Inquiry Learning and the Science Fair

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Abstract

Surveys from 617 high school science fair participants (2004-2008) provide insight into four aspects of their teachers' instruction: inquiry learning, direct instruction, science as real-life, and science as authority. These original scales offer a valuable resource for large-scale observational studies and teacher self-reflection. Higher awards were associated with teachers' use of inquiry-based learning and emphasis on real-life applications, while lower awards correlated with direct instruction and an emphasis on science as an authority. With mostly medium-to-large effect sizes and p-values less than .0005, these findings were consistent across competition levels and analysis methods. Results contribute to the active-versus-passive child debate in developmental psychology and inform science educators on effective project-based learning strategies.

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Do we develop as passive recipients of external forces, or do we develop by actively constructing the person we will become? The active-versus-passive child debate divides overarching theories within developmental psychology – notably Piagetian Theory and Information Processing. Despite different accounts of mechanisms underlying development, both theories view children's scientific reasoning as crucial developmental milestones. Consequently, each approach offers teachers pedagogical recommendations, especially for the subject of science. The present study examines whether instructional methods based on each theory predict different achievement in adolescent science fair participants.

Piagetian Theory offers an account of an active child, who takes experiences and struggles through seeming contradictions with their prior understanding (disequilibrium) to build their own understanding (constructivism) (e.g., Piaget, 1954). Information Processing offers accounts of a relatively passive child who absorbs experience, detects patterns, and acquires expertise (e.g., Liben, 1987; Siegler, 1986). Whereas Piagetian Theory construes our *struggle* with experience as paramount, Information Processing construes *data* from experience as paramount.[1] The pinnacle of developmental achievement in Piagetian Theory is the Formal Operations stage of thinking abstractly and systematically like a scientist (hypothetical-deductive reasoning) (e.g., Martorano, 1977). From its earliest roots, Information Processing theory has sought to model the scientific discovery process as the pinnacle of human creative achievement (e.g., Langley, Simon, Bradshaw, & Zytkow, 1987). Given the importance both theories place

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[1] Portraying the child as unequivocally active in Piagetian Theory and unequivocally passive in Information Processing is an over-simplification. Constructivist Piagetian accounts acknowledge the importance of more passive learning (e.g., Liben, 1987) and several Information Processing models have been construed with an active child (e.g., Mueller & Grobman, 2003; Siegler & Ellis, 1996).

on scientific achievement, it is not surprising that they offer practical advice on teaching children science; Piagetian Theory suggests Inquiry Learning while Information Processing suggests Direct Instruction.

From a Piagetian perspective, what matters most is children's struggle with scientific concepts because acquiring scientific reasoning is acquiring a way of thinking in everyday life (e.g., Piaget, 1969/1971). Inquiry learning has students figure things out for themselves. The teacher provides an over-arching question, acts as a resource, and provides structural support necessary for students to invent the concept. Some research supports inquiry learning. For example, high school juniors with a year of inquiry-oriented chemistry became seniors in physics who designed more complex studies with more quantitative hypotheses and fewer confounds than a control group of students from a typical chemistry class (Hofstein, Shore, & Kipnis, 2004). This study involved only two classrooms, so idiosyncratic differences other than instructional approach remain viable alternative interpretations of the results.

From an Information Processing perspective, what matters most is efficiently getting accurate knowledge into the child's mind, with the correct relationships (semantic network) and with minimal distraction or errors (focused attention, few encoding errors, low working memory demands). Through direct instruction, expert teachers provide novice students with authoritative knowledge. Quality lectures offer students well-organized information without the risk of misinterpretation that comes from, for example, accidentally encoding arbitrary or incorrect details from a self-produced experiment (e.g., Kirschner, Sweller, & Clark, 2006). Some research supports direct instruction. For example, 3rd and 4th grade children were either directly instructed on designing experiments without confounds (control of variables strategy) or left completely on their own to discover the scientific approach in a single-session experiment.

While direct instruction helped students learn and apply their skill to evaluating another's science fair project, inquiry learning failed abysmally. Consistent with the theory, students who learned to control variables transferred that knowledge with equal skill regardless of what kind of instruction led to that knowledge (Klahr & Nigam, 2004). This study involved only a brief lesson with no adult support for inquiry on a skill that is a hallmark achievement of reasoning that children do not typically reach until adolescence. As such, interpreting the results as primarily about researcher's methodological decisions rather than about children's development remains a viable alternative interpretation.

The present study associates children's actual months-long instructional experiences, across many different classrooms in many different schools, with an authentic scientific reasoning experience – achievement in a regional or state science fair. Students consider the science fair a fun opportunity to learn new things. Moreover, they consider learning about the scientific process a special benefit of science fairs that is not central to other scientific competitions like Science Olympiads (Abernathy & Vineyard, 2001).

High schools hold science fairs and students who score highest compete in a regional fair against the top-performing students from other schools in the county. Those who score highest at the regional fairs compete in a state fair against the top-performing across the state. Those who score highest in the state fair compete against other state fair top-performers from other states and other countries at the international science fair. I anticipated the regional fair would produce the strongest associations because student science fair projects reflect the best performance from each teacher; since state fair participants placed well at the regional fair, the range of achievement is smaller.

From a constructivist perspective, I hypothesized that: *better* science fair projects come from students who learn science through *inquiry*, and with teachers who present science as part of *real-life*. Furthermore, *worse* science fair projects come from students who learn science through *direct instruction*, and with teachers who present science as an *authority* of skills and concepts to be mastered.

Method

Ninety-two (92) high school students participating in a recent regional or state science fair completed a survey about their forty-two (42) science teachers' instructional approaches. I created teacher ratings by averaging each student's z-scored ratings and linearly transforming the result so that the teacher's items had the same average and standard deviation as the raw data. This procedure ensured each student's answers had equal weight. Teacher scores were matched to archival data of high school student participants from the East Baron Rouge Parish and Louisiana State 2004 to 2008 science fairs. This maximized the number of students providing data and separated individual student's perceptions of their teacher from a consensus view of each teacher. Students completing surveys were mostly first-year and sophomore (74%) Caucasian (64%) girls (79%) (mean age = 16.15 ± 0.93). The 617 students in the archive were mostly first-year and sophomore (75%) girls (68%) (mean age = 15.16 ± 1.00). Teachers were mostly Caucasian (76%) women (74%).

Students provided 7-point frequency scale ratings across questions organized into nine domains (Appendix A). For each domain students answered one item from each of four teaching approaches (Appendix B). Inter-item reliability was sufficient for all scales except science-as-authority (table 1). Exploratory factor analysis suggests those questions were of two types: (1) teacher's use of authority while instructing and (2) teachers' requirement that students learn authority sources in detail. Below I analyze the entire scale; further analysis revealed that the associations strengthen with items emphasizing teacher authority (factor 1) and weaken but remain significant with items emphasizing science as an authority (factor 2).

Results

Within each project category (e.g., physics), science fairs awarded one 1^{st}, two 2^{nd}, three 3^{rd}, and four 4^{th} place awards. This dataset included 12% 1^{st}, 20% 2^{nd}, 30% 3^{rd}, 21% 4^{th}, and 28% "5_{th}" place awards (i.e., all projects not placing were coded 5 for "5^{th}" place). Preliminary correlations[2] with award place suggest younger children produced better projects at the regional fair, $r = +.128$, $p < .05$, but older students produced better projects at the state fair, $r = -.203$, $p < .0005$. There may be greater enthusiasm among younger students but greater expertise among students who continue with the fair into their later high-school years. Girls produced better projects at the regional fair, $r = +.159$, $p < .05$, but were equal to boys at the state fair, $r = +.021$, p = ns. This gender difference may correspond with anecdotal observation a disproportionate number of projects presented with less conscientiousness (e.g., neat writing, practiced oral presentation) were by boys. Since these projects failed to advance to the state fair, the gender difference disappeared. Private school students produced better regional fair projects, $r = -.408$, $p < .0005$, but public-school students produced better state science fair projects, $r = +.162$, $p < .0005$. The benefit for private schools may be due to social class. Prior research suggests that students with more resources perform better at the science fair (Bellipanni, 1994). Since survey questions were phrased in neutral to positive language, I examined average teacher rating across

[2] Positive correlations indicate a hindrance since lower place (e.g., 1_{st}) represents better performance. Girls were coded as 0 and boys as 1. Public schools were 0, private schools were 1, and publicly funded schools with admission standards were 0.5 (i.e., charter, laboratory).

all items as a proxy for positive views of students toward their science teacher. Students of teachers perceived positively did no better at the regional fair, $r = -.085$, p = ns, but oddly this positive view of their teacher hindered performance at the state level, $r = +.168$, $p < .005$.

To test each hypothesis, I conducted two analyses. First, to maximize external validity and use all available data with whatever confounds naturally exist, I conducted zero-order correlations of place and each sub-scale (regional n=276, state n=341). Second, I sought to maximize statistical control for confounds and idiosyncratic student survey responses by conducting partial correlations controlling for age, gender, school kind, and average survey response with only students whose teacher was rated by at least 3 different students (regional n=195, state n=119). Figures 1 to 4 summarize results and graphically depict the zero-order correlations at the regional fair.

Students with teachers who fostered more inquiry learning placed better at the regional science fair, whether measured with the zero-order or partial correlation. They placed better at the state science fair when measured with a partial correlation (figure 1).

Students with teachers who emphasized how science is part of real life placed better at the regional science fair, whether measured with the zero-order or partial correlation. They placed better at the state science fair, whether measured with the zero-order or partial correlation (figure 2).

Students with teachers who extensively use direct instruction placed no better or worse at the regional or state science fairs when measured with zero-order correlations. This is likely a ceiling effect as the typical teacher was rated with 6 on a scale from 1 to 7. The high mean corresponds with prior work indicating teachers' use of inquiry does not mean a free-for-all with nominal teacher guidance, but teachers' careful selection of moments for scaffolding and exposition (Hmelo-Silver, Duncan, & Chinn, 2007). Since the partial correlation controls for the other scales, a higher direct instruction score effectively becomes a measure of direct instruction being more heavily endorsed than the other scales. As such, students with teachers who disproportionately used direct instruction placed worse at the regional and state science fair (figure 3).

Students with teachers who emphasized how science is a source of authority placed worse at the regional fair, whether measured with the zero-order or partial correlation. They placed worse at the state science fair when measured with a partial correlation (figure 4)

Discussion

Consistent with hypotheses, *better* science fair projects came from students who learned science through *inquiry*, and with teachers who presented science as part of *real-life*. Furthermore, *worse* science fair projects came from students who learned science through *direct instruction*, and with teachers who presented science as an *authority* of skills and concepts to be mastered. Results were consistent when measured at two levels of science fair competition and regardless of the kind of correlational analysis. All but one of the 12 significant results were significant at $p < .0005$; two non-significant relationships were likely ceiling effects because of the ubiquity of direct instruction. Two associations failing to reach significance were at the state fair, where variation between projects is reduced, but the corresponding analyses chosen to control variation revealed the expected results.

Teaching approaches accounted for 9.4% to 22.0% of the variation in science fair performance as measured using r^2. Conventionally described as “medium” to “large” effect sizes, the significant correlations are surprisingly powerful for an observational study. Teaching approach contrasts with the demographics of age and gender that, at most, accounted for 4.1% of variance. Greater resources accounted for only 3.1% of the variance in better science fair performance in the previously cited study (Bellipanni, 1994). To the best of my knowledge, this is the only prior study associating any construct with science fair performance.

Beyond the results, the present study aids future methodological decisions. Despite a paucity of prior research with science fairs, they hold promise as a context with external validity in which to explore hypotheses about children's active role in shaping development of their scientific reasoning. Results of the study show promise with consistency across analyses, significance with especially low alpha levels, and notably high effect sizes. Moreover, most prior research compares inquiry learning and direct instruction clusters around two designs. Research supporting inquiry learning tends to explore contexts with external validity using qualitative analysis (e.g., ethnographic accounts of months-long curriculum created by teachers in real classrooms). Despite the methods' virtues, those with more quantitative inclinations may worry researchers' prior beliefs might distort results. Research supporting direct instruction tends to explore tightly controlled experimental contexts over brief time-periods (e.g., 1 hour single-sessions including lessons and tests) using quantitative measures to uncover causal relationships. Despite the methods' virtues, those with more qualitative inclinations may worry something crucial is lost and the artificial context might distort results. To the best of my knowledge, the present study is the first to combine the strengths of both approaches by using a survey methodology to simultaneously explore the research question quantitatively without sacrificing external validity. This study contributes a reliable scale for measurement of inquiry learning in large samples (Appendices A & B)

A limitation of the present observational design means future research is necessary to demonstrate causal relationships. Though it may be most natural to conjecture that science teachers' approach to instruction caused student ability to conduct scientific research, there may be a third factor, not removed in the partial correlations, causing both the teachers' instruction and the student's achievement. Causality may be reverse with students who do well in the science fair evoking inquiry learning techniques in their teachers. Explanations are not mutually exclusive. A long-term goal is a comprehensive model of children's developing scientific reasoning including multiple and bi-directional causes.

Inconsistent with an information processing perspective, the path followed by children learning science predicted their rigorous scientific reasoning. Results lend support to the educational value of inquiry learning and suggest the importance of children's active construction of their own knowledge fostering their most intensive early scientific experiences. Debate over inquiry learning and direct instruction provides a rich situation for testing theoretical questions about the active child while solving a real-world educational problem.

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Table 1.

Scale Inter-Item Reliability (〈) with Sample Items and Domains

Teaching Approach Scale	α	Sample Item	Domain of Sample Item
Direct-Instruction	.720	When our teacher does a demonstration, he/she says aloud what he/she is doing and what is happening.	demonstration
Inquiry-Learning	.709	We're given in-class assignments with a big problem where, once we figure it out, we discover a new science concept for ourselves.	in-class assignments
Science-as-Authority	.556	We work in groups (or on labs) to look up facts in our textbook or another source (e.g., encyclopedia, internet).	group/lab work
Science-as-Real-Life	.836	My teacher asks us questions that make us think about how science matters and relates to our lives.	teachers' questions

Figure Captions

Figure 1. *Inquiry Learning*

Figure 2. *Science as Real Life*

Figure 3. *Direct Instruction*

Figure 4. *Science as Authority*

Figure 1. Inquiry Learning

Regional (Zero-Order)

r = -.339, p < .0005

Regional (Partial)

r = -.469, p < .0005

State (Zero-Order)

r = -.046, p = .395

State (Partial)

r = -.307, p = .001

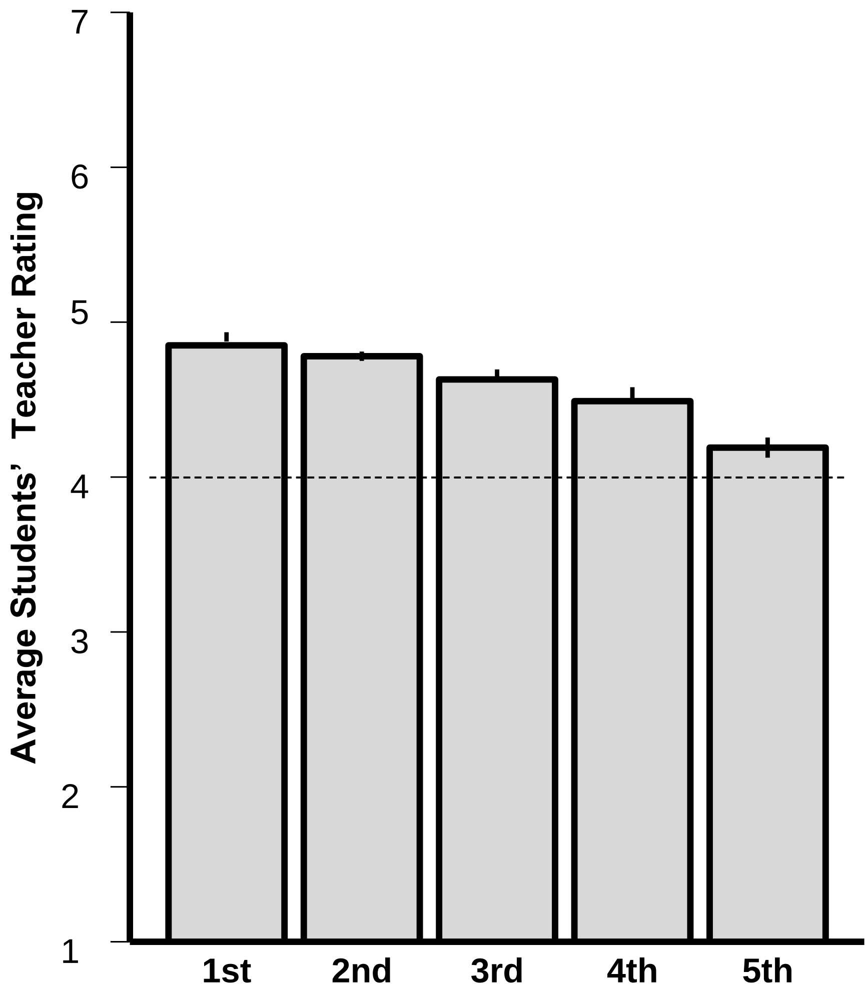


Figure 2. Science as Real Life

Regional (Zero-Order)

r = -.411, *p* < .0005

Regional (Partial)

r = -.341, *p* < .0005

State (Zero-Order)

r = -.067, *p* = .214

State (Partial)

r = -.379, *p* < .0005

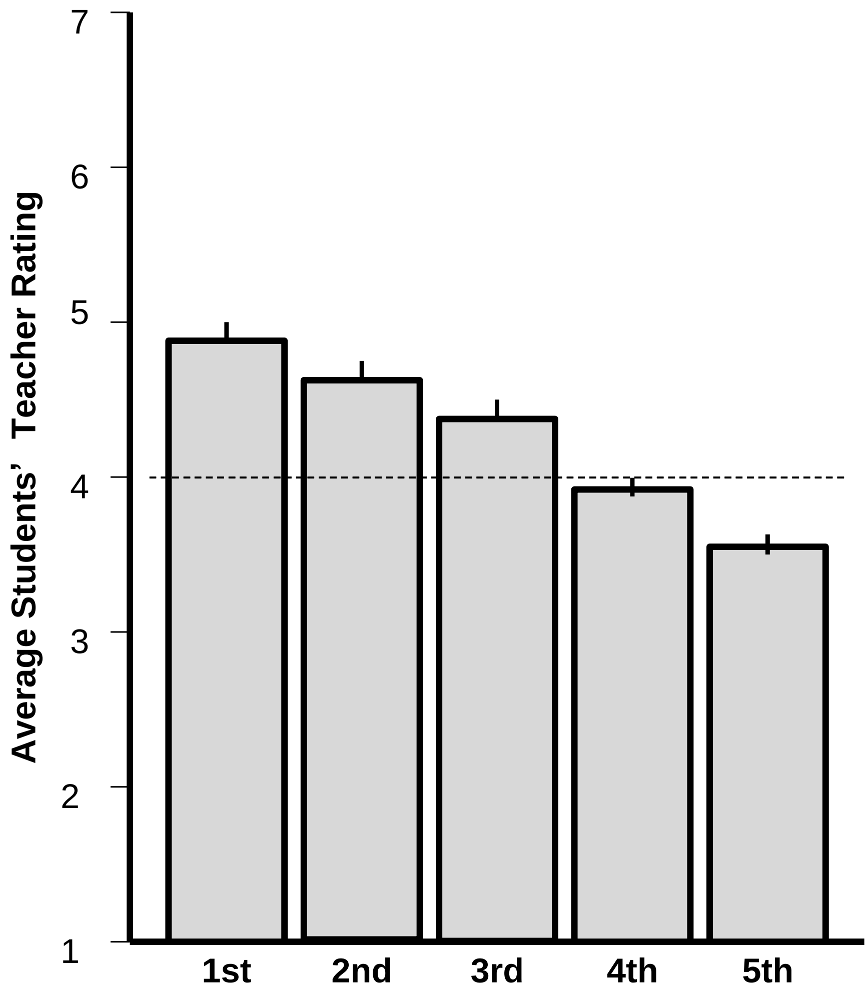


Figure 3. Direct Instruction

Regional (Zero-Order)

$r = .000$, $p = .997$

Regional (Partial)

$r = .305$, $p < .0005$

State (Zero-Order)

$r = .027$, $p = .613$

State (Partial)

$r = .358$, $p < .0005$

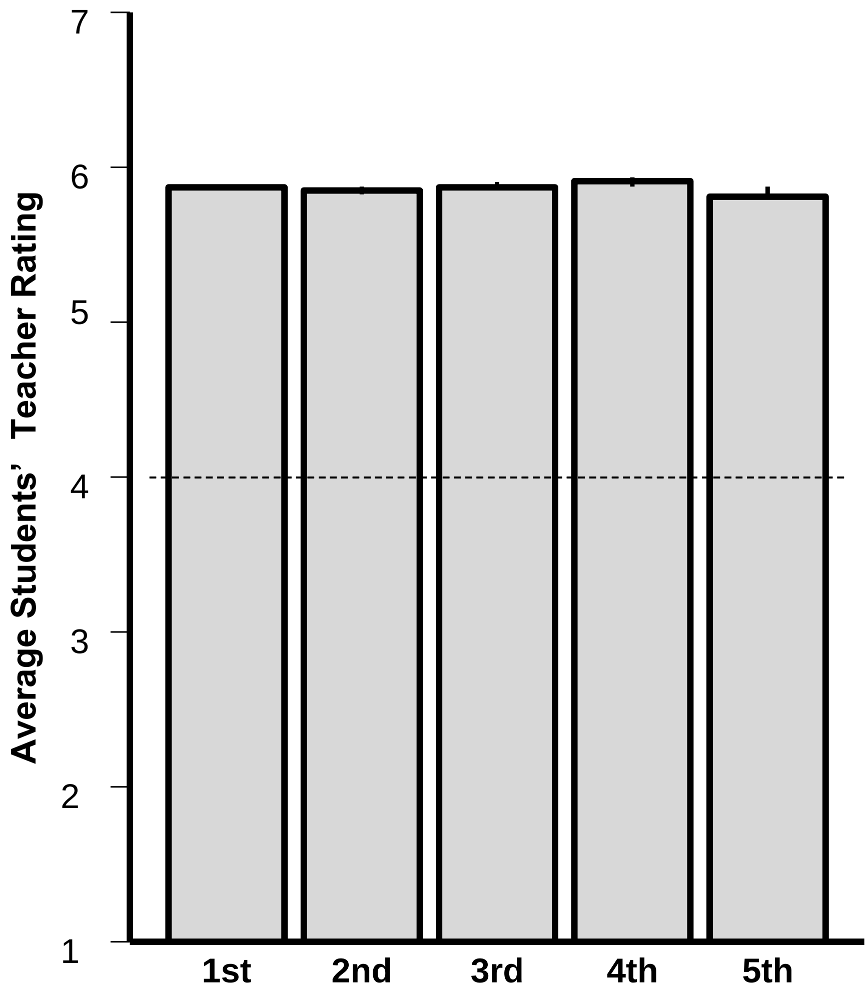


Figure 4. Science as Authority

Regional (Zero-Order)

$r = .453$, $p < .0005$

Regional (Partial)

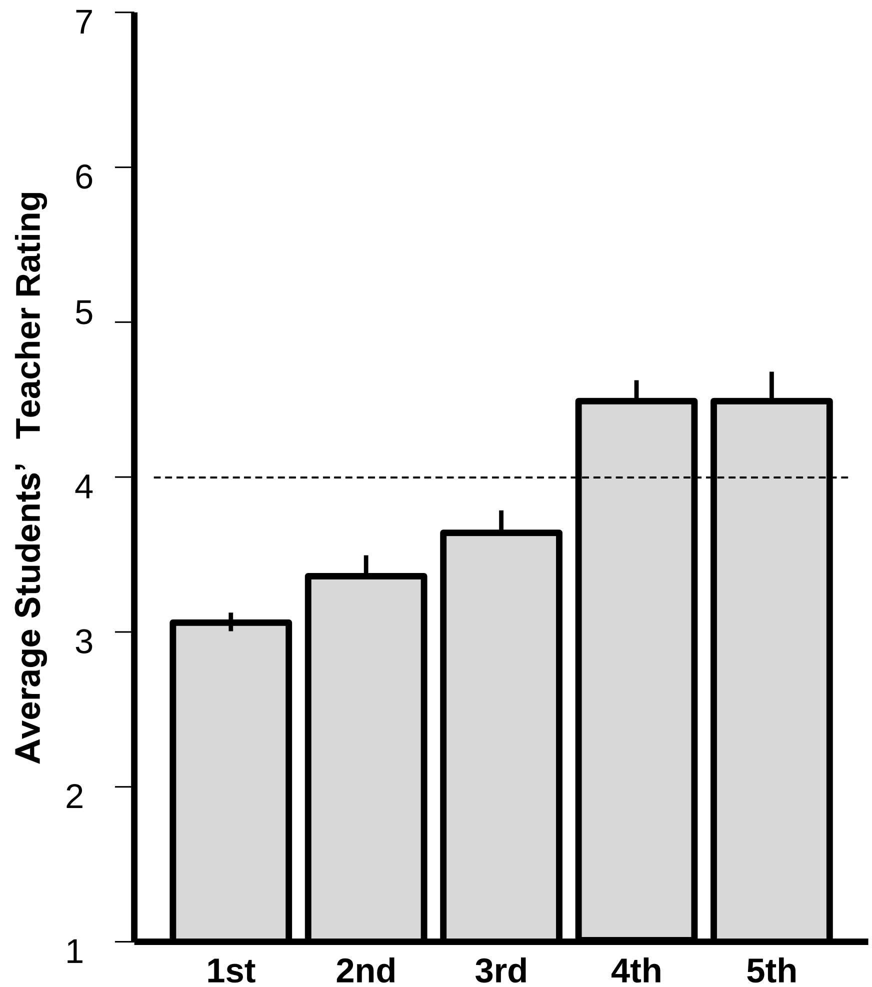
$r = .382$, $p < .0005$

State (Zero-Order)

$r = .383$, $p < .0005$

State (Partial)

$r = .360$, $p < .0005$



Appendix A. *Science Class Survey*

In-Class Demonstrations	***Rarely***						***Often***
01. When our teacher does a demonstration, he/she says aloud what he/she is doing and what is happening.	○	○	○	○	○	○	○
02. When our teacher does a demonstration, he/she asks us to guess what will happen and asks us to explain what happened with science concepts.	○	○	○	○	○	○	○
03. When our teacher does a demonstration, we usually also read about it in our textbook.	○	○	○	○	○	○	○
04. When our teacher does a demonstration, it shows us how a science concept connects to real-life.	○	○	○	○	○	○	○

How Teacher Asks Questions	***Rarely***						***Often***
05. My teacher asks us questions with answers that we will know the answer to if we were paying attention in class or did the reading assignments.	○	○	○	○	○	○	○
06. My teacher asks us hard questions where we have to remember the answer from earlier in class or from our textbook.	○	○	○	○	○	○	○
07. My teacher asks us questions that make us think about how science matters and relates to our lives.	○	○	○	○	○	○	○
08. My teacher asks us big questions that seem impossible at first, but with our teacher's guidance the question get easier.	○	○	○	○	○	○	○

Asking Our Teacher Questions	***Rarely***						***Often***
09. When we ask our teacher a question, he/she explains the answer clearly.	○	○	○	○	○	○	○
10. When we ask our teacher a question, he/she says to look it up in the book.	○	○	○	○	○	○	○
11. When we ask our teacher a question, he/she connects the answer to everyday life.	○	○	○	○	○	○	○
12. When we ask our teacher a question, he/she asks us questions back leading us to answer our own question.	○	○	○	○	○	○	○

Our Tests and Quizzes	*Rarely*						*Often*
13. Our test and quizzes introduce new perspectives on the material so we figure out something new about science while taking the test or quiz.	○	○	○	○	○	○	○
14. Our tests and quizzes clearly show if we learned the important science facts.	○	○	○	○	○	○	○
15. Our tests and quizzes ask us to apply what we learned so we really have to know the concept well to do well.	○	○	○	○	○	○	○
16. Our tests and quizzes repeat what our teacher or the textbook said, almost word-for-word, so if we pay attention we get the questions right.	○	○	○	○	○	○	○

Labs and Group Project Work	*Rarely*						*Often*
17. We work in groups (or on labs) to look up facts in our textbook or another source (e.g., encyclopedia, internet).	○	○	○	○	○	○	○
18. We work in groups (or on labs) where we have been assigned to do particular things and if we do them the way our teacher says to, we get the right answer.	○	○	○	○	○	○	○
19. We work in groups (or on labs) where we are given a goal and we have to discover something new about science.	○	○	○	○	○	○	○
20. We work in groups (or on labs) where we apply science to real-word situations.	○	○	○	○	○	○	○

In Class Assignments (but not Group Projects or Labs)	*Rarely*						*Often*
21. We're given in-class assignments where we look up the answers in our textbook, our notes, or other sources (e.g., encyclopedia, internet).	○	○	○	○	○	○	○
22. We're given in-class assignments that involve connecting science concepts to real-life issues.	○	○	○	○	○	○	○
23. We're given in-class assignments where we practice using a science concept that we have been taught.	○	○	○	○	○	○	○
24. We're given in-class assignments with a big problem where, once we figure it out, we discover a new science concept for ourselves.	○	○	○	○	○	○	○

Using our Textbook	*Rarely*						*Often*
25. When given assignments the textbook is an important place we look for information to solve problems that our teacher poses for us.	O	O	O	O	O	O	O
26. We're given assignments to make sure that we read our textbook.	O	O	O	O	O	O	O
27. We're given assignments to read the textbook so we know the important concepts.	O	O	O	O	O	O	O
28. We're given assignments that make our textbook come alive by connecting science to real life (e.g., by adding newspaper and magazine articles).	O	O	O	O	O	O	O

Homework (beyond Reading your Textbook)	*Rarely*						*Often*
29. Our homework includes interesting work that makes learning fun by connecting science to our lives.	O	O	O	O	O	O	O
30. Our homework includes a review of the science concepts we have been taught or introduces us to new science concepts before class.	O	O	O	O	O	O	O
31. Our homework includes complex problems to solve where we use our science concepts to discover something new.	O	O	O	O	O	O	O
32. Our homework includes things to make sure we know the right answers to questions about science concepts.	O	O	O	O	O	O	O

Guest Speakers & Field Trips	*Rarely*						*Often*
33. Our teacher tells us specific science concepts to look for when we have guest speakers or go on field trips.	O	O	O	O	O	O	O
34. As part of big questions raised in science class, we have guest speakers and field trips to help us figure out the answer.	O	O	O	O	O	O	O
35. Our teacher arranges for guest speakers and field-trips so we see how the science we learn in class applies to the real world.	O	O	O	O	O	O	O
36. Our teacher arranges for guest speakers and field-trips so we see what actual scientists do.	O	O	O	O	O	O	O

Appendix B. *Science Class Survey Scoring*

Code frequency responses from 1 (rarely) to 7 (often) for bubble chosen. While items are organized by domain for students, average one specified item from each domain for sub-scales. No reverse-scoring is necessary..

Inquiry Learning: 2, 8, 12, 13, 19, 24, 25, 31, 34

Direct Instruction: 1, 5, 9, 14, 18, 23, 27, 30, 33

Real Life: 4, 7, 11, 15, 20, 22, 28, 29, 35

Authority: 3, 6, 10, 16, 17, 21, 26, 32, 36