Using Cognitive Acceleration Materials to Develop Pre-service Teachers' Reasoning and Pedagogical Expertise

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ABSTRACT

The present work outlines two approaches taken at Winona State University (WSU) to increase the reasoning ability of pre-service elementary education majors through exposure to the "Cognitive Acceleration" materials produced by Shayer, Adey, and collaborators in the UK. These materials, which stimulate the development of reasoning ability, have been tremendously effective in Europe for pupils aged 5-6 and 11-13.

Intervention 1: Elementary Education students at WSU take two classes in science to meet general education requirements. In Spring 2011, one of these classes was modified to include 11 of the 30 "Thinking Science" lessons, which employ techniques of Cognitive Acceleration in a science context (CASE). As a direct result of including these materials, we saw post-pre Lawson CTSR gains of roughly 2.2 points, on the paired 13 point scale. Normal gains for a one-semester reformed-pedagogy science class are about 0.8-1.0 points.

Intervention 2: Over the 2011-12 academic year, a group of first and second year Elementary Education majors facilitated Cognitive Acceleration activities with children in the context of after-school "science clubs" at several elementary schools. As a result, these college students had substantial increases in CTSR score over the course of the two semesters and also demonstrated more mature attitudes towards science teaching.

Keywords: STEM, Conference Proceedings, K-12 Outreach, Teaching Quality

INTRODUCTION

As children advance through primary school, the topics and skills discussed move from concrete operations (eg "What does the letter 'A' look like?", "`How many words are in this sentence?") towards formal logical operations (eg "Are all squares also rectangles?", "Where in a sentence does the verb go?", "Why are many of a bird's bones hollow?", "If a chicken has 4 fingers, is their number 10 the same as our number 10?"). If a teacher lacks the ability to reason formally, we assume it is likely that they have always learned science by memorization. It is unreasonable then to expect such a teacher to ever fully address the "why" part of a scientific explanation adequately without communicating the model building and testing ability that an effective scientific explanation requires.

Although not widely know, it is understood beyond anecdote that reasoning ability has decayed precipitously since the late 1990's, (Shayer, Ginsburg, and Coe, 2007). The authors describe a series of reasoning ability measurements made with the same measure over the past 30 years. Their data, taken over thousands of students, shows that the average 11 year old child in Britain in 2003 reasons at the level of a 7.5 year old in the early 1970s. For the present emphasis on improving STEM education to bear any fruit, it is imperative to accordingly improve the reasoning ability of pre-service teaching majors.

The present work describes two modifications to pre-service teachers' early collegiate experience, which are intended to build reasoning ability. The goal of the modifications are to substantially affect the reasoning ability of future teachers by either (1) reducing content coverage to allow the use of "Cognitive Acceleration" intervention lessons, which have substantial impacts when used with younger populations, (Shayer and Adey, 1990, 1992, 1993), (Shayer 1999), or (2) allow pre-service teachers the opportunity to facilitate Cognitive Acceleration lessons with elementary students, with the assumption that in so doing, their own reasoning would proportionally develop. Before describing the interventions, the stage should be set.

BACKGROUND: INVESTIGATIVE SCIENCE AT WINONA STATE UNIVERSITY

To build reasoning ability and cover content standards, Elementary Education majors at Winona State University (WSU) take two 4-credit courses in science to fulfill their general education laboratory science requirements. The courses, Investigative Science 1 & 2, address licensing standards in Physics, Chemistry, Earth Science, and Biology. The courses are formulated to present science content in the way we hope our children are taught at the elementary level: always in the lab, always experiencing data before learning formal concepts, and always coming to consensus about the meaning of data through group discussion and metacognition. The Investigative Science course is meant to build reasoning ability and reduce the trepidation many pre-service elementary education majors feel toward science by providing experience with inexpensive "5-E," (Bybee et al., 2006), activities, which can be easily done in the students' future classrooms.

A mix of faculty from the College of Science and Engineering teaches the two courses. Students in the course are generally sophomores and juniors, at various stages in the Education curriculum. All of the students in the course initially aspire to be teachers, but their formal preparation and experience with pedagogy varies. While not a new approach to teaching introductory science, (Gerson and Primrose, 1977), (Loverude, Gonzalez, and Nanes, 2011), (Rice and Neureither, 2006), (Edgcomb et al., 2008), (Varelas et al., 2008), these classes have run regularly for the past 7 years and have been sufficiently successful to be part of the regular curriculum for elementary education students.

Historically, progress in teaching this course has been measured with content exams and Anton Lawson's "Classroom Test of Scientific Reasoning'" (CTSR), (Lawson, 1978), a multiple choice instrument which correlates to a student's Piagetian reasoning level. The CTSR has been shown to be a meaningful predictor of success on learning measures in physics, such as the Force Concept Inventory (Coletta and Phillips, 2005). Scores on this measure indicate that many of our students are under-prepared to reason through college work, see Table 1 or (McKinnon and Renner, 1971). In general, we consider gain on the CTSR an indication that the course is changing, for the better, the way pre-service teachers reason about the world.

BACKGROUND: THE CLASSROOM TEST OF SCIENTIFIC REASONING

The CTSR is a 24 item assessment with paired questions in the style of "Given this situation, what will happen?" and "Why?" Students must get both parts of each pair of questions correct to score a point. The paired scoring, plus two stand-alone questions at the end of the assessment give a maximum score of 13. Scores of 0-4 on the CTSR correspond to concrete reasoners, 5-10 transitional reasoners, and 11-13 formal. The transitional period is often broken into early (5-7) and late (8-10) transitional reasoning groups. If the reader accepts these categories, in a hand-waving sense, a gain of one point on the CTSR suggests growth of roughly 1/3 of a developmental level, but average gain is a coarse measure, as students often show "all or nothing" gain within a developmental level on this measure.

Via personal communications, (Lawson, 2009), Lawson acknowledged that these assignments were acceptable and seemed to corroborate with theoretical predictions, and an overview of these reasoning levels is given in (Lawson et al., 2000). The CTSR is a controlled exam, available online, (Deming and O'Donnell, 2011).

While some, (Coletta and Phillips, 2005), describe growth on the CTSR via a normalized gain, the test is only scored out of 13 points, and we feel such a fancy metric is unnecessary. Although normalized gain is commonly used in Physics Education Research, we feel it is a poor measure to use on such a low-scoring test. First, given that the test outcome is on a 13 point scale and is scored discretely, the map of possible gain scores is far from continuous, and a decimal gain value gives false impressions (similar to FCI measurements at Harvard, (Hake, 1998)).

More importantly, once one starts using normalized gain, one loses perspective on a student's Piagetian reasoning ability, which is the whole point of our use of this measure. Instead, we describe growth on the CTSR by the raw change in a student's score, $gain = postscore - prescore$. This has the advantage of mapping easily to meaningful developmental categories, which a normalized measure obfuscates.

Table 1: Typical Results from Lawson's "Classroom Test of Scientific Reasoning", Administered at WSU

	Semester	N	Average pre-CTSR	Average CTSR Gain
Investigative Science	Spring 2008	26	5.7±0.4	1.3±0.4
	Spring 2009	26	5.9±0.4	0.8±0.3
	Spring 2011	**28**	**6.4±0.4**	**2.2±0.4**
	University Average	160	6.25±0.17	1.13±0.13
College Physics	Summer 2009	32	8.7 ± 0.4	1.0±0.3
	Summer 2011	26	8.4±0.5	1.5±0.3
	Fall 2009	11	7.5±0.8	1.8±0.6
	Fall 2010	19	7.5±0.6	1.2±0.5
Science Club Facilitators	**Freshmen**	**21**	**4.5±0.3**	**1.8±0.5**
	Sophomores	13	8.0±0.6	0.7±0.5

The thinking skills measured by the CTSR can be divided into four categories that are parallel to Jean Piaget's theory of cognitive development. According to this theory, (Piaget et al., 1966), students should begin to transition to formal reasoning, around the age of sexual maturity, age 11 in girls and 12 in boys. Measurements with the CTSR, (O'Donnell, 2011), suggest that either Piaget was optimistic or standards have slipped, see Table 1 for example scores from several of Moore's classes. These data corroborate many other studies, which have found relatively small percentages of students that have acquired (Piagetian) formal reasoning ability, (Lawson, 1985). This reasoning ability is necessary if students are going to sum the forces on the international space station, imagine and make predictions about the motion of nitrogen molecules within a balloon, or hypothesize about the accelerated development of antibiotic resistance in the sanitary sewers of India. Scientific fields quickly reduce to a set of disconnected rules and special cases for the students so lacking. Further, the ability to create a controlled experiment (hypothetical-deductive reasoning, for example "if-and-then-therefore" statements) is very difficult for students not at the "formal" reasoning level, (Lawson, 2002). Future teachers must be equipped with these skills.

Table 1 lists CTSR pre-scores and gains for a number of classes at WSU. At present, the authors are aware of no published normal distributions of score or gain for reformed/traditional science classes on this measure. “Thinking Science” Cognitive Acceleration materials were used in the spring 2011 section of Investigative Science. Except for the University Average listed, all results posted are those of the author. The University Average gains in Investigative Science do not include the Spring 2011 class, the difference being the motivation for this work. Data from students participating in a year-long elementary field experience, in which Cognitive Acceleration materials were facilitated by the college students in the elementary setting are given in the “Science Club” rows.

The N given is the number of students who were present to take both pre and post tests (typically 80% of the students registered), and class averages are taken only over students with a complete pre/post pair of scores. The uncertainty cited is “Standard Error of the Mean'”, $\boldsymbol{\sigma}/\sqrt{\mathbf{N}}$, where $\boldsymbol{\sigma}$ is the standard deviation of the measurements described.

As the existence and utility of the CTSR is known unevenly across Science, Education, and Engineering fields, the table also lists average performances for College Physics, which is primarily taken by health sciences majors, who, when compared to Education majors, generally have higher initial reasoning ability level and better work habits, but similar gain on the CTSR. This group seems to demonstrate that the unusually high CTSR gains seen in 2011 are not simply the product of an especially motivated or high pre-CTSR-score section of Investigative Science. At our institution, it seems that a “typical” gain on the measure seen from a “good” science class is about 1 point. Anecdotally, many science classes show gains of zero.

No growth in reasoning ability may seem an unexpected result from a science class, but the CTSR “measures” scientific reasoning ability, which develops both in response to stimulation and as a part of normal maturation. A content-driven, passive, “lecture-based'” science class may not provide sufficient stimulation for reasoning ability growth. Some studies, (O’Donnell, 2011), suggest that gain on the CTSR in middle and high school grades (due primarily to maturational effects) is less than one point per year.

The authors didn't teach Investigative Science in Spring 2010, and since the data are our own scores, we can't report for that semester (note that implicitly, we're trying to control for variations in instructor). Post-test scores are implicit from gain measurements. We think it is more meaningful to state where the students start (to see if a comparison is fair based on initial ability), and to compare treatments via gain (a better treatment would have a higher gain).

BACKGROUND: COGNITIVE ACCELERATION INTERVENTIONS

At the middle school level, Adey, Shayer, and Yates have developed supplementary lessons, which stimulate the development of reasoning ability. Their results in the field of “Cognitive Acceleration” over the past twenty years are, without hyperbole, tremendous, (Shayer and Adey, 1990, 1992, 1993), (Shayer 1999), and have culminated in a series of curricular interventions appropriate for students in US grades K-6. The original series of Cognitive Acceleration interventions, “Thinking Science,” (Adey, Shayer, and Yates, 2001), are a series of 30 “intervention lessons” which are designed for 11-14 year old children.

In the late 1990's, these lessons were implemented at a number of schools in the UK with pupils aged 11-13. Three years later, these students scored, on average and compared to students who had not received the “treatment” of working on the Cognitive Acceleration lessons, about a letter grade higher on the national GCSE exams (roughly equivalent to the SAT/ACT) than their incoming ability (at age 11) would have predicted.

Given the science context used in the interventions, the authors anticipated higher science scores - but the surprising part of the study was that student scores were higher than predicted in science, math, and english subject areas. A plausible explanation for these data is that the Cognitive Acceleration materials stimulate the development of a generalized processing ability, which all academic subjects utilize. The papers describing this measurement compare the schools implementing Cognitive Acceleration with a number of controls, and clearly demonstrate that the growth seen was not a result of normal maturation. This persistent and far transfer effect from implementing the materials is described for a general audience, (Adey, 1999), in great detail, (Adey and Shayer, 1994), or in a highly technical sense, (Shayer and Adey, 1990, 1992, 1993), (Shayer 1999).

Because of curriculum constrains imposed by the UK educational system, the Thinking Science lessons were originally designed to be inserted into the regular curriculum at the rate of once every two weeks over a period of two years. They are specifically designed to create the cognitive conflict which stimulates the development of students' reasoning ability. The specific skills targeted by the materials are: control of variables, classification, ratio and proportionality, inverse proportionality and equilibrium, probability and correlation, and the use of abstract models to explain and predict. For further discussion of the material's implementation and effect in the classroom, see (Adey et al., 2008).

EXPERIMENT AND RESULTS

Given this educational resource, there are two general paths to take in exposing pre-service teachers to the material. First, one might introduce the Thinking Science materials into the Investigative Science classroom via an implementation schedule similar to that used in middle-school the UK. While it might seem an insult to use middle school materials in a college class, the fundamental goal of the Thinking Science materials is to develop reasoning ability. Given that the students in Investigative Science are, based on their CTSR scores, below their developmental potential, the treatment seems appropriate. This idea was implemented by the authors in the Spring 2011 section of Investigate Science at WSU.

A second approach, following the cliché that “students learn most when they teach,” is to set up an environment in which the pre-service teachers, with guidance, facilitate Cognitive Acceleration lessons with elementary students. The hope in this intervention is that in order to effectively facilitate a lesson, one needs to plan for and guide student discussions. We assume this planning occurs at a higher reasoning level than the materials themselves, and expect reasoning ability growth to occur. This idea was implemented in the context of a year-long field experience course at WSU. Students facilitated Cognitive Acceleration lessons at after-school “Science Clubs” at several elementary schools in the community.

IMPLEMENTATION IN INVESTIGATIVE SCIENCE

In the Spring 2011 semester, one of the authors taught a section of Investigative Science 1, which discusses ideas from Physics and Chemistry. Given the reputation of the Cognitive Acceleration materials, the authors proposed the following investigation. The course would be taught with the traditional curriculum, with a small modification to accommodate the Thinking Science materials. Each Friday, the students would be given one of the Thinking Science lessons, (Adey, Shayer, and Yates, 2001), (Adey et al., 2008), to work on over the weekend.

On the following Monday, the class would engage in an ~30 minute discussion of the lesson. Note that in this plan, coverage of traditional content was reduced by about 1/12, as the class meets for 6 hours each week. The end goal for the effort was two-fold, both to increase the reasoning ability of the students in the course, and to prepare them to deliver the materials in an after-school setting, with the intent of making connections to the students' teaching methods classes

To make the exercise seem more sophisticated to the students than simply working through 6th grade science homework, the students were given a two-part assignment for each Thinking Science lesson. First, they were directed to work through the lesson as though they were students in a class going through the activities, rather than as prospective teachers looking at lesson plans. Second, to build connections to pedagogy, the students were directed to identify the learning objective for each lesson and plan more activities to follow, with the explicit requirement that follow-up activities reinforce the learning objective.

For example, after working through lesson 7, which builds classification ideas through arranging birds by habitat, beak shape, diet, and other variables, a student proposed the extension activity of classifying the sinking and floating behavior of objects in water. Specifically, cans of sugar-laden soda sink, and cans of artificially sweetened soda float. This particular student thought that the classification skill was particularly useful for explaining this divergent behavior, which leads to a discussion of sugar content and density.

Student work was recorded in a lab journal and students used whiteboards to explain their extension activities to the rest of the class each Monday. Further, metacognitive questions were posed each week on a Google Doc that students were required to fill out. These questions were designed to simulate connections between subjects. For example, in the week we discussed Thinking Science lesson 10, which investigates inverse proportionality via measuring the thickness of tree trunks and branching, the students were asked how pupils internalize the idea of mathematical division.

RESULTS FROM IMPLEMENTATION IN INVESTIGATIVE SCIENCE

Over the course of the semester, the class worked through lessons 1-11 of the Thinking Science curriculum in this manner. The specific reasoning patterns targeted by these lessons include variables, classification, and direct and inverse proportionality. To someone familiar with the population, it was fairly obvious that the students were affected by the interventions. Terms from the materials, like “fair test” from the control of variables lesson, regularly began to appear in normal class discussions outside of the time allotted to Thinking Science. In addition, in the time devoted to Thinking Science materials, student resistance to work on the lessons decreased as the semester progressed. Group and class discussions became more in depth throughout the semester (as compared to the one word answers from the beginning of the term). This result is worth reporting, as at WSU this specific population seems to be the least willing to embrace the identity and practice of scientists.

In our view, the most substantial result from the intervention is the gain in CTSR score of about 2.2 over the semester. As can be seen from the data in Table 1, this is roughly double the normal increase seen in students of this ability and college major.

Given this data, it is reasonable to look for other explanations of the results seen. We address a few possible alternatives below.

The experimental section of Investigative Science had a higher initial CTSR pre-score. Could it be that their better initial ability allowed them to gain more over the course of the semester? How do we know that these Investigative Science students are not just a special group?

Table 2 uses T-Tests to demonstrate both that the section of Investigative Science implementing Thinking Science materials was typical in terms of initial preparation and that the results were significantly atypical in terms of CTSR gain, when compared both to other groups of Elementary Education majors as well as gains and pre-scores seen among pre-med majors in College Physics. Specifically, the table shows p-values (probabilities) associated with the “Student's” T-Test. A reminder for the reader, a p-value less than 0.05 indicates that we are quite certain the differences observed between the two sets of samples are not attributable to random chance. In a hand-waving sense, a p-value greater that 0.05 suggests that the two sets of samples probably come from the same distribution and a p-value less than 0.05 indicates that the samples likely come from different distributions.

The variables being compared via T-Test in Table 2 are the students' initial CTSR pre-score, and the students' gain on the CTSR. Broadly, the comparisons show that the Spring 2011 section was fairly typical in terms of initial preparation (CTSR pre-score), but substantially atypical in terms of gain on the CTSR.

Given that the Spring 2011 section had slightly higher CTSR pre-scores, one might argue that the greater reasoning ability of this population allowed them to gain more on the CTSR. However, the College Physics data listed fail this hypothesis. In every case the College Physics courses had higher pre-CTSR scores and lower gains than the Spring 2011 course. In terms of T-Test p-values, the only course to have gains similar to those seen in the Spring 2011 course is the Fall 2009 section of College Physics, which was offered in the "SCALE-UP" style, (Gaffney et al., 2008), and was specially designed to address the CTSR score of deficient students.

Table 2: T-Tests Comparing the Spring 2011 Section of Investigative Science to other Sections of the Same Class and College Physics Students via Students' pre- CTSR Score and CTSR Gain.

	Semester	N	P-value, pre-CTSR	P-value, CTSR gain
Investigative Science	Spring 2008	26	0.18	0.091
	Spring 2009	26	0.37	0.0066
	University Average	160	0.68	0.0099
College Physics	Summer 2009	32	0.00019	0.018
	Summer 2011	26	0.0033	0.18
	Fall 2009	11	0.21	0.63
	Fall 2010	19	0.14	0.10

The experimental section was taught one time, by one instructor, at one university. Could it just be an artifact of the person teaching the course?

The experimental section of Investigative Science used 11/12 ~ 91% of the traditional curriculum (in terms of time) for the course. Further, earlier sections of the course taught by the author are quite similar, both in terms of pre-score and average gain (Table 1) to the running University average result for Investigative Science. While we intend to employ the approach in future semesters, the teaching schedule hasn't cooperated with this research work, and we won't have further results in 2012. On a broader note, the efficacy of the Cognitive Acceleration materials is, we feel, well established, and we see the present work as a sort of "look, the technique works for college students as well...".

IMPLEMENTATION VIA "SCIENCE CLUB" FIELD EXPERIENCE

It is traditional for education majors to participate in "field experience" classes in their sophomore and junior years. In general, the general idea is that student will find their teaching methods and educational psychology courses more meaningful if they are in regular contact with their future students and classroom. These courses normally begin after a student is admitted to the education program – generally in their sophomore or junior year. At WSU, we have recently begun to experiment with "very early" field experience during the first and second semesters of the students' freshmen year. The effort seeks to extend the educational benefit already described of seeing a K-12 classroom from the perspective of a teacher, with the hope of improving disposition towards future coursework.

As part of this experimental approach to pre-service teacher education, two of the authors taught two pairs of field experience classes in the Fall 2011-Spring 2012 academic year, with approximately 50 freshmen and sophomore students enrolled each term. The students all intended to pursue elementary education majors and were at various stages in being admitted to the education program. The students' field experience work was to facilitate the delivery of age-appropriate Cognitive Acceleration lessons via after-school "Science Clubs" held at three local elementary schools. To support the field experience, the students and instructor met for a weekly seminar.

Given that the students who would be facilitating the Science Clubs were (pedagogically) nearly complete novices, seminars in the first 5 weeks of the semester were spent in familiarization with the Cognitive Acceleration Materials (similar to what has already been described for Investigative Science), and in discussion of assigned readings, eg (Adey, 1999), (Zvonkin, 1992), (Shayer, Ginsburg, and Coe, 2007), (Miller, 1956), etc.

The field experience consisted of about 10 weeks each semester of university students (facilitators) going out to elementary schools and facilitating Cognitive Acceleration lessons for about an hour each week (~20 hours of contact over the two semesters). The facilitators worked in small teams, specific to grade level and school, with the materials listed in Table 3, and were reminded to prepare additional activities that reinforced that day's learning outcome or reasoning pattern, for example, the puzzles in (Kordemsky, 1992). Two of the authors were regularly in in the elementary schools to act as mentors and coaches for issues of student behavior, material coordination, and to debrief the facilitators after the science club ended each day.

Logistically, groups of facilitators went out to 3 schools each week. Two of the elementary schools served students grades K-4, and the third, grades 1-6. Weekly science club student attendance fluctuated over the year from nearly 100 children per school for a few weeks at the beginning of the effort down to about 5-10 children per grade and school. Because of this variability in attendance, we made no effort beyond anecdote to measure elementary student growth as a result of the interaction. The clubs were generally attended more often by younger students (~15 students per grade each week in grades 1-3, and ~3-5 students per grade each week for grades 4-6). This biased attendance meant that science club facilitators were more likely to interact with lower-level Cognitive Acceleration materials than the Investigative Science (University) students already described. The specific materials used in the science clubs are listed in Table 3.

Table 3: Cognitive Acceleration Materials Used at Science Club Sites in the 11-12 Academic Year, Described Further in (Adey, Robertson, and Venville, 2002).

Grade	Cognitive Acceleration Materials Used	Publisher
1	Let's Think!	GL Assessment
2	Let's Think! and Let's Think! Through Maths 6-9	GL Assessment
3	Let's Think Through Science 8&9 and Let's Think! Through Maths 6-9	GL Assessment
4	Let's Think! Through Maths 6-9 and Thinking Science	Nelson Thornes
4, 5 and 6	Thinking Maths	Pearson (UK)

RESULTS FROM THE SCIENCE CLUB IMPLEMENTATION

With regard to reasoning ability, the science club facilitators' growth on the CTSR is listed in Table 1. The sophomore students' growth was moderate, 0.7, and could be attributed to normal maturation. The freshmens' average score grew by 1.8, which is on the high end of gains seen in past sections of Investigative Science and College Physics. We should note though that administration of the CTSR happened in August 2011 and March 2012, so the gains seen should be compared to ~1.5 semesters of maturation, for which we don't have data to make an honest comparison.

This said, it is worth pointing out that the freshmen science club facilitators showed substantially larger gains over roughly the same period of time and experience. One could argue that since the science club participants were primarily in grades 1-3, the Cognitive Acceleration lessons they facilitated focused largely on consolidation of concrete operations: classification, causality, seration, concrete modeling, relating variables, conservation, etc. Based on the freshmen's initial CTSR average, 4.5, facilitating lessons with these operations is conceivably closer to their zone of proximal development, while the sophomores' initial CTSR average, 8.0, implies they may not be similarly engaged. This may lead to the differential gain observed, and suggests further study.

At the end of the experience, the authors gave the science club facilitators the following Likert-style "retrospective" survey, scored from 0-5.

1) Given your experience over the past 2 semesters, how would you rate your knowledge of science teaching?
2) Given your experience over the past semesters, how would you rate your knowledge of science teaching when the year began (back in Aug 2011)?
3) Given your experience over the past two semesters, how would you rate your knowledge/skill of/with classroom management (discipline)?
4) Given your experience over the semesters, how would you rate your knowledge/skill of/with classroom management (discipline) when the year began (back in Aug 2011)?

Table 4: Average of Numerical Survey Responses from Science Club Facilitators

	N	Q1	Q2	Q3	Q4	Q1-Q2	Q3-Q4
Freshmen	23	3.0	1.2	3.4	2.1	1.9	1.3
Sophomore	13	3.1	1.5	2.8	1.3	1.6	1.5

In terms of engendering "teachability," it seems that the average science club facilitator realized over the course of the experience that they knew very little about teaching and classroom management. This would seem to be a good initial state for them to enter their teaching methods classes in coming semesters.

The authors were present during science club sessions during the 2011 - 2012 year and noticed dispositional maturation in the behavior of the facilitators. In the free-response portion of the surveys given at the end of the experience, students reflected on their perception of their own gains in knowledge of pedagogical skills, specifically: classroom management, styles of teaching, lesson planning, delivering an effective lesson, and relationships with students. They also spoke to the importance of having well planned lessons and the flexibility to adapt to unforeseen circumstances.

The authors also witnessed most of the pedagogy expressed by the students. Seeing freshman and sophomore teacher candidates involved in higher levels of metacognition, in regards to pedagogy, is evidence of dispositional maturation. This type of higher-level thinking is typically seen during student teaching or even later. We believe that by exposing teacher candidates to the realities of a classroom earlier in their university education, we are allowing for richer and more nuanced discussion and insight in future discussions in the university classroom. Further, as the facilitators gained knowledge over the year (from experience and discussion) they were able to manage behaviors, stifle interruptions and get to the heart of education, facilitating inquiry rather than giving answers.

CONCLUSIONS AND FUTURE WORK

With regard to using Cognitive Acceleration materials in the university classroom setting, the gains in CTSR score described in this work should be seen as evidence that reasoning ability, as measured by the CTSR, can be affected by classroom practice. Although using Cognitive Acceleration lessons in the after-school field experience produced large improvements in disposition and pedagogical sophistication, they do not seem to have the same effect on reasoning ability, at least as measured by the CTSR.

In both of these measurements we are fundamentally limited in our conclusions by not knowing what "baseline" maturational growth on the CTSR is for students of a given age. We would be happy to see such a result appear in the literature. In a different vein, we intend to continue and report on both directions of work described. It seems imperative to figure out if, in a single field experience, students can simultaneously develop both pedagogical skill and reasoning ability. It may be that the intellectual demands of managing students and developing one's own scientific thinking skills is too much to ask, but we see it as a meaningful challenge.

When training future educators, reasoning ability must be targeted for improvement, as teachers are not able to communicate material beyond their own level of intellectual sophistication. The Thinking Science curriculum is one way to increase this critically important ability. It would be interesting to examine if the use of Thinking Science interventions has similar effect on other populations with immature reasoning ability, for example, underprepared students in University (calculus-based) Physics or College Chemistry.

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