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Effects of Active-Learning Experiences on Achievement, Attitudes, and Behaviors in High School Biology

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Abstract: Active-learning labs for two topics in high school biology were developed through the collaboration of high school teachers and university faculty and staff and were administered to 408 high school students in six classrooms. The content of instruction and testing was guided by State of Texas science objectives. Detailed teacher records describing daily classroom activities were used to operationalize two types of instruction: active learning, which used the labs; and traditional, which used the teaching resources ordinarily available to the teacher. Teacher records indicated that they used less independent work and fewer worksheets, and more collaborative and lab-based activities, with active-learning labs compared to traditional instruction. In-class test data show that students gained significantly more content knowledge and knowledge of process skills using the labs compared to traditional instruction. Questionnaire data revealed that students perceived greater learning gains after completing the labs compared to covering the same content through traditional methods. An independent questionnaire administered to a larger sample of teachers who used the lab-based curriculum indicated that they perceived changing their behaviors as intended by the student-centered principles of the labs. The major implication of this study is that active-learning–based laboratory units designed and developed collaboratively by high school teachers and university faculty, and then used by high school teachers in their classrooms, can lead to increased use of student-centered instructional practices as well as enhanced content knowledge and process learning for students. © 2007 Wiley Periodicals, Inc. J Res Sci Teach 44: 960–979, 2007

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There are several distinct ways in which students can change as the result of science instruction: they can acquire new content knowledge, consisting of facts and principles; they can develop lab and investigative skills; they can develop the ability to reason scientifically; they can learn about the complexity of the world and gain an appreciation for the scientific approach to this complexity; and, through an adequate knowledge of the content and processes of scientific inquiry, they can act as informed citizens in public discussions of social issues involving science. These outcomes are complementary and are included in the current science education standards established by the National Research Council (1996, 2000, 2003, 2005).

The actual outcomes of instruction depend largely on what happens in classrooms. If scientific knowledge is presented in terms of proven facts and absolute truths readily communicated through texts and lectures, then students will come to regard science as a static body of knowledge that is founded on well-defined methods (Roth & Roychoudhury, 2003). Knowledge, for these students, consists of memorizing a body of information for later retrieval (e.g., for a test). If, on the other hand, students actively engage in science processes, they can come to recognize that scientific knowledge is based on experiments in which the meaning of data is negotiated and theories are not absolute. Knowledge, in this context, consists of learning experimental methods and the norms and practices of scientific communities as much as it does learning known facts and current theories within a domain (Wheeler, 2000).

These two orientations to science knowledge in the classroom correspond roughly to two distinct approaches to instruction. In teacher-centered instruction, learning focuses on the mastery of content, with little development of the skills and attitudes necessary for scientific inquiry. The teacher transmits information to students, who receive and memorize it. Assessments of knowledge typically involve one right answer. The curriculum is loaded with many facts and a large number of vocabulary words, which encourages a lecture format of teaching (Leonard & Chandler, 2003). Studies of science teaching in the late 1990s led to the observation that most teachers still used these didactic methods of instruction and determined that ‘‘many students were mastering disconnected facts in lieu of broader understandings, critical reasoning, and problem solving skills’’ (National Research Council, 2000, p. 17). In contrast, in a student-centered curriculum, learning science is active and constructive, involving inquiry and hands-on activities. The goal is to develop critical thinking and problem-solving skills by posing and investigating relevant questions whose answers must be discovered. The teacher acts as a facilitator, creating the learning conditions in which students actively engage in experiments, interpret and explain data,and negotiate understandings of the findings with co-experimenters and peers. In this model, the teacher puts less emphasis on memorizing information and more emphasis on inquiry and hands-on activities through which students develop a deeper knowledge and appreciation of the nature of science (Marx et al., 2004; National Research Council, 1996, 2000, 2003; Singer, Marx, Krajcik, & Chambers, 2000).

Even when there is a shift in the direction of implementing inquiry learning in the classroom, teachers can still take away from the true nature of science by giving students cookbook experiments—activities through which students carefully follow step-by-step instructions and collect data without a clear understanding of the question or concepts, and without opportunities to reason about their observations (National Research Council, 2005). Mohrig (2004) identified several ways to make lab experiences associated with inquiry authentic and meaningful. Questions or problems should come first, and serve as the basis for an experiment or investigation. The lab should provide the means to collect evidence and discover answers to questions from the results of experimental work. Labs should create opportunities to examine experimental results and draw reasonable conclusions from data. Long-term projects are ideal, as well as those involving teamwork. Lab projects should encourage students to investigate a topic in detail and foster a sense of ownership for the findings (National Research Council, 2003).

Students in a typical middle or high school biology curriculum have few opportunities to engage in inquiry-based activities (Leonard & Chandler, 2003), and learning environments are needed in which students can engage in scientific discussion and explain and defend their thinking (Tsai, 2001). Inquiry-based curricula are not without challenges and require students and teachers to change the way they view learning (Bybee, 2000). Students need to develop ways of thinking that characterize scientific exploration and explanation. Teachers accustomed to lecturing and assigning worksheets and homework must acquire new teaching materials and develop new approaches to teaching, assessment, and classroom management (Kang & Wallace, 2004; Marx et al., 2004; National Research Council, 1996).

In this study we test whether an active-learning curriculum is more effective in teaching science than a traditional, teacher-oriented curriculum. Active learning, as used here, is the implementation of a variety of specific student-centered instructional strategies to teach science. It includes using hands-on, inquiry-oriented activities and organizing students into collaborative learning groups that analyze problem-oriented scenarios. We contrast this to what we term ‘‘traditional’’ instruction, by which we simply mean a curriculum that is relatively more dependent on lecture and textbooks for instruction. Both instruction terms—active learning and traditional—will be operationalized in this study using data collected from teachers that described what they did in the classroom on a day-to-day basis.

Based on active-learning (National Research Council, 1996, 2000, 2003, 2005) and constructivist (Roth & Roychoudhury, 2003) theories, we predicted that when students participated in active-learning they would demonstrate measurable advantages on test and questionnaire instruments, compared to traditional instruction. Because active learning is consistent with a student-centered classroom, we predicted that, when teachers used an active-learning curriculum, their behaviors would shift toward more student-centered instruction.

Traveling Labs Program

The tested curriculum was developed within a so-called ‘‘traveling labs’’ program. The TTU/HHMI (Texas Tech University Howard Hughes Medical Institute) Science Education Program traveling labs are laboratory kits for middle and high school students that include standards-based curricula along with all the materials that the students and teachers need to complete the activities. The kits were originally developed by high school teachers working in conjunction with Texas Tech faculty (see details in what follows), as part of the TTU/HHMI Precollege Outreach Program, which had as its goal to create and maintain a seamless community of scientists consisting of faculty and students at Texas Tech and science teachers and students at the regional schools. The overall premise was that the best way to meet the curriculum needs of the students was to have practicing teachers design the learning materials and activities because they know their students. Specific goals were to cover current topics, such as biotechnology, the molecular basis of disease, and genetics, and to develop materials to help students meet the State of Texas science education requirements, which are based on the *National Science Education Standards*. The laboratory kits investigated in the current experiments are the Biotechnology traveling lab and Microscopy traveling lab. The two labs implement the BSCS (Biological Science Curriculum Study) instructional cycle: engage, explore, explain, elaborate, and evaluate (Bybee, 2002), which applies an inquiry approach to teaching and learning.

In the Microscopy lab, students learn about prokaryotic and eukaryotic cells. They are first introduced to a problem that, as laboratory scientists, they are called upon to help solve. This problem sets the stage, allowing learning to be framed in a context that makes it meaningful and relevant, while revealing prior knowledge about target concepts. Students are trained in pertinent lab techniques before being asked to work in ‘‘medical’’ teams to design and conduct a series of experiments to solve the problem. This guided-inquiry activity allows the students to ask questions, decide how best to answer them through investigations, carry out experiments, and draw conclusions based on their evidence, which they share with the class. Students transfer their newly found knowledge to other real-world situations. In the Biotechnology lab, students learn about DNA structure and function, protein synthesis, and natural selection. Students are first introduced to a problem that, as scientists for the Centers for Disease Control and Prevention, they are called upon to help solve. Students' role playing leads them to discover a health problem involving a high mortality rate in infants in a fictitious village in Africa. Using laboratory techniques and working collaboratively, students derive patterns from their experimental data that imply a genetic basis for the disease, which they identify and investigate further. Through this guided inquiry activity, they work backwards from problem to causation and learn biological concepts that apply to this context as well as others. Students work in cooperative groups and apply their knowledge to new situations in order to extend what they have learned.

These traveling labs, among others, are provided to schoolteachers within an ongoing science outreach program. Regional high school teachers are invited to attend summer workshops at the University conducted by faculty and TTU/HHMI staff. Through the workshops they explore biology content, are exposed to inquiry-oriented teaching methods and assessment, and learn about the specific traveling labs. Toward the end of each summer, teachers completing the summer workshop, and teachers from past summer workshops, reserve specific labs for use during the upcoming school year. Throughout the school year, the kits are delivered to science teachers in the region for a set period of time, after which they are returned to Texas Tech for maintenance and to replenish lab consumables. The traveling labs are part of a year-round outreach to regional science teachers that includes mini-workshops, summer research programs, and guest lectures.

Assessment of Student Learning, Attitudes, and Behaviors, and Teacher Behaviors

The goals of Experiment 1, a classroom study, and Experiment 2, a survey of teachers, were to carry out a controlled analysis of the effects of active learning at the high school level, using objective test measures and self-report questionnaire data from students, and teaching records and questionnaire data from teachers. We collected data from both students and teachers because we wanted to test whether student learning would improve, and whether students and teachers would change behaviors in an active-learning context. A methodological reason for using objective and self-report measures with students, and activity records and self-reports with teachers, was to seek converging evidence for change, if it occurred, and through these multiple sources of evidence to establish the reliability of the findings. A specific reason for using self-reports in addition to objective measures with students had to do with the importance of epistemological beliefs to learning (Louca, Elby, Hammer, & Kagey, 2004; Roth & Roychoudhury, 2003; Tsai, 2001); we wanted to know what students thought they gained from the instruction and to learn more about their attitudes about learning science.

The experimental conditions in Experiment 1 in which students used the traveling labs are labeled the *active-learning* conditions, and those in which they did not use the traveling labs are labeled the *traditional* conditions. In the traditional conditions, compared to active-learning conditions, we assumed that classroom instruction conformed to the descriptions provided by Roth and Roychoudhury (2003) and consisted of relatively more direct transmission of information, more whole-class noninteractive and interactive activities, seatwork, and cookbook laboratory activities. However, we used the term ‘‘traditional’’ largely as a matter of convenience to refer to the teaching that took place when the traveling labs were not used by teachers, recognizing that our teachers would be at various positions along a traditional-to-inquiry continuum. Teachers’ records of teaching behaviors, which were provided as part of the data, were designed to be sufficient in establishing what teachers did—that is, how ‘‘traditional’’ these behaviors were.

In Experiment 1, we were interested in three kinds of gains related to students’ science learning experiences—content knowledge, knowledge of science process skills, and attitudes toward science. We posed the following questions:

- *Content Knowledge*—Would students achieve higher grades on content tests after active learning compared to traditional classroom instruction? Would they indicate more learning from active learning compared to traditional instruction in self-reports of their learning experiences?
- *Knowledge of Science Process Skills*—Would students demonstrate more knowledge of the nature and processes of science (e.g., forming and testing hypotheses, communicating findings) after being involved in active learning than after traditional classroom instruction? Would they indicate more knowledge of the nature and processes of science and facility in the use of those methods in self-reports after active learning compared to traditional classroom instruction?
- *Attitudes Toward Science*—Would students express more enthusiasm for inquiry and science when they engaged in active learning compared to traditional instruction, as indicated in self-reports of their learning experiences?

At the conclusion of Experiment 1, a questionnaire was developed for Experiment 2 and was offered to all high school teachers who had used the traveling labs during the academic year. The purpose was to independently assess the pedagogical effects that the traveling labs had on a broader sample of teachers. We predicted that some teacher behaviors did not depend on using the traveling labs, as reflected in teacher responses to statements like *When I teach* with *the traveling lab, I try to keep the students motivated*. However, we predicted that other behaviors were more likely when using the traveling labs: *When I teach* with *the traveling lab, students design their own experiments.* Statements like these were organized in advance into contrasts, so that we also predicted that behaviors like designing experiments would exceed behaviors like using cookbook exercises when using traveling labs, and that the converse would hold when implementing traditional instruction.

Method

Experiment 1

Participants. Thirty teachers who had attended a summer training workshop for the traveling labs were invited to participate in this study. Six teachers were selected from a larger pool of volunteers, in order to provide a mix of experienced and less experienced teachers, and urban and rural students. Teaching experience ranged from 2 to 29 years and, of the six schools represented, three were rural and three were urban. In addition, a cross-over data collection design (in which each teacher used both treatment and control materials) was used so that each teacher could serve as her own control to reduce error variation. A total of 408 high-school students participated in the study, as shown in Table 1. Based on self-reported demographic data, there was a nearly equal number of females ($n = 183$; 44.9%) and males ($n = 197$; 48.3%) (28 students, or 6.9%, did not

Table 1
Experiment 1 Design

Teacher	Cohort	Class Size	Microscopy Topic	Biotechnology Topic
A	1	33	Active learning	Traditional
B	1	43	Active learning	Traditional
C	1	73	Active learning	Traditional
D	2	18	Traditional	Active learning
E	2	91	Traditional	Active learning
F	2	150	Traditional	Active learning

respond to this question). Just over two-thirds of the students ($n = 274$; 67.2%) were sophomores; the remaining students were freshman ($n = 85$; 20.8%), or unclassified ($n = 49$; 12%) due to a failure to respond to this question.

Materials. Two traveling labs were chosen for this study. One was on the topic of prokaryotic and eukaryotic cells, called the Microscopy traveling lab, and the other was about DNA structure and function, protein synthesis, and natural selection, called the Biotechnology traveling lab. Teachers who did not use the traveling labs to teach these topics used materials that were available to them through their school for normal classroom instruction.

The Microscopy and Biotechnology traveling labs were developed, field-tested, and used extensively in the regional high schools prior to the beginning of this study. There was one curriculum development team for each lab, consisting of two high school teachers, one Texas Tech faculty member, and an undergraduate student in science education. The teachers in the current study were not on the development teams. The TTU/HHMI Precollege Outreach Director contributed to the development of both labs. The high school teachers carried out most of the curriculum development. Prior to working on the labs, they participated in curriculum development workshops at Texas Tech. After drafting the labs, they met several times during the academic year and summer to fine tune the material. In order to field-test the labs, a cohort of high school teachers were recruited and introduced to the labs, and then implemented them in their classrooms in a pilot run. Students and teachers provided feedback during the first year and changes were made accordingly. The overall process fulfilled the goal of developing curriculum materials through a collaborative process involving practicing teachers and university faculty.

Content tests for the two topics were drafted by one of the experimenters. The questions on the test were designed to serve as evidence of achievement on TEKS (Texas Essential Knowledge and Skills) learning objectives. Some of the questions were adapted or drawn from materials published by Glencoe/McGraw-Hill (2001) and some were original. Items were formatted to resemble the Texas Assessment of Knowledge and Skills (TAKS), a statewide assessment given to grade 10 and 11 students that monitors their mastery of the TEKS objectives. Participating teachers reviewed the questions and provided suggestions, including the modification, addition, or elimination of certain questions. The test was restructured based on their feedback and a general consensus was reached that the questions were a fair representation of what the students were expected to learn during the course of the units, independent of the mode of teaching—active or traditional. Three types of questions were included: factual recall, critical thinking, and process-skills knowledge. To increase the reliability of the classifications, two of the experimenters also classified the questions in the final version as belonging primarily to one of the three possible types, through mutual agreement. Examples of the three kinds of questions can be found in the Appendix. The classification labels were not included when the tests were administered to students. We expected that each teacher would score the tests somewhat differently; therefore, to score all test instruments uniformly, the questions were also rated for complexity and importance by three independent raters familiar with the test content, and were given a weight. The final weightings were the average of the three weights.

A questionnaire consisting of two open-ended questions (1. What are two of the most important things that you learned from this unit? 2. What are two ways that the unit might be changed to help you learn more?[1]) and 23 statements (see Table 4) using Likert-type ratings was constructed to quantify students' perceptions of learning, their attitudes toward the two topics, and their suggestions for improving instruction. The 23 statements were constructed by two of the experimenters, with feedback from two participating teachers, and were then classified as primarily addressing content knowledge, process skills, or attitudes about science, through mutual agreement. Students rated each statement using a 7-point scale, with: 0 = totally disagree, 3 = neutral, and 6 = totally agree.

Log sheets and instructions were also provided to teachers for describing the day-to-day activities when teaching the DNA and cell topics.

Procedure. At the outset of the experiment, the six teachers received a description of the TEKS learning objectives that were to be covered in lessons on the two topics, independent of the learning condition—active learning or traditional. Students received instruction in both topics using a cross-over design of instructional format (active learning or traditional), as shown in Table 1. The two topics were incorporated into the curriculum individually by each teacher. The teachers were asked to maintain detailed records of how each lesson was taught, to allow the experimenters to later describe how the active-learning and traditional teaching methods were implemented. After each topic was completed, students took a test on the material and filled out a questionnaire about their attitudes and experiences with the lessons on that topic. Students completed the open-ended questions in the questionnaire before rating the statements, in order to avoid biasing their open-ended responses. The same tests and questionnaires were given after both types of instruction.

Experiment 2

Participants. Thirty high-school teachers (including, but not limited to, teachers who participated in the classroom study) who had used the Microscopy and/or Biotechnology traveling labs during the academic year were contacted by e-mail and asked to complete a questionnaire. Participation was voluntary. Teachers received a paperback book on teaching as an incentive for their participation.

Materials. There were two versions of each question and three kinds of questions (see Table 8). One version of each question was worded in terms of teaching WITH the traveling labs, and the other version was worded in terms of teaching WITHOUT the traveling labs. The "A" questions probed five behaviors that characterized teaching and learning with traveling labs. The "B" questions probed five contrasting behaviors that characterized traditional instruction and learning, based in part on teachers' logs from Experiment 1 (see Tables 6 and 7) and students' self-reports (Tables 4 and 5). The "C" questions were constructed to reflect behaviors that were equally true for both kinds of instruction. The A, B, and C question types are referred to as *active learning*, *traditional learning*, and *neutral*, respectively.

Procedure. Each teacher received the full set of 30 questions in random order in an e-mail message and rated them using a 5-point Likert-type scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. Completed questionnaires were returned to the experimenters using the e-mail reply function.

Statistical Methods

The primary factors for analysis of the in-class tests were type of instruction (traditional, active) and question type (factual recall, critical thinking, process skills); both were within-subjects factors. Multivariate statistics using SPSS (SPSS, Inc., 2005) GLM procedures were applied to control for threats to the sphericity assumption for factors with more than two levels, based on Mauchly's test of sphericity (SPSS, Inc., 1990). *F*-values adjusted using the Huynh–Feldt correction (SPSS, Inc., 1991) were reported when the sphericity assumption was violated. Otherwise, univariate procedures were applied. Pairwise comparisons were conducted using the error term from the multivariate analyses with the Bonferroni method (Keppel, 1982), which adjusted the significance level for the number of tests to control for Type I error. Ratings for questionnaire statements were evaluated using paired *t*-tests (Box, Hunter, & Hunter, 1978). The frequency data from the open-ended questions were analyzed using the Wilcoxon rank test for two related samples (Conover, 1999). This is a nonparametric test that is appropriate when the data do not follow a normal curve distribution. The alpha level in all tests was set at 0.05, and all tests were two-tailed.

The use of the two topics was motivated by the methodological goal of counterbalancing method of instruction in a within-subjects design (see Table 1), allowing for better control of potential confounding variables. This is a typical goal of a cross-over design. Because students participated in both treatments, we were better able to control for individual differences across conditions. Furthermore, participation in both conditions within the same class should have served to equalize the influence of biasing group membership variables on the effects of interest. Similarly, teachers' participation in both conditions was meant to reduce the influence of individual teacher differences on the observed effects.

Results

Experiment 1

In-class tests. A total of 321 of 408 students (78.7%) completed tests for both topics. Missing data were due largely to absenteeism during the administration of one or both of the tests. Multiple-choice and short-answer questions were scored by a single rater blinded to experimental conditions. Two raters, also blinded to experimental conditions, scored questions with open-ended responses. Initial disagreements on open-ended responses were resolved by discussion, and, if no consensus could be found, then the average of the scores was used as the final score. To examine internal consistency reliability, Cronbach's alpha was computed for the Microscopy test ($\alpha = 0.753$) and for the Biotechnology test ($\alpha = 0.813$). Both values were considered to be in the acceptable range because group comparisons would be made rather than decisions about individual students.

In the initial analysis of test data, we made no assumptions about type of test question (factual recall, critical thinking, process-skills knowledge) and simply computed an overall test score for each student for active learning and traditional learning. Our rationale was to avoid any potential biases associated with our classifications of question types and also in acknowledgment of standard classroom practice in which a teacher constructs an exam with a variety of questions (as we did) and computes an overall test result for each student. We also wanted to know if there were differences when Microscopy versus Biotechnology was used as the active learning lab. To examine these effects, test data were aggregated for the three teachers who taught Microscopy as a traveling lab and Biotechnology through traditional instruction (Cohort 1 in Tables 1 and 2), and

Table 2

Experiment 1 Mean percent test accuracy (SD) by teacher cohort and learning method

Teacher Cohort[a]	Active	Traditional	Mean
1 ($n = 126$)	51.19 (17.21)	45.95 (13.99)	48.57
2 ($n = 195$)	66.88 (13.27)	61.51 (15.92)	64.20
Mean ($N = 321$)	60.72 (16.77)	55.40 (16.97)	

[a] See Table 1 for a specification of teacher cohorts.

the three teachers who followed the converse assignments (Cohort 2 in Tables 1 and 2). The column marginals in Table 2 show that there was a 5.32% advantage for active learning. Test performance on the Microscopy topic ($M = 57.46\%$) is expressed as the weighted average of the left diagonal in Table 2 and performance on the Biotechnology topic ($M = 58.66\%$) as the weighted average of the right diagonal; there was a small 1.2% difference in performance on these topics. The effect due to teacher/student cohorts can be found by examining row marginals. The difference (15.63%) was far greater than that due to the instructional manipulation, demonstrating the benefits of the current design that uses teachers and students as their own controls. A 2 (instruction type: traditional, active) × 2 (teacher cohort) analysis of variance (ANOVA) showed a significant effect for instruction type [$F(1{,}319) = 39.46$, mean square error (MSE) $= 109.18$, $p < 0.001$] and for teacher cohort [$F(1{,}319) = 108.38$, $MSE = 344.74$, $p < 0.001$], but not for the interaction of the two factors [$F(1{,}319) = 0.01$, $\mathrm{MSE} = 109.18$, not significant (NS)]. These results confirm that active learning produced a significant difference in student performance. They also showed that active learning was equally effective in the Microscopy and Biotechnology labs, based on the nonsignificant interaction effect.

In a second analysis, we computed students' mean accuracy for each question type to determine whether active learning improved accuracy for each type. Test performance is summarized in Table 3. A multivariate analysis using instruction type (traditional, active) and question type (factual recall, critical thinking, process-skills knowledge) as factors indicated a significant violation of the sphericity assumption for question type and for the interaction of instruction type and question type, thus adjusted F-values are reported. There was a main effect for instruction type [$F(1{,}320) = 34.78$, $MSE = 457.57$, $p < 0.001$], for question type [adjusted $F(1.85, 592.14) = 62.60$, $MSE = 342.69$, $p < 0.001$], and for the interaction of the two factors [adjusted $F(1.56, 498.68) = 4.29$, $MSE = 543.53$, $p < 0.03$]. The two effects of interest here were the main effect for instruction type, which showed that students gained significantly more through active learning, and the interaction, which showed that the advantage of active learning over traditional instruction differed by question type. The mean accuracy advantage of 6.89% for factual recall questions under active-learning versus traditional instruction was significant, as was the 8.39%

Table 3

Experiment 1 Mean percent correct (SD) on in-class tests by instructional method and question type, and effect size (d)

Method	Factual Recall	Critical Thinking	Process Skills	Mean
Traditional	55.02 (21.58)	57.00 (22.21)	63.65 (27.69)	58.56
Active learning	61.91 (19.52)	58.97 (20.48)	72.04 (29.66)	64.31
d[a]	0.32	0.09	0.30	

[a] d estimates effect size as: $(M_{\text{active}} - M_{\text{traditional}})/SD_{\text{traditional}}$.

advantage for process-skills questions, based on a critical difference of 4.46. The 1.97% difference in accuracy for critical thinking questions favored active-learning instruction; however, it did not exceed the critical difference for significance.

Questionnaire statement ratings. Twenty-five fewer students completed questionnaires than tests due to one teacher's inability to administer the questionnaire to one of her classes following a Biotechnology test. In addition, a number of students failed to provide ratings for all the statements. In the first analysis of statement ratings, only the data from students who completed all ratings were analyzed. For this, a mean rating across all statements was computed for each student for each type of instruction. The mean rating of 3.61 ($SD = 1.02$) for students responding to the questions after completing active learning was significantly higher than the mean rating of 3.37 ($SD = 1.10$) after completing traditional instruction, based on a paired t-test [$t(230) = 3.39$, $p < 0.001$]. Thus, in students' overall responses to these statements, there was a significant preference for active learning.

In follow-up analyses, paired t-tests were carried out for each statement, using data from all students who completed the relevant pair of ratings. The results are summarized in Table 4. For *Knowledge Acquisition*, nine of nine mean ratings made after active learning exceeded the paired mean ratings made after traditional instruction, and five of nine (56%) differences in means achieved statistical significance. It was noteworthy that students more strongly affirmed the statement "I applied critical thinking skills" following active learning, indicating that they perceived that more critical thinking had taken place through active-learning instruction compared to traditional instruction. This is noteworthy because the in-class test scores did not show a statistical advantage for critical thinking skills with active learning. For *Process Skills*, eight of nine means favored active learning over traditional instruction and, of these, five (56%) differences statistically favored active learning. For *Attitudes Toward Learning Science*, four of five means favored active learning, and two of these differences were statistically significant. It is worth noting that the statements that did not achieve a statistical advantage were broadly phrased (e.g., "I like learning"), and that the two statements that did achieve significance were more directly related to the form of instruction that the student had received (i.e., "I enjoyed learning this material"; "I am interested in careers in this topic area"). Overall, there was a general trend across all statements, as well as significant effects for the majority of statements, indicating that students favored active learning.

The most important things learned. An open-ended question asked students to list the two most important things that they learned in the completed unit. To classify these responses, two experimenters previewed the responses and agreed on the 11 categories listed in Table 5. Each category was further classified as either a knowledge comment, a method comment, or relating to attitudes toward learning science. Each response was classified by two independent evaluators, who were blinded to students' experimental conditions. The initial reliability of the classifications, measured as a percentage of agreement, was 95%. All initial disagreements were resolved through discussion; when both viewpoints were deemed tenable, a third evaluator was called upon as an arbitrator to classify the item in question. The majority assessment was used as the final classification. Total frequencies for each type of response, for the two forms of instruction, are shown in Table 5, with representative examples provided in the footnote. The largest difference in frequencies between traditional instruction and active learning relates to *Lab Methods*—when asked about the most important things that they learned, students more often mentioned a lab skill after active learning than after traditional instruction. Participants also generally had more to say following active learning and made significantly more comments about what they learned compared to traditional instruction (Wilcoxon $Z = -3.59$, $p < 0.001$; frequencies for *Negative comments* (#9 in Table 5) were excluded from this analysis).

Table 4
Experiment 1 Mean ratings (SD) for questionnaire statements by instructional type, paired t-test values, and probability (p) values

Statement	*N* Pairs	Traditional	Active Learning	*t*-Value[a]	*p*
Knowledge acquisition					
(4)[b] The materials were easy to use	289	3.77 (1.44)	3.87 (1.50)		
(5) The materials helped me learn	290	3.68 (1.42)	3.86 (1.43)		
(6) I used a variety of learning methods	290	3.44 (1.65)	3.72 (1.43)	−2.61	0.010
(10) I applied critical thinking	294	3.76 (1.59)	4.02 (1.50)	−2.72	0.007
(11) I used scientific problem-solving	290	3.57 (1.66)	3.62 (1.56)		
(12) I used biology models	291	3.54 (1.81)	3.84 (1.54)	−2.49	0.013
(13) I thought of new questions	293	2.87 (1.72)	3.02 (1.74)		
(14) I asked new questions	294	2.84 (1.70)	3.08 (1.72)	−1.97	0.050
(23) Overall, I learned a lot by doing these activities	295	3.92 (1.61)	4.14 (1.65)	−1.94	0.053
Process Skills					
(8) I carried out hands-on investigations	293	3.22 (1.90)	3.75 (1.76)	−4.57	0.0002
(9) I used new tools	292	3.19 (1.90)	4.62 (1.64)	−11.29	0.0001
(15) I formed hypotheses	293	3.36 (1.68)	3.46 (1.67)		
(16) I designed experiments	291	2.41 (1.85)	2.68 (1.88)		
(17) I selected appropriate equipment	291	3.08 (1.83)	3.43 (1.71)	−2.86	0.005
(18) I collected data	295	4.11 (1.63)	4.18 (1.49)		
(19) I summarized data	294	3.69 (1.64)	3.93 (1.52)	−2.10	0.037
(20) I graphed data	293	3.27 (1.84)	3.27 (1.98)		
(21) I communicated my findings	294	3.39 (1.66)	3.65 (1.59)	−2.39	0.017
Attitudes Toward Learning Science					
(1) I enjoy science	296	3.18 (1.53)	3.20 (1.64)		
(2) The material was important	296	3.58 (1.50)	3.66 (1.53)		
(3) I enjoyed learning this material	280	2.88 (1.52)	3.30 (1.60)	−4.01	0.0002
(7) I am interested in careers in this topic area	294	1.76 (1.85)	2.00 (1.84)	−2.08	0.038
(22) I care about learning	290	4.57 (1.65)	4.49 (1.64)		

[a] *t*-values and associated probabilities are shown only if the difference between means is significant at ≤ 0.05. No adjustments were made for the number of tests. The significance levels shown allow the interested reader to adjust the alpha level as appropriate (e.g., through a Bonferroni method).

[b] Numbers in parentheses indicate the position of the item in the questionnaire administered to students. Ratings are based on a 7-point scale, with $0 =$ as totally disagree, $3 =$ neutral, and $6 =$ totally agree.

Table 5
The most important things learned—frequencies of students' responses by category and type of instruction

Response Category	Traditional	Active Learning
Knowledge comment		
1. Structure of cells/DNA	128	105
2. Functions of cells/DNA	71	29
3. Bacteria/mutations(oddities)	29	68
4. General principles	10	9
5. Indirect applications	12	17
6. Functional other (how-to)	2	7
Process Skills comment		
7. Scientific method	7	4
8. Lab methods	12	95
Attitudes Toward Learning Science		
9. Negative comments	10	3
10. Positive comments	25	21
11. Other	4	3

Examples of each type of statement: 1. I learned the parts of the cell; 2. I learned what mitochondria do in a cell; 3. I learned how antibodies affect bacteria; 4. I learned that cells are everywhere; 5. Law enforcement can do a lot with DNA; 6. I learned to draw and use a concept map; 7. I learned to form hypotheses; 8. I learned how to use a microscope; 9. I didn't learn anything; 10. I learned that I want to be a scientist; 11. I learned a lot about biology.

Teacher behaviors. At the outset of the study, teachers were asked to record their class activities and account for all the time spent in teaching the Microscopy and Biotechnology lab topics as a way to verify instructional treatment and document the differences in teacher behaviors. The completed logs included information about the form and content of instruction, including information about TEKS objectives, worksheets, activities, and other assignments; the time spent; and specific comments, including those about difficulties that arose during the lessons. An experimenter who was blinded to the experimental conditions categorized the entries in the teacher logs, relying primarily on eight predetermined labels used by the teachers to catalogue their daily in-class activity. The rater deferred to the categorization of the teacher and only appealed to the descriptions offered when the teacher label was ambiguous. Where combinations of activities were reported (e.g., lecture/lab), that combination was retained for the purpose of categorization.

Teachers spent an average of 17.67 days (range 10–31) on active-learning instruction and 19.00 days (range 8–56) on traditional instruction. Table 6 summarizes the average number of typical kinds of activities per class, as a function of instruction type. The means indicate that,

Table 6
Mean number of teacher-reported activities per class meeting by instruction type

Activity	Traditional	Active Learning
Homework	1.00	0.33
Labs	2.33	3.33
Worksheets	2.67	1.17
Activities	2.83	3.33

A *worksheet* is defined as a pen-and-paper task. *Activities* are basically paper labs (drawing, cutting out, coloring, manipulating) and are more interactive than worksheets. In *labs* students interact directly with the phenomenon being investigated (e.g., looking at cells through a microscope) and collaborate with other students.

within the framework of active learning, there were more labs and activities, and less homework and fewer worksheets, compared to traditional instruction. Thus, although teachers spent comparable time implementing the two instructional types, there were notable differences in what they did during implementation.

Table 7 shows a finer breakdown of classroom activities for categories containing 30 minutes or more. A mean total of 1019 minutes (range = 340–2520) was allocated to traditional instruction and 1044 minutes (range = 700–1395) to active learning. Given the total number of days per topic reported by teachers and the length of class periods, 98.34% of expected class time was accounted for in the table, indicating that teachers were quite diligent in keeping a detailed record of their activities. For the first four categories in Table 7, which include lecture but no lab, more time was allocated when the instruction was traditional (229 minutes) compared to active learning (130 minutes). For the five categories that include lab and no lecture, there was a reversal—less time was allocated when the instruction was traditional (152 minutes) compared to active learning (302 minutes). These data, in conjunction with those in Table 6, portray the traditional classroom as involving relatively more lecture, homework, and worksheets, and the active-learning classroom involving relatively more lab work and fewer worksheets.

Experiment 2

Teacher survey. Of the 30 teachers who were asked to complete a questionnaire, 16 teachers (53%) submitted responses. Responses to individual questions are summarized in Table 8.

Table 7
Mean teacher-reported total class time (in minutes) for activities by instructional type

Activity	Traditional	Active Learning
Lecture	90.50	84.17
Lecture/discussion	57.50	38.33
Lecture/independent practice	50.83	7.50
Lecture/independent practice/guided practice	30.00	0.00
Lecture/lab	0.00	41.67
Lab	129.17	178.50
Lab/guided practice	15.00	33.83
Lab/independent Practice	7.50	30.00
Lab/cooperative learning	0.00	30.00
Lab/discussion	0.00	29.17
Independent practice	135.50	98.50
Independent practice/cooperative learning	74.17	61.50
Independent/guided practice	35.00	22.50
Guided practice	42.50	45.00
Cooperative learning	154.17	140.83
Presentations	32.50	25.83
Review	34.67	10.83
Test	64.67	63.83
Other	65.00	102.17
Total	1018.68	1044.16

Lecture—one-sided pedagogy. *Discussion*—used when student participation or discussion took place. *Cooperative learning groups*—any activity performed by at least two students working collectively. *Independent practice*—work done individually by the student and typically incorporated reading, worksheets, and activities. *Guided practice*—work done with the instructor walking the student through the relevant processes. *Lab work*—any work consisting of a substantial "hands-on" component. *Other*—video presentations or individual "catch-up" days as well as other atypical teaching methods (e.g., slide presentations, etc.); and classifications with <30 minutes of total time.

Table 8
Traveling lab teachers' mean (SD) ratings for With and Without versions of questionnaire statements

Contrasts and Questionnaire Items	With	Without
Contrast 1: Design own experiments vs. cookbook-type exercises		
A. When I teach_the traveling lab, students design their own experiments	3.56 (0.81)	3.06 (0.93)
B. When I teach_the traveling lab, students learn from cookbook-type exercises	2.44 (0.89)	3.38 (1.02)
Contrast 2: Small-group discussions vs. teacher-directed discussions		
A. When I teach_the traveling lab, students learn through small-group discussions	4.31 (0.48)	3.94 (0.68)
B. When I teach_the traveling lab, students learn through teacher-directed discussions	3.06 (1.18)	3.94 (0.25)
Contrast 3: Process skills vs. facts		
A. When I teach_the traveling lab, students practice process skills	4.19 (1.17)	3.94 (0.57)
B. When I teach_the traveling lab, students learn science facts	4.19 (0.40)	4.06 (0.25)
Contrast 4: Hands-on experiences vs. independent practice		
A. When I teach_the traveling lab, students get hands-on experiences	4.81 (0.40)	3.81 (0.83)
B. When I teach_the traveling lab, students get independent practice	3.94 (0.93)	3.94 (0.68)
Contrast 5: Well-defined vs. undefined roles in learning groups		
A. When I teach_the traveling lab, students have well-defined roles in cooperative learning groups	4.00 (0.89)	2.88 (1.15)
B. When I teach_the traveling lab, students have undefined roles in learning groups	2.38 (1.02)	3.00 (1.10)
Neutral statements		
C. When I teach_the traveling lab, students are provided with learning objectives	4.38 (0.50)	3.50 (1.03)
C. When I teach_the traveling lab, I prepare students for the science portion of the TAKS	4.31 (0.60)	4.44 (0.63)
C. When I teach_the traveling lab, students receive constructive feedback on their performance	4.25 (0.45)	3.75 (0.68)
C. When I teach_the traveling lab, students receive individual assessments	3.88 (0.81)	4.13 (0.72)
C. When I teach_the traveling lab, I try to keep the students motivated	4.13 (1.02)	4.06 (0.44)

N = 16. The WITH version of "*A*" statements is oriented to active learning, and the WITHOUT version of "*B*" statements is oriented to traditional instruction; "*C*" statements are neutral with respect to type of instruction (see text). Ratings are based on a 5-point Likert-type scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

Analyses were carried out using paired t-tests (Box et al., 1978). The mean for Neutral-WITH questions ($M = 4.19$, $SD = 0.37$) was marginally higher than Neutral-WITHOUT questions ($M = 3.98$, $SD = 0.33$), favoring active-learning instruction for these pedagogical goals, although, as predicted, the difference did not reach statistical significance [$t(15) = 2.04$, $p = 0.059$]. The mean for active-learning-WITH questions ($M = 4.18$, $SD = 0.43$) was significantly higher than active-learning-WITHOUT questions ($M = 3.53$, $SD = 0.52$) [$t(15) = 4.30$, $p < 0.001$], and significance was reversed for traditional-learning questions, with ratings for WITHOUT versions ($M = 3.66$, $SD = 0.31$) exceeding those of WITH versions ($M = 3.20$, $SD = 0.49$) [$t(15) = 3.43$, $p < 0.004$], as predicted. Tests of the contrasts show that ratings for WITH versions of active-learning statements ($M = 4.18$, $SD = 0.43$) exceeded the ratings of WITH versions of traditional-learning statements ($M = 3.20$, $SD = 0.49$) [$t(15) = 5.76$, $p < 0.001$], as predicted; ratings for WITHOUT versions of traditional-learning statements were higher ($M = 3.66$, $SD = 0.31$) than WITHOUT versions of active-learning statements ($M = 3.53$, $SD = 0.52$), but the difference did not reach significance [$t(15) = -0.89$, NS].

Discussion

A major hypothesis in this study was that active learning would produce measurable advantages in test and questionnaire performance, compared to traditional instruction. Results in Experiment 1 provided several convergent pieces of evidence to support that hypothesis. An overall analysis of test data showed a significant advantage of active learning over traditional instruction (see Table 2). A second analysis showed significant effects specifically for factual recall and knowledge of process skills (see Table 3). An overall analysis of questionnaire ratings on statements about knowledge acquisition, process skills, and attitudes toward learning science, as well as a majority of the specific statements in the questionnaire, significantly favored active learning over traditional instruction (see Table 4). When asked about the most important things learned, students gained content knowledge (e.g., *structure of DNA*) when instruction was traditional and when it was active; however, they appeared to gain more in terms of lab methods when learning was active (see Table 5). The advantages for active learning were modest, but they were reliable and consistent.

A second hypothesis was that teachers would shift their behaviors toward student-centered learning when using an active-learning curriculum. This hypothesis was also supported. Qualitative data (see Tables 6 and 7) suggest that an active-learning curriculum led teachers to provide students with relatively more lab work and fewer worksheets compared to traditional teaching, which involved relatively more lecture, homework, and worksheets. The emphasis on active-learning activities over lecture and independent practice in the teacher logs was consistent with a constructivist approach (Roth & Roychoudhury, 2003) to teaching science and supported our hypothesis that inquiry-oriented teaching would require teachers and students to change their behaviors (cf., Bybee, 2000). To clarify and provide a statistical test of the differences in the two kinds of instruction, an additional assessment was conducted with traveling-lab teachers in Experiment 2. These results show that the traveling labs changed the way the teachers perceived how they taught science. Their perceived behaviors reflected the hands-on inquiry-oriented aspects of the active-learning curriculum. When teachers used active learning, instruction was consistent with the "new science curricula" identified by Shymansky, Kyle, and Alport (1983), in biology, consisting mostly of BSCS programs: "emphasize the nature, structure, and processes of science, integrate laboratory activities as an integral part of the class routine, and emphasize higher cognitive skills and appreciation of science" (p. 388). Ironically, without the active-learning curriculum, there was a significant shift toward 1950s-style traditional instructional methods as defined by Shymansky et al., who further noted "emphasize knowledge of scientific facts, laws, theories, and applications, and use laboratory activities as verification exercises or as secondary applications of concepts previously covered in class" (pp. 388–389).

The impact of the traveling-labs curriculum on learning is comparable to other studies reported in the literature. The effect sizes reported in Table 3 are comparable to those reported by Shymansky, Hedges, and Woodworth (1990, Table IV) for high school biology curricula. Although the fit of the two sets of categories is only approximate, it is informative that the mean effect size for *Achievement* was 0.43 compared to 0.32 for *Factual Recall*, but that *Process* achieved a mean of only 0.22 and 0.30 for *Process Skills*, according to Shymansky et al. (1990) and Table 3, respectively. The average effect size of 0.24 in this study is comparable to the mean effect size of 0.25 for active teaching methods in biology, and slightly lower than the mean effect size of 0.29 for active teaching methods in high school, according to Wise and Okey (1983). Although the use of posttests allowed us to fulfill our goal of comparing the relative effectiveness of active and traditional pedagogies, future studies should include pretest data in order to estimate effect sizes over the entire course of instruction, as in the inquiry-based curricula for grades 6–8 science studied by Marx et al. (2004).

In the metaanalysis by Shymansky et al. (1990) and here, students were weak in critical thinking: the mean effect size for *Analytic* according to Shymansky et al. was −0.05, compared to 0.09 for *Critical Thinking* in the present study. We speculate that it is difficult for students to gain skills in critical thinking, and that development of these skills may depend on attaining a certain amount of content knowledge and experience with the phenomena in the domain through experiments and other hands-on methods. Students develop confidence in inquiry through a "deep foundation of factual knowledge" (National Research Council, 2003, p. 14–15) organized into a conceptual framework that facilitates retrieval and application. In spite of students' weak test performance on critical thinking questions, they perceived that their critical thinking had been enhanced to a greater extent when studying a topic within the traveling-lab curriculum. That effect in the survey data along with the other advantages associated with the traveling-lab experience are consistent with our hypothesis that content knowledge and inquiry-based active learning underlie the development of critical thinking.

Although the data presented herein provide reasonable support for the hypotheses, they are only modestly strong and in several ways puzzling and disappointing. The active-learning materials were designed to develop critical thinking, but there was only suggestive evidence of student gains. Furthermore, students' questionnaire ratings after active learning (see Table 4) were noticeably low on points associated with active learning; for instance: *I used scientific problem-solving*; *I thought of new questions*; *I formed hypotheses*; and *I designed experiments*. These questions tap into facets of inquiry-based active learning that distinguish it from teacher-centered instruction, and we expected the ratings to be more strongly associated with active learning. Similarly, in their perceptions of their greatest gains (see Table 5), students rarely mentioned learning the scientific method or general principles and concepts after active learning.

Methodologically, there were also several limitations to the present studies. To cover the same content in all conditions, learning objectives were communicated to the participating teachers prior to the beginning of the study. Teachers kept a record of what they did in the classroom, but typically communicated only the gist of their activities, and did not always indicate the objectives that were being covered. Thus, it is difficult to say for certain that content was adequately covered in the six classrooms in this study. In a related sense, the in-class tests were designed to address the learning objectives. However, they were not adequately field-tested to assure their reliability and validity. Furthermore, a qualitative reading of the teachers' logs suggests that the experimental treatments were not as rigorously implemented as we would have wished. In the traditional-instruction situation, four of the six teachers did lean toward what is considered traditional instruction. One teacher, however, incorporated sequencing strategies that were more inquiry-oriented, and one teacher mixed strategies, following a more traditional approach at times and switching to a more inquiry-oriented approach in other instances. In the active-learning conditions, five of the six teachers followed an inquiry-oriented sequence of instruction. The remaining teacher followed this basic format but omitted the lab activity that provided students an opportunity to design and carry out an experiment, one of the key components of the active-learning condition. Thus, it is difficult to assure that all teachers carried out the intended treatments. Other concerns include the limited sampling in these experiments. It is also possible that teacher selection factors distorted the effects. The teachers who volunteered to participate in this study were supporters of the TTU/HHMI program, with program involvement ranging from 2 to 12 years. Perhaps a sense of loyalty to the program biased them toward the traveling-labs curriculum. A way to address several of these concerns is through a replication of these experiments with a broader sampling of teachers and students and additional control conditions. Finally, the test format that we used in this classroom study is widely accepted by teachers and administrators and readily communicates outcomes in terms that are easily understood, but it provides limited information about students' development. The form of assessments can be extended in future studies to include performance assessments in which we may observe students carrying out target skills, evaluate the products that students create, and test them on novel problems.

The results from this study raise the broader question of why inquiry-based active learning makes a difference. One possible reason is because the physical manipulations and outcomes require students to explain observations in a way that does not occur in typical classroom instruction. In a lecture format, students may be called upon to explain a phenomenon in response to active teacher questioning (Wise & Okey, 1983). However, as Glasson (1989) suggested, hands-on activities "promote peer interaction where students are free to argue, make mistakes, and challenge each other" (p. 129). Teacher demonstrations also differ from hands-on labs. The teacher's close control of the outcomes can limit the number of conflict situations that promote learning (Glasson, 1989). Thus, the hands-on experiences are a medium for evoking the "minds-on" experiences recommended in the *National Science Education Standards* (National Research Council, 1996). Interacting with materials also leads to positive attitudes, whereas passive listening leads to boredom and more negative attitudes (Ajewole, 1991).

A science curriculum should lead students to raise questions about their world, and should equip them with the means to reason about these questions, explore them through empirical methods, and draw conclusions and develop explanations from data. "Research gives students a sense of empowerment over a body of knowledge and instills in them the confidence to succeed" (National Research Council, 2003, p. 17). The process of discovery is authentic science; it does not reinforce an "illusion of certainty" (Bencze & Hodson, 1999, p. 522) through which students believe that discovery in science is unproblematic and leads to definite proof. Young students must develop an appreciation for the complexity of the world around them. Not all students are bound for post-secondary science programs, but nonetheless, need to comprehend the process and nature of science, its benefits, and its limitations, in order to participate as responsible citizens. The major implication of this study is that active-learning–based laboratory units designed and developed collaboratively by high school teachers and university faculty, and then used by high school teachers in their classrooms, can lead to increased use of student-centered instructional practices as well as enhanced content knowledge and process learning for their students.

Notes

[1] This question was ultimately dropped from the analyses, because, for many of the responses, it was not clear whether the participant intended a positive comment or a negative comment, which prohibited reliable interpretation of the intended meaning.

Appendix

Sample test questions (adapted from Glencoe/McGraw-Hill, 2001):
Factual Recall question:

An RNA molecule is composed of a series of _.

a. Polysaccharides
b. Ribose molecules
c. Nucleotides
d. Uracil molecules

Critical Thinking question:

Bacteria that grow in the presence of the antibiotic, penicillin, develop holes in their cell walls. Which of the following explains why penicillin is effective against some bacteria?:

a. Water enters the holes in these bacteria and causes osmotic rupture.
b. Penicillin causes the flagella to become inactive.
c. The pili of the bacteria puncture the penicillin.
d. Penicillin produces oxygen, which kills any kind of bacteria.

Process Skills question:

One hundred pregnant women and their developing fetuses were monitored over the course of pregnancy in a study designed to compare the average weight gain of a woman during pregnancy with the average weight gain of the developing fetus. This is shown in Table 1 and 2. (Note that the weight gain of the developing fetus is its actual weight.)

Graph the data for the mother and the fetus on the grid in Figure 2-2. Decide on a method to distinguish the sets of data. Be sure to label each graph.

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