

Table IV. All student responses from the comments section of the survey

Comments on traditional lecture format	
Positive	It works better.
	Easy and straight-forward.
	This is my preferred method of learning.
	They help me know what is going on.
	The interaction with the teacher helps a lot.
	As long as example problems are worked, I am fine.
	Good for non-math related courses.
Neutral	Most classes taught this way so nothing to compare to.
	They're okay for history classes but for science or math classes I do not like lecture style teaching.
	I actually like both teaching styles.
	They are boring yet effective.
	Traditional classes are okay, but it does not motivate me to learn.
	Kind of boring at times, but they're important concepts/material to understand.
	Some classes function better in traditional lecture than active learning (i.e. O-chem I).
	Depends highly on the material/course; if a course in my field/focus of interest, I enjoy it greatly. If not, very much dislike it.
Negative	Too boring and don't feel very engaged.
	Way too boring, it's all memorization.
	They are boring and tedious.
	I don't like monotone voices and PowerPoints.
	Very hard to stay focused.
	It's a little boring. A more effective environment will keep students focused.
	A lot to take in at one time.
	BORING.
	Most of my courses have not used the book.
	Sometimes I'm getting confused about material.
	They don't help to understand what is going on.
	It's a ton harder to remember the things I've learned in other courses.

. . . .

Table IV *(continued)*

Comments on active learning format	
Positive	Awesome format. Makes things easier to understand. I learn the concepts by the board work. Much more incentive to prepare for class. I personally prefer being required to read on my own and working problems together in class. I like going to the boards and working problems and having the teacher help out that way. I like it because the professor isn't lecturing the whole time. Great experience. The group work helped one to have friends to study with. Great teaching style. I preferred this method because it kept me alert in class and I didn't have to do as much at home learning the information. I like this method because I am a visual learner. Love active learning courses! Much better! More enjoyable. I learned a lot of info from active learning courses. The small exams were helpful in showing where I needed to study more. It's straight forward, I like that. It helps me think outside of the box by how others show me their ways of seeing things. It's fun, get to talk to peers about concepts. Group effort. Courses in active learning help me understand the material better. Awesome.
Neutral	I believe that it needs to be a balance between lectures and active learning. This way students can also be hands on as well. I find this slightly more challenging, but more interactive. It helps to interact with other classmates but not the majority of the time.
Negative	It does not work. We as students pay to learn/be taught by professors, not our peers. I don't like the amount of quizzes. I have only missed two classes and both days we had an unexpected quiz. Now I have a failing grade because of it. I feel as if I am doing all of the work. Why do I even come to class, if I am just going to teach myself everything anyways?

The student attitudes presented here are consistent with those previously reported on the use of the Thayer method (Paredes et al. 2010) including student appreciation for a highly structured class format, knowing in advance what will be presented in each class, and class time spent on solving problems. This study builds on previous literature on the Thayer method, but with the benefit of being a large scale, multi-faculty and multi-discipline study. Future work will include investigating deeper aspects into students' desire to stay in college, retention rates, and which aspects of active learning are effective at achieving these gains.

There are limitations in education research because there are many variables and not all of them can or should be controlled. For example, one should not control a variable if the faculty reasonably assume that it will harm the students' education. In this study, the biggest limitation is that we did not use a control section where we taught using the lecture method. We did this because we do not use this method and do not want to harm our students' education. Attempting to do so would also introduce bias in the study because we would probably not be as good at lecturing as we are with using active learning. Another limitation is that we used a survey that we developed rather than a previously published survey.

CONCLUSIONS

Eight faculty members across science and math disciplines used a consistent set of teaching principles modeled after the Thayer method. A total of 51 classes and 542 students were surveyed about their attitudes before and after a teaching implementation. A significant number of students reported that they favor the modified Thayer method over the traditional lecture method on all questions which asked for their preference. This result is drawn from the significance tests with p values below 0.005. Students reported no significant difference on time spent reading the textbook or working on problems outside of class between these courses and traditional lecture courses, which is an important result in a learning environment where students have limited time to spend studying outside of class. This may be a valuable pedagogy at colleges where students spend a large amount of time at part-time jobs. The students most positively responded to frequent quizzing over large exams, group work over lecture, and working at the whiteboards. Students reported feeling more encouraged to stay in college from this teaching method, which is a very important result amid interest in student retention and completion of a college degree.

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