# THE EFFECTS OF AN INQUIRY-BASED

# DATA-TO-CONCEPT CURRICULUM

by

Brandon Honzel

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Brandon T. Honzel

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ABSTRACT

This action research evaluates the effects of the implementation of an inquiry-based, data-to-concept curriculum on students and teachers. The data-to-concept model is a pedagogical approach where students gather data first and formulate their own explanations or mental models for the observations prior to any introduction to the concept or vocabulary associated with the concept. While a previous study supports achievement gains in science after implementing a data-to-concept curriculum, there is uncertainty about the distribution of achievement gains in science across various subpopulations such as gender, Title I status and income status. Comparisons were made using students' scores from MontCas (Montana's state achievement test), Lawson's Classroom Test of Scientific Reasoning, a modified Science Attitudes, Skill and Knowledge survey along with interviews of both teachers and students.

Analysis indicates that in general, students make gains in their reasoning skills after two years of data-to-concept science classes. There does not appear to be a difference in science achievement based on gender or income status, but there seems to be an achievement gap based on Title I status. In relationship to attitude, students generally have a positive attitude towards science after one semester of data-to-concept instruction. Both teachers and students prefer the data-to-concept method to more traditional, expository methods of teaching and learning.

In general, this study supports the use/implementation of a data-to-concept curriculum. While in general this is true, there are some improvements to the data-to-concept model, which will be necessary to make achievement equitable for all students regardless of status. The science department at Big Sky High School will have to address the achievement gap based on Title I status. In my classroom, I will need to work to help students understand the limitations and power of science as a way of understanding the natural world. The data-to-concept model of instruction is supported by data and preferred by both students and teachers.

# INTRODUCTION AND BACKGROUND

## Project Background

### Teaching and Curriculum History

Over the last few years, my involvement in "Transitions to inquiry" (a project sponsored by the Montana Office of Public Instruction) has allowed me to implement curriculum in my freshman integrated science classes with a data-to-concept learning cycle as its focus. The data-to-concept model is a pedagogical approach where students gather data first and formulate their own explanations or mental models for the observations prior to any introduction to the concept or vocabulary associated with the concept. This is in contrast to a traditional approach where students might get a lecture or an assigned reading to introduce a topic and then do a lab or data analysis (explained further in Methodologies section). The Big Sky High School science department has data and analysis supporting our change to this model for the two years of required science coursework. The first years of this project had a "control" group in which some students did not participate in a data-to-concepts class. For our two years of required science classes, some students had two years of a data-to-concepts model course, some only had one year, and some only took "traditional" science classes. An unpublished study by Mark Cracolice (The University of Montana, Dept. of Chemistry) and Dave Jones (Big Sky High School) supported the implementation of the data-to-concept model and presently, all students participate in the data-to-concepts model classes for their two years of required science.

While data supports achievement gains in science after implementing a data-to-concept curriculum, we are uncertain about the distribution of achievement gains in science across various subpopulations such as (not limited to) gender, Title I status, or low income status. One concern is that student achievement gains may not be distributed equally based on particular student characteristics or inclusion in particular sub-populations. While the overall population was shown to benefit from the initial implementation of the data-to-concept model, there are questions about achievement gaps which may persist with use of the data-to-concept model. Without strong evidence, our department has engaged in anecdotal discussions about various groups' success rates in science. This project is a descriptive study attempting to evaluate the effectiveness of the implementation of an inquiry based, data-to-concept curriculum.

## School Demographics

Big Sky High School in Missoula, MT serves students grades 9-12. Over the last three years, the student population has remained fairly stable with approximately 1070 students. The student population is primarily Caucasian (89.9%) while American Indians make up the largest minority (4.81%). The Big Sky High School Profile reported that for the 2010-2011 school year, 26.2% of the student body were identified as students with special needs and were served by special programs including Special Ed, 504 plans, and Title I. The school profile also indicated that 38% of students were enrolled in the free and reduced meal program. Big Sky serves a diverse population of students with equally diverse needs.

All students at Big Sky are required to complete two years of laboratory science coursework. Students are required to take Integrated Earth, Space and Physical Science (IESPS) and Biology I. Most students take IESPS their freshman year and Biology I their sophomore year. We offer ten elective courses including an independent research course in an attempt to serve the varied interests of students.

## Research Focus and Purpose

The focal question of my action research project is, “How are various subpopulations of students impacted by the implementation of an inquiry-based data-to-concept curriculum model?” This is important to my teaching situation in that all students enrolled in my three freshman integrated science classes (required course) engage in a data-to-concept curriculum. The Big Sky science department utilizes the model to teach freshman and sophomore required courses (240-260 students per year). Many of our advanced courses are adapting to this model including all chemistry, geology and advanced biology; so, the results of this study are of direct importance to all teachers in the department in regard to the delivery of curriculum. In relationship to the research focus, the following questions are addressed in an attempt to evaluate the primary research question:

- How does the data-to-concept model of teaching science impact various sub-populations of students?
- How do student attitudes towards science change as a result of a data-to-concept curriculum?

• What, if any, factors may be correlated to “high” and “low” gains on the Classroom Test of Scientific Reasoning (CTSR)?

•How does the data-to-concept model of teaching science impact teachers?

Addressing these questions provides a framework to ensure achievement in science for all students.

Project Support

I assembled a support team composed of people I trust would give me honest and open feedback to help me complete my capstone. The individuals I relied on are Walt Woolbaugh (MSSE instructor, Committee Chair), Stephanie MacGinnis (MSU-Bozeman), Dave Jones (Big Sky science department chair), Trevor Leboski (Big Sky principal) and Meleina Helmer (Big Sky English Teacher).

Walt Woolbaugh and Dave Jones were instrumental in guiding the research process and giving critiques/feedback. Trevor Leboski helped ensure ethical and legal standards for data collection were followed. He also provided valuable feedback and ideas related to components of the capstone. Meleina Helmer was primary editor of the capstone paper throughout the writing process. This group of dedicated educators has been and continues to be an integral part of my action research process. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

# CONCEPTUAL FRAMEWORK

## Learning and Inquiry

In the essay, “What is Science?,” the renowned physicist Richard Feynman recounts his personal experiences with science starting at a young age and gives credit to his father for helping him understand science. One key concept from the essay is his distinction between words and science, “It's a good idea to try to see the difference, and it's a good idea to know when we are teaching the tools of science, such as words, and when we are teaching science itself” (Feynman, 2011, p. 865). One of the key aspects of teaching with the inquiry process is allowing students to use their own words to describe what they observe and then attach our “science words” to the concepts they have described. This is one key distinction between inquiry and more traditional methods of instruction. “And that is what science is: the result of the discovery that it is worthwhile rechecking by new direct experience, and not necessarily trusting the [human] race['s] experience from the past” (Feynman, 2011, p. 871). Feynman reminds us science is not dogma to be presented as fact, something often done as schools work to meet federal and state testing requirements.

While Feynman wrote from personal experience, Piaget and Vygotsky provide a theoretical framework for inquiry learning through theories of constructivism--where learning is a shared experience between students and teachers in creating new meanings (Atherton, 2011). Constructivism requires a more student centered learning environment than the traditional lecture based classroom. It also demands students have opportunities to interact effectively (Webb, 1980). Lawson and Renner (1975) provide arguments related to Feynman but relate the work of Piaget to the biology classroom experience. They argue the Piagetian model of learning should be highly regarded in relation to biology teaching. The researchers reported their study demonstrates students taught using inquiry methods can change their level of thought (Lawson & Renner, 1975). By using knowledge of how we learn from Piagetian theory, students will have more opportunity to develop formal levels of thinking.

Johnson and Lawson (1998) and Mao (1998) both provide evidence supporting the implementation of inquiry-based curricula in science classrooms. Based on their findings that reasoning ability is a significant predictor of achievement, Johnson and Lawson concluded that, "students would be better served by courses that teach by inquiry and focus on the development of scientific reasoning and the acquisition of fewer concepts" (Johnson & Lawson, 1998, p. 100). In "two companion studies," comparing traditional and inquiry models of teaching, Mao reported that inquiry instruction is more effective than traditional teacher centered instruction in learning earth science concepts (Mao, 1998). Data driven studies such as those presented have influenced changes in pedagogy and curricular development.

## Inquiry and Educational Standards

The National Science Standards (National Research Council, 1996) and the Montana Science Standards ("Science content standards," 2010) indicate the importance of inquiry in science teaching. The National Standards identify Inquiry as one of the eight content standards stating, "Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry" (National Research Council, 1996, p. 105). The Montana Science Standards have taken this one step further—each of the six content standards begin with the phrase, "Students, through the inquiry process, demonstrate…" ("Science content standards," 2010, p. 7).

The recently published "A Framework for K-12 Science Education Standards" builds upon previous works including the National Science Standards to provide a guide for revising the standards and using new knowledge to improve educational practices. Dimension 1 of the framework specifies, "what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires" (National Research Council, 2011, pp. 2-5). In an attempt to build a more universal concept of inquiry, the authors draw attention to the practices of science, "such as modeling, developing explanations, and engaging in critique and evaluation (argumentation), that have too often been underemphasized in the context of science education" (National Research Council, 2011, pp. 2-3). These skills/practices are at the heart of the data-to-concept model of learning.

While there are key components of all inquiry models, there are various levels of inquiry instruction. Some descriptions include discrete types of inquiry instruction like guided inquiry or open inquiry models. Inquiry can be viewed as a continuum with variations on essential features (Table 1).

Table 1
*Inquiry Continuum*

**Table 2-6. Essential Features of Classroom Inquiry and Their Variations**

| Essential Feature | Variations | | | |
|---|---|---|---|---|
| 1. Learner engages in scientifically oriented questions | Learner poses a question | Learner selects among questions, poses new questions | Learner sharpens or clarifies question provided by teacher, materials, or other source | Learner engages in question provided by teacher, materials, or other source |
| 2. Learner gives priority to **evidence** in responding to questions | Learner determines what constitutes evidence and collects it | Learner directed to collect certain data | Learner given data and asked to analyze | Learner given data and told how to analyze |
| 3. Learner formulate **explanations** from evidence | Learner formulates explanation after summarizing evidence | Learner guided in process of formulating explanations from evidence | Learner given possible ways to use evidence to formulate explanation | Learner provided with evidence and how to use evidence to formulate explanation |
| 4. Learner connects explanations to scientific knowledge | Learner independently examines other resources and forms the links to explanations | Learner directed toward areas and sources of scientific knowledge | Learner given possible connections | |
| 5. Learner communicates and justifies explanations | Learner forms reasonable and logical argument to communicate explanations | Learner coached in development of communication | Learner provided broad guidelines to use sharpen communication | Learner given steps and procedures for communication |

More ——— Amount of Learner Self-Direction ——— Less
Less ——— Amount of Direction from Teacher or Material ——— More

*Note.* From *Inquiry and the National Science Standards: a Guide for Teaching and Learning* (p. 29), by National Research Council, 2000, Washington, D.C.: National Academies Press. Copyright (2000) by National Academies Press. Reprinted with permission.

The National Academy of Science describes there are five necessary components of inquiry models and a range of learner involvement and teacher involvement within each category (Table 1). While the level of teacher and student direction varies by lesson and unit, the data-to-concept model includes all five "essential features" of inquiry instruction.

## Inquiry and Equity

One key aspect of this project is the issue of equity of achievement opportunities in relation to subpopulations of students. "Equity in science education requires that all students are provided with equitable opportunities to learn science and become engaged in science and engineering practices" (National Research Council, 2011, pp. 2-4). This means that the pedagogy must be accessible to all students. If inquiry based curricula comes from the students, then teachers can meet them where they are at and not vice versa. Kowalski (2008) relates that, "constructivist instructional materials *should* promote equity in the science classroom" (p. 25). With this in mind, the data-to-concept model should not create any achievement gaps based on student status or inclusion in a particular subpopulation because all students receive the same instruction using the data-to-concept method.

Inquiry learning promotes reasoning skills better than commonplace methods (Johnson & Lawson, 1998). A clinical study from BSCS comparing students taught using the 5E's learning cycle model to those using more "commonplace teaching strategies" supported the use of 5E's instructional methods and materials over commonplace materials and methods (Wilson, 2010). The 5E's learning cycle (attributed to Roger Bybee) is a lesson planning model in which students declare prior knowledge, investigate a phenomenon/object, explain their understandings and then are introduced to new concepts and skills to build a clear mental model. They are challenged to use their new model to explain new situations. Finally students assess their development. In the clinical study, Wilson (2010) found the inquiry group outperformed the commonplace materials group regardless of race, gender, and Free and Reduced Meals status (Wilson, 2010). In agreement with the BSCS findings, Johnson and Lawson (1998) found reasoning ability to be the strongest predictor of success in college biology and students in inquiry courses outperformed those in expository courses (Johnson & Lawson, 1998).

In contrast to the BSCS study, Von Secker analyzed data from 4377 students in 1406 classes using hierarchical linear models and found that while inquiry based pedagogy is correlated to overall higher achievement, some groups of students are likely to experience a narrowing of achievement gaps while for other groups, the achievement gap actually widened. This widening of achievement gaps was attributed to teacher emphases such as laboratory techniques, problem solving or scientific writing (Von Secker, 2002). These findings serve as a foundation for my research to determine if achievement of students at Big Sky is equitable.

## Summary

Constructivist theories of learning have helped shape a paradigm shift in science education in which active, student-centered inquiry is the focus. Studies have provided evidence to support inquiry models of teaching over more traditional models. Inquiry is at the heart of both national and state science education standards. While there is evidence based on overall achievement gains to support inquiry based curricula, there is however, some contradictory evidence that all students benefit equally from this approach. While there is some contradictory evidence about achievement gaps in the literature, our department has felt the benefits of an inquiry-based curriculum are greater than the benefits of a more traditional approach. This study was an attempt to determine if the data-to-concept curriculum provides equity of achievement opportunities for students regardless of status.

# METHODOLOGY

## Description of Data-To-Concept Curriculum

The data-to-concept model adopted by the Big Sky High School science department is a student-centered pedagogy. The data-to-concept name is not a formally described curriculum; the name was derived from professional discussions over the last few years that narrow the focus not to a particular learning cycle such as the 5E's, but rather, a focus on the fundamental principles of learning cycles. The central focus of the pedagogical model is the acquisition of data and manipulation/analysis of the data in order for students to derive a particular concept or mental model. The students then assess or critique their mental model by comparing it to accepted explanations or models and apply their newly constructed conceptual model to new situations. For example, to introduce the concept of atoms, students filled a thin stem of glass tubing with blue water and yellow ethanol and no air space. They capped the tube, slowly mixed, and a space appeared in the tube. Students were then asked to offer explanations as to why there was a change in the system. Students were asked to share and critique explanations. Students were asked to think/share other situations they have observed where mixing two materials of equal volume did not equal double the volume of each. After developing their mental models—through discussion and guided questioning, students were asked to explain how the mixing of the fluids is support for atomic theory.

This is in contrast to more traditional teacher centered approaches where a teacher explains a concept with notes, demonstrations and/or algorithms and then has students complete a lab to validate that concept. In my class, there are few notes, no textbooks, and often no "wrong" answers as students are clearly instructed that scientific claims rely on evidence. Each lesson and unit is developed with a learning cycle as a focus—specifically the data-to-concept model. Students are explicitly given their learning targets for every lesson and unit through handouts and verbal/visual reminders. After engaging the students and trying to have them identify their preconceptions, students are asked a guiding question (in most, but not all situations, this question is provided by me). Generally, this question must be answered with the acquisition of data and manipulation or analysis of that data. Whenever possible, students write hypotheses for the question. After analysis, I assist students to develop a conceptual framework from their experiences. This learning cycle can be completed in single class period exercises, but often take several classes to complete.

The following is an example of the data-to-concept model from an introductory set of lessons on ecosystems. Students were asked the guiding question, "what makes the slough and the river different ecosystems?" On the first day, students went to a study site at the Bitterroot River near campus and made observations in the field thinking about influences to each ecosystem.   After students shared their observations, they were asked to write a hypothesis about the communities found in each ecosystem. Students were asked to fill in the blanks in the following statement: “If we collect benthic macroinvertebrates (river insects and bugs) from the river and slough ecosystems and compare the communities, then we will find _____________ (similar or different) communities, because, _______________.”

After designing a method to test their hypothesis, they collected data and analyzed them to determine if the data supported or contradicted their hypotheses. All students participated in a two-day collection and identification of macroinvertebrates to determine the composition of the communities at each sample site. Depending on their hypothesis, the student research groups (on a return trip to the study site) sampled substrate, velocity, discharge, dissolved oxygen, amount of sunlight, nitrate levels, phosphate levels, temperature or water clarity. Students shared their findings and wrote a summary synthesis of the investigations conducted by all students. After these experiences, students were given formal definitions and explanations of ecosystems and asked to critique their explanations. This example is fairly typical of the sequence of events which students experience with lessons and units (Table 2) using the data-to-concept model.

Table 2
*Integrated Earth, Space and Physical Science Scope and Sequence*

| Unit of Study | Approximate length of time for unit (block schedule) |
|---|---|
| Earth's subsystems, ecosystems, and conducting and investigation | 6 weeks |
| Newton's laws | 6 weeks |
| Forms and transfers of energy | 4 weeks |
| Weather | 4 weeks |
| Climate | 4 weeks |
| Chemistry | 4 weeks |
| Astronomy | 4 weeks |
| Geologic features/plate tectonics | 4 weeks |

Each unit in the above table was designed with the data-to-concept model as a primary focus. This shift in pedagogy has been slow and is ongoing as I explore ways to get students doing science instead of learning about science.

## Instrumentation

### Data Collection Instruments and Analysis

In order to adequately address my research questions, the primary data collection instruments were Anton Lawson's Classroom Test of Scientific Reasoning (CTSR) (Appendix A), an adapted version of Anton Lawson's Scientific Attitudes, Skills and Knowledge Survey (SASKS) (Appendix B), student transcripts, and MontCAS CRT test results (referred to as MontCas to avoid confusing CRT with CTSR). The CTSR data were collected from students who began high school in the fall of 2009 and the SASKS data were collected from students who began high school in fall 2011. The data are independent of each other and are not compared.  Student interviews, my teacher journal, and teacher interviews were used to help explain/interpret trends uncovered during analysis (Table 3).

Table 3
*Focus Questions Data Collection Matrix*

| Research Questions | Data collection Method | Explanation |
|---|---|---|
| *How does the data-to-concept model of teaching science impact various sub-populations of students?* | 1. Classroom Test of Scientific Reasoning (CTSR)<br>2. MontCAS Test<br>3. Scientific Attitudes, Skills and Knowledge Survey(SASKS) | Pre to Post comparison of CTSR (after two years required science), level of Achievement on MontCAS, attitude |
| *By comparing achievement on the CTSR and MontCas—what, if any, factors may be correlated to level of achievement?* | 1. CTSR<br>2. Student Transcripts<br>3. Student Demographic data | Data revealed patterns, which allowed for determining whether particular characteristics (or inclusion in a particular sub-population) can be used as predictors of achievement gains. |
| *How do student attitudes towards science change as a result of a data-to-concept curriculum?* | 1. SASKS<br>2. Student Interviews<br>3. Teacher Journal | Pre to Post comparison of SASKS (1 year), interviews to probe deeper and teacher observations to identify changes. |
| *How does the data-to-concept model of teaching science impact teachers?* | 1. Personal Journal/Reflections<br>2. Teacher Interviews<br>3. Teacher Questionnaire<br>4. Student interviews | Students and teachers alike are impacted by the implementation of new curricula. Through interviews and reflection, I attempted to identify trends related to the impacts of the data-to-concept curriculum on teachers. |

The Classroom Test of Scientific Reasoning (Revised Edition: August 2000) was one primary data source for quantifying how the data-to-concept curriculum impacts various subpopulations of students. The test was designed to measure the level of student reasoning skills. In the development of the test, Lawson found the test to be reliable and have three levels of validity (Lawson, 1978). I used the paired scores from students who took the exam in the fall of 2009 and again in the spring of 2011 (*N* = 116). This sample represents only those students who completed a pre and post CTSR for the time frame--representing approximately 45% of the students who started their two years of required science in 2009. Along with the CTSR scores, student data in the sample included their fifth semester cumulative GPA, their grade 10 MontCas scores in science, math and reading, along with demographic data: Title I, low income (as reported on MontCas), gender, and race. Due to the limited racial diversity in the sample, the category was ignored for the purposes of this study.

The MontCas criterion referenced test is the state of Montana's federally mandated test given to students in grades 3-8 and 10. The test is designed to, "assess how well students have met Montana grade-level expectations for each content area" (Measured Progress, 2009-10, p. 4). The test is divided into three primary subjects: science, reading and math. For each subject, scores are used to categorize each student as advanced, proficient, nearing-proficiency or novice. According to the technical report, 20-26% of the points on the test are at the recall level (Level 1) and 5-20% are at the strategic thinking level (Level 3) (Measured Progress, 2009-10, p. 16). Measured Progress, a testing company, analyzes the MontCas for bias, reliability and validity. Because the MontCas and the CTSR were designed to measure different aspects of student learning, using both scores gives a more complete picture of achievement.

Normalized gains were used to determine the changes in CTSR test scores for students completing two years of data-to-concept classes. Various comparisons between groups were made using the t-test and ANOVA to determine if there were achievement differences between males and females, between Title I students and non-Title I students, between low income identified students and non-low income students. CTSR scores were compared to achievement on the MontCas as well. The normalized gains scores were also used to separate the students into a high achieving group (one standard deviation above the mean) and a low achieving group (one standard deviation below the mean). These groups were compared to identify possible predictors of achievement.

The SASKS survey was analyzed for change in student attitude. Anton Lawson, Arizona State University, developed the SASKS instrument. I took selections from each of three versions of the SASKS survey to create a modified SASKS Because the survey included knowledge as well as attitude questions, I asked each of my seven colleagues in the science department to mark the survey questions as to which items they believe reflect attitude. Through consensus, I determined which statements reflect student interest/attitude. The SASKS instrument directs students to choose, "strongly agree, agree, disagree, strongly disagree or I don't know," for each statement. Some of the statements are written such that agreement would indicate a "negative" attitude while other statements are phrased so that agreement would indicate a "positive" attitude. To account for this, I numerically coded student responses dependant on the phrasing. For questions 1, 9 and 14 agreement indicates a negative attitude, while for questions 2, 8, 16, 17, 20 and 21, agreement indicates a positive attitude. I assigned each response choice with a numerical value of 2, 1, 0, -1 or -2 (Table 4).

Table 4
*Numerical Coding (Values) for SASKS Instrument*

| | Response Choices and numerical values | | | | |
|---|---|---|---|---|---|
| Questions | Strongly Agree | Agree | I don't know | Disagree | Strongly Disagree |
| 1, 9, 14, 20 | -2 | -1 | 0 | 1 | 2 |
| 2, 8, 16, 17, 21 | 2 | 1 | 0 | -1 | -2 |

The survey was administered to my three Integrated Science classes in early October, 2011 and again in late January, 2012. Only students who completed the survey twice were used in this study (*N* = 44), representing approximately 70% of the students enrolled in my three classes. Student responses were numerically coded and analyzed for patterns and change. Item analysis was used to review each question. Responses were also correlated to students' first semester science grades.

Student interviews were conducted at the end of the data collection in April 2012. I interviewed a stratified random sample of students who had also completed a pre and post SASKS survey. The sample group (*N* = 10) was selected to obtain a cross section of students by gender and Title I inclusion. Income status was not available for this student sample. All interviews were video recorded and transcribed. The transcripts were analyzed for identifiable trends (eg. generally positive, generally negative) and compared to trends uncovered in the SASKS survey.

In order to examine the effects of the data-to-concept model on my teaching, I used my teaching journal in conjunction with teacher interviews and a teacher survey. My teacher journal consisted of observations made after each lesson throughout the first semester during the 2011-2012 school year. My observations were primarily aimed at student response to the curriculum and my thoughts regarding the efficacy of the lessons. My colleagues completed a questionnaire regarding their experiences with the data-to-concept model, which I followed with interviews. I was able to reflect upon my experiences compared to those of other teachers to get a more complete picture of the effects of the data-to-concept model on my teaching.

# DATA AND ANALYSIS

## How does the data-to-concept model of teaching science impact various sub-populations of students—are there differences?

In order to determine if students made gains on the CTSR, normalized gains were calculated for all students. “The normalized gain, g, is defined as

g = (postest-pretest)/(100-pretest), measuring the fraction of available improvement obtained” (Stewart, n.d.). The normalized gain for each student was based on the student’s Fall 2009 scores (pre) and his/her Spring 2011 scores (post). As outlined in the methods section, the CTSR data set was comprised by only students who took both pre and post tests. A paired t-test of raw scores was performed to determine if curriculum improved CTSR scores. The mean normalized gain ($M$=0.160, $SD$=0.328, $N$=116) was significantly greater than zero, $t(115)=-5.91$, one-tail $p$= <0.001, providing evidence that the data-to-concept curriculum improves CTSR scores (Figure 1).

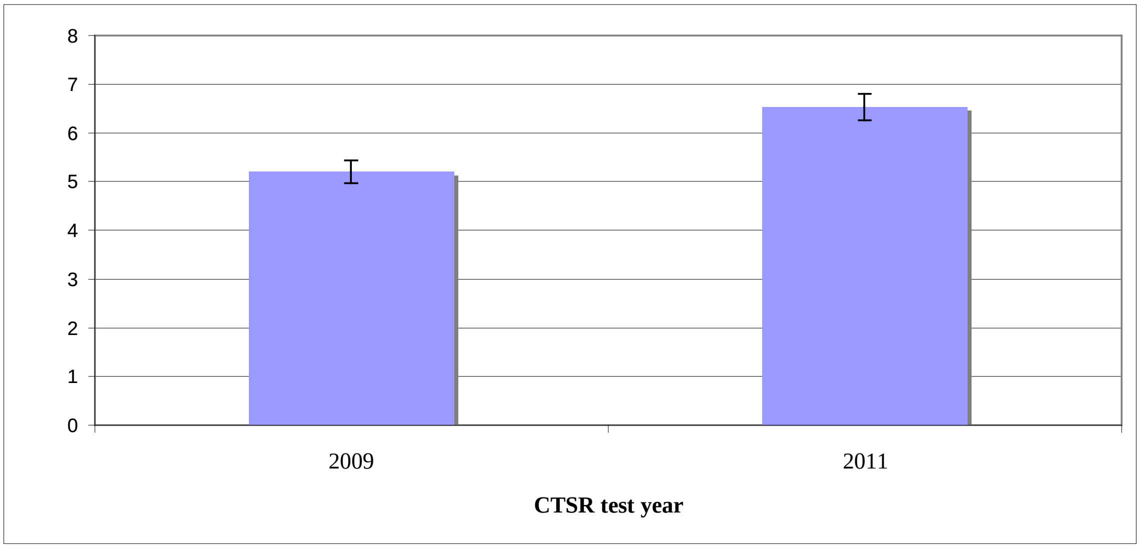


*Figure 1.* Mean CTSR score (all students), (*N*=116).

*Note.* The above figure represents the mean CTSR sores (N=116). Only students who completed both the 2009 and 2011 tests were included. The students' 2009 scores were compared against their 2011 scores. The mean score increased from 5.198 to 6.526. A paired t-test revealed the change was significant, t(115)=1.981, two tail p<0.001. Error bars are one standard error.

The raw scores also indicate students improved their reasoning skills. Only seven students (6%) achieved a score of 10 or better (out of 13) on the initial CTSR test; 21 students (18%) achieved a score of 10 or better on the final CTSR test. This data revealed that in general, students' science reasoning skills improved while in data-to-concept science classes.

While not all students made gains, comparison of students who only made positive normalized gains (*N*=71) revealed that for students who made positive gains, the gain was significant (Figure 2).

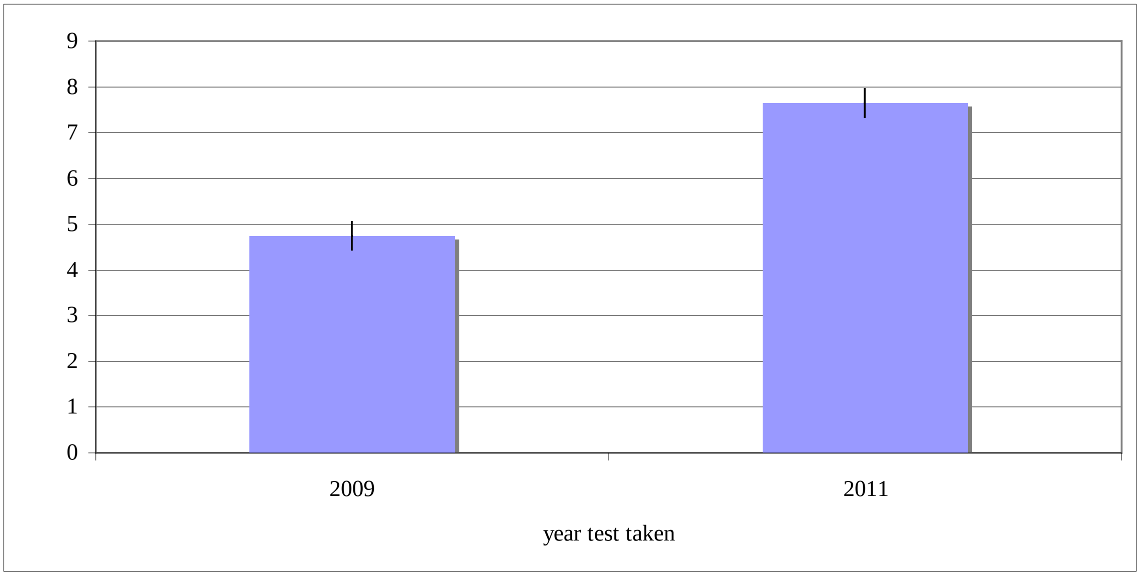


*Figure 2.* Mean CTSR score (students with positive gains), (*N*=71).

*Note.* The above figure represents the mean CTSR sores for students who made positive gains (*N*=71). The students' 2009 scores were compared against their 2011 scores. The mean score increased from 4.746 to 7.648. A paired t-test revealed the change was significant, t(70)=-16.360, two tail p<0.001. Error bars are one standard error.

It is possible that some students did not take the tests seriously as there is no grade associated with the tests—which means students do not have incentive other than intrinsic rewards. There are some outlier students who made significant losses on the CTSR. No interviews were conducted to explore the reasoning for the losses, but it is unlikely that these outlier students actually lost significant reasoning skill as a result of the data-to-concept curriculum.

There were 71 total students out of 116 who made positive gains on the CTSR, 18 students made no change and 27 showed a negative gain. The mean score for students making negative and no gain for the CTSR (*N=45)* changed from 5.9 to 3.8 and the median score changed from 6 to 3.  For students who made positive gains (*N*=71), the mean score increased from 4.7 to 7.6 and the median score changed from 4 to 8. Students who had no gain and negative gain on the CTSR had higher average first-test scores than students who showed positive gains. Nevertheless, the final test mean score of students who made positive gains surpassed the first-test mean score of those who made no gain or negative gains. It may be that some students do not respond as well as others to the data-to-concept curriculum and therefore, do not make the same gains. It is also possible some students, especially those who showed significant losses, did not approach the test seriously. This is indicated by five students who had GPA's of 3.5 or higher and were also advanced or proficient on the MontCas but made negative gains on the CTSR.

A t-test shows that the mean GPA of the positive gains group, 3.339, was significantly higher than the no-gain/negative gain group's mean GPA, 3.039, $t(106)=1.983$, two-tail $p=0.025$.In the positive gains group ($N=71$), 15 students had a GPA lower than 3.0 (4.0 scale). While in the no gain/negative gains group ($N=45$), 18 students had GPAs lower than 3.0. There is a trend comparing GPA to normalized gains on the CTSR but the relationship is not a strong one (*correlation*=0.315). A stronger correlation exists between a student's sophomore raw CTSR score and their GPA (*correlation*=0.558). In the no-gain/negative gains group the GPAs ranged from 1.188 to 4.0 and in the positive gains group, the GPA range was from 1.322 to 4.0. The data indicate that all students are capable of making gains, regardless of overall GPA and that generally, the higher a student's reasoning skills, the higher a student's overall GPA.

Results of the CTSR scores were also analyzed by comparing the results of male and female normalized gains on the CTSR. There was not a significant difference between males and females $t(114)=1.710$, two-tail $p=0.090$. Comparing the gains of only students who made positive CTSR gains (*N* = 71) revealed a nearly identical normalized gain for both males (g = 0.372) and females (g = 0.373). Furthermore, there was an equal distribution, 36 males and 36 females who made advanced and proficient levels on the science MontCas—the levels used by the state to measure adequate yearly progress. On the other end of the spectrum, 20 females and 24 males failed to make advanced and proficient levels. Taken together, these data indicate there is not an achievement gap based on gender when using the data-to-concept model.

Comparing Title I students to non-Title I students, however did indicate differences. There were 24 Title I students identified representing 21% of the sample (*N* = 114). This was consistent with the entire graduating class which has 22% Title I students (*N* = 260). While there was a difference in normalized gains ($M_{Title\ I}$=0.059 and $M_{non\text{-}Title\ I}$=0.186), a t-test revealed no significant differences based on Title I status, $t(114) = -1.696$, two-tail $p = 0.093$. Nevertheless, analyzing only students making positive gains on the CTSR (*N* = 71) indicated a significant difference in the average gain of Title I students compared to non-Title I students, $t(69) = -2.387$, two-tail $p = 0.020$ (Figure 3).

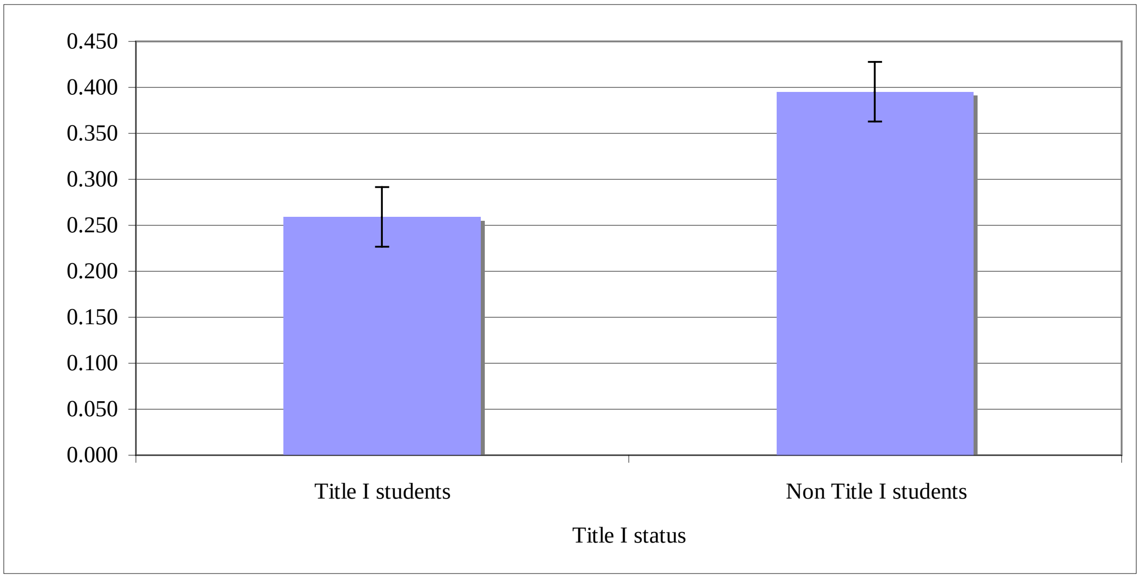


*Figure 3.* Title I vs. Non-Title I CTSR normalized gains, (*N*=71).

*Note.* This graph shows the average (mean) normalized gains on the CTSR for students who made positive normalized gains by Title I status. The students' 2009 scores were compared against their 2011 scores. There were 12 Title I students and 59 non-Title I students. Error bars are the pooled variance.

This apparent gap could be the result of the CTSR posing specific language problems for Title I students and not necessarily a gap in reasoning ability. In general, however, Title I students made less gains on the CTSR as measured by normalized gains.

Comparison of Title I students to non-Title I students also revealed differences as indicated in the percent of students making Advance and Proficient levels on the MontCas tests (Figure 4).

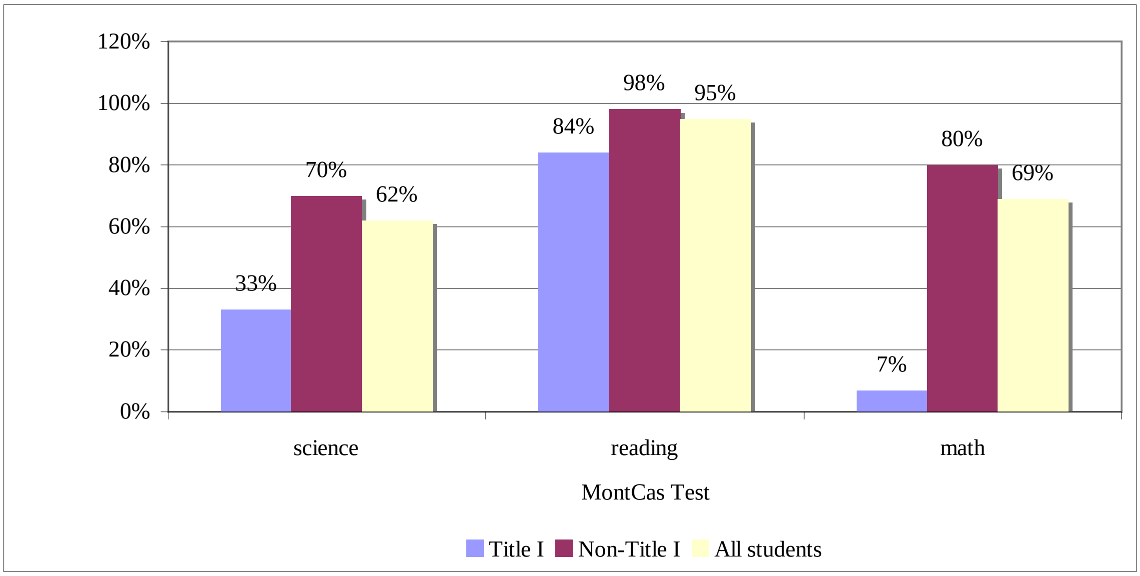


*Figure 4.* Advanced and Proficient Levels on MontCas by Title I status, (*N*=116).
*Note.* This graph shows the percent of students (*N=116)* making advanced and proficient levels on the MontCas test.

The data indicates a disproportionate distribution of students achieving advanced and proficient levels on the math and science tests. The reading scores indicate less disproportion of Title I students. The math and science MontCas scores had a high level of correlation (0.759)—and of the 16 Title I students who did not make advanced and proficient levels on the science test, 11 also did not make advanced and proficient on the math test. These data, however, indicate there is some achievement gap between Title I and non-Title I students in science. Perhaps the data-to-concept model is not as accessible to Title I students compared to non-Title I students. Another possibility is there was already an achievement gap between Title I and non-Title I students in science and the data-to-concept model could have influenced that achievement gap neutrally, negatively or positively.

Aside from gender and Title I status, income status was also analyzed for equity of achievement because income status has been correlated to student achievement (Sirin, 2005). Low-income is a reporting category on MontCas and for this study, the group identified as low-income came from student data reported on the MontCas. While there does appear to be a difference between low income students and non-low income students related to normalized gain, it is not a significant difference, $t(114)=1.213$, two-tail $p=0.227$). There is overlap between students identified as Title I and low income; 10 of 28 low-income identified students were also Title I. While none of the 24 Title I students' normalized gains fell one standard deviation above the mean normalized gain ($N=19$), two of the 28 students identified as low income had normalized gains one standard deviation above the mean. On the other end of the spectrum, in the group one standard deviation below the mean ($N=20$), there were five students identified as Title I. Three of those students were both low income and Title I; two students identified as low income and not Title I had normalized gains one standard deviation below the mean. The distribution of low-income students making advanced and proficient is close to the distribution of non low-income students, again indicating there is little difference between the groups (Figure 5).

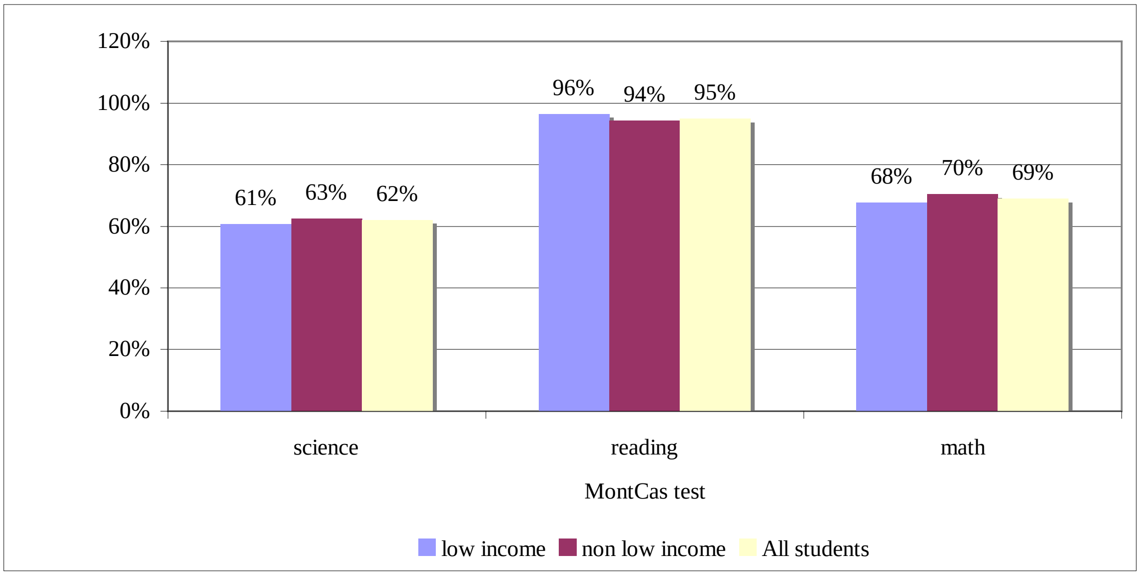


*Figure 5.* Advanced and proficient levels on MontCas by income status, (*N*=116).
*Note.* The graph above shows the percentage of students (*N*=116) making Advanced and Proficient Levels on MontCas test by income level.

Overall, there does not seem to be a difference in achievement based on income status of students. This would indicate the data-to-concept curriculum makes achievement equitable regardless of income status.

<u>What, if any, factors may be correlated to level of achievement?</u>

In an effort to identify factors related to normalized gains on the CTSR, students were categorized as “high achievers”--one standard deviation above mean normalized gain (*N*=19), or “low achievers”--one standard deviation below the mean (*N*=20). Distribution of males and females was within expected ranges, chi square $p_{\textit{high achievers}}$ = 0.590 and $p_{\textit{low achievers}}$ = 0.135. There does not appear to be a relationship between gender and level of achievement, indicating the data-to-concept model allows for equitable achievement based on gender.

Five Title I students fell into the low achievers category and no Title I students made the high achievers category. There were two low-income students in the high achievement group and four in the low achievement group. As indicated before, there was only one student in the low achievement group who was identified as low income but not Title I. Title I students are disproportionately represented in the low achievement group. As noted earlier, the data indicate equitable achievement based on income status but not based on Title I status. The distribution of achievement gains seems to indicate Title I students have a more difficult time with the data-to-concept model than non-Title I students.

There was a significant difference in overall GPA between the high achieving ($M$=3.682, $SD$=0.357) and low achieving groups ($M$=2.946, $SD$=0.662), $t(36)$=4.262, two-tail $p$=0.0001. Students who made the most positive gains on the CTSR were more likely to have a high GPA. It is possible students who make the most gains in their reasoning skills, a focal point of the data-to-concept model, are more likely to succeed in classes other than science.

Students in the high achievement group also differed from the low achievement group based upon their MontCas scores. Comparing the distribution of advanced and proficient scores revealed a large discrepancy in science and math scores between students in the high achievement group and the low achievement group (Figure 6).

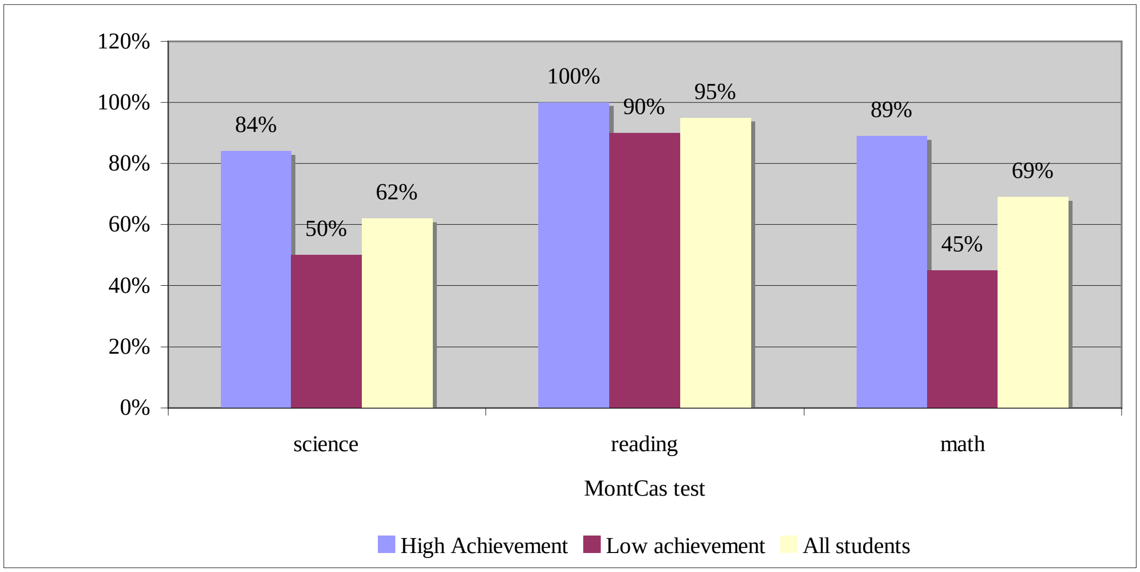


*Figure 6.* Percent of students making advanced and proficient on MontCas, (*N*=116). *Note.* The graph above shows the percentage of students (*N=116)* making advanced and proficient levels on MontCas. The high achievement group (*n*=19) is comprised of students one standard deviation above the mean normalized gain on the CTSR and the low achievement group (*n*=20) is the group of students one standard deviation below the mean normalized gain on the CTSR.

Students making the highest gains on the CTSR are more likely to achieve proficiency levels on the MontCas. If there is a strong correlation between science reasoning skills and success on standardized tests used for evaluating programs and schools, then using the data-to-concept curriculum offers students opportunities to practice and improve their reasoning skills unlike a traditional approach.

The normalized gains of all students in advanced, proficient and nearing proficiency groups were compared using a one-way ANOVA. The test revealed a significant difference between MontCas achievement group and normalized gains on CTSR, $F(2)$, 108=4.028, $p$=0.021. Students with higher normalized gains were more likely to be in the advanced and proficient group. A t-test revealed no significant differences between the normalized gains of advanced and proficient level students, *t*(70)=0.334, two-tail *p*=1.994).

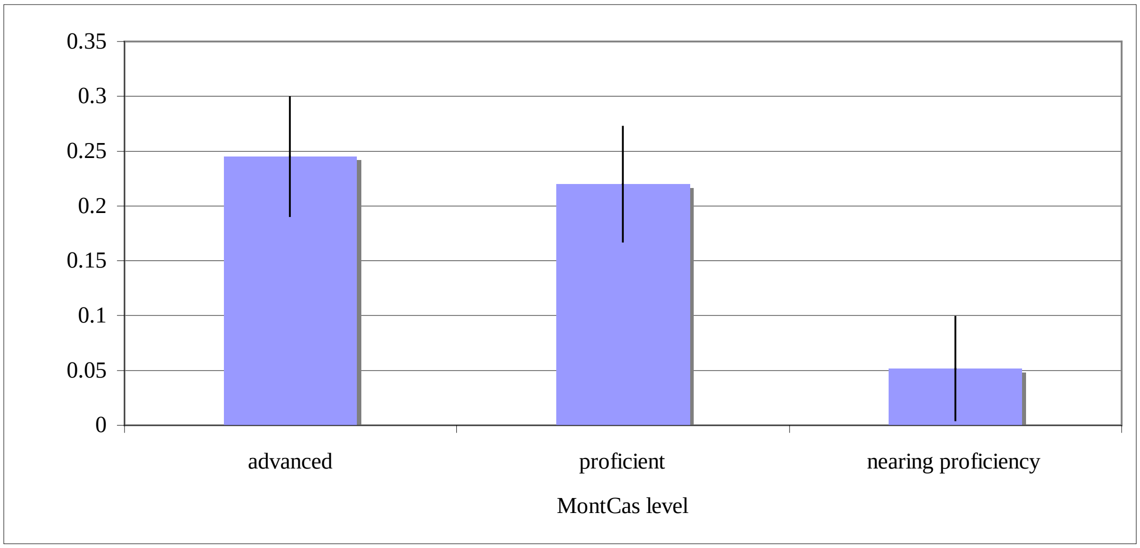


*Figure 7.* MontCas level compared to normalized gain on CTSR, (*N*=111).
*Note.* The graph above shows that the advanced and proficient groups on the MontCas typically had higher gains on the CTSR. Error bars are one standard error.

By combining advanced and proficient students and comparing to combined nearing proficiency and novice students, there is a significant difference in normalized gain, *t*(114)=-3.157, *p*=0.002) (Figure 7). We know we do not reach all the standards by the time students take the MontCas test because the data-to-concept model requires less breadth of topics and more depth of understanding. The data indicate use of the data-to-concept model does not sacrifice content knowledge, a primary component of the MontCas.

How do student attitudes towards science change as a result of a data-to-concept curriculum?

SASKS scores for each student were calculated by averaging the coded responses of the nine survey items. The score is meant to serve as a general gauge of student attitude towards science. The possible range was from -2 (indicating an overall negative attitude) to +2 (indicating a positive attitude). Generally, students have positive attitudes towards science as indicated by the slightly positive average SASKS scores. The first test average was 0.51 and the final test average was 0.45. This difference was not tested for significance as the measure was meant as a relative gauge only. Item 8 on the SASKS states, “I like science;” and 33 students responded with either agree or strongly agree on the second administration of the survey. Seven students did not change their initial response of *disagree* or *strongly disagree*. The only changes in regard to the statement was that two students changed from *agree* to *I don’t know*. A similar pattern emerged from the SASKS statement, “if given a choice, I would not study science.” Most (70%) disagreed and only one student made a change, from *I don’t know* to *agree*. The student said this change was because, “after the day we had to go around and talk to all our teachers about what classes we’re taking next year like, I don’t know, I kinda realized that you need science if you’re going to do anything.”

While these two items showed little change, other items from SASKS illustrated change (Table 5).

Table 5
*SASKS Response Items Indicating Change. The Numbers of Students in Each Category (N=44)*

| | statement #1: Science is mostly memorization. | | statement #2: The primary goal of modern science is to explain natural phenomenon. | | statement #14: Explanations that seem reasonable and make intuitive sense need not be tested. | | statement #20: The primary goal of modern science is to discover facts about nature. | |
|---|---|---|---|---|---|---|---|---|
| | pre | post | pre | post | pre | post | pre | post |
| Uncertain | 7 | 2 | 21 | 23 | 10 | 10 | 17 | 8 |
| Positive | 31 | 29 | 15 | 9 | 28 | 33 | 18 | 20 |
| Negative | 6 | 13 | 8 | 12 | 6 | 1 | 9 | 16 |

There was an overall change towards the negative with only six students initially indicating agreement with, statement 1: “Science is mostly memorization.” On the second take, 13 students indicated agreement. This could be due to the timing of the second SASKS, which was administered the day after the first semester final. Most of the change can be attributed to students changing from *I don’t know* to *agree* rather than *disagree* to *agree*. In general, students do not feel science is mostly memorization and their short experience with the data-to-concept curriculum did little to change the overall perception.

Students indicated uncertainty regarding the nature of science. Statement 2, “the primary goal of modern science is to explain natural phenomenon,” had more than double the number of *I don’t know* responses (*n=23)* on the second take compared to any other statement. Initially there was more uncertainty regarding statement 20, “the primary goal of modern science is to discover facts about nature,” but on second take, the number of students indicating *I don't know* had dropped from 17 students to nine. The reasoning for the change is not readily apparent. Five students switched from *agree* to *disagree* yet three switched from *disagree* to *agree*. There were a total of 26 students who changed their answers from pre to post tests.

Due to the conflicting information on the SASKS survey, I asked students to complete a quick-write activity to complete the following statement with their own words, "The primary goal, or aim, of modern science is…" Just over half (62%) of the students responded with statements which could be grouped as "explaining observations/things" The remaining third could be relatively, equally subdivided into categories of "nonsense", "discovering new things", "making new things," and "finding solutions for problems." When asked during an interview, one student shed light on the conflicting information from the quick write and the SASKS: "I don't just think it's about nature, it's used in computers and stuff." I believe the disconnection arose from the concept of the word, "natural." I thought the author intended the term to indicate that the limits of science are the observable world and that science cannot explain the supernatural. Obviously, at least one student associated the nature referred to in the question as materials, objects and processes not created by humans. These results may indicate that the data-to-concept model alone does not give students a good concept of the strengths and limitations of science as a way of knowing.

While the previous examples indicate some uncertainty about student attitudes about the nature of science, statement 14, "Explanations that seem reasonable and make intuitive sense need not be tested," seemed to have the most overt change. Five students who initially chose *agree* switched to *disagree* on the post-test, which accounted for almost all of the overall change in the category. This change may be attributed to my constant reminders that the correct answers are supported by evidence. By learning with the data-to-concept model, students become aware they can only make claims based on observation and evidence.

Students were made aware of the importance of evidence when they practiced argumentation when pressed on how they know the earth actually moves around the sun--or, how we know atoms exist. By giving students alternative explanations to consider, they are forced into working with the foundations of hypothesis testing. During the interviews, however, I discovered that students did not fully understand the role of hypothesis testing in science. Three students did not answer the question. Others claimed, “it’s a goal to aim for,” “guess and checking so it gives you a set of what you’re looking for and kind of what you want,” and “you have to be able to prove what you set out to prove.” While students seemed to be aware that alternative explanations need testing, they did not seem to understand, or at least communicate, the role of generating alternative explanations to test against one another. This may indicate students do not have enough opportunities to practice generating multiple hypotheses with the way I have implemented the data-to-concept curriculum.

To follow up with trends uncovered with achievement gains, comparisons were made between SASKS scores by Title I enrollment and by gender to determine if differences exist. The SASKS survey indicated there was a difference between attitudes towards science between Title I and non-Title I students. Title I ($N$=8) students in my classes had a slightly lower average SASKS score ($M$=0.19, $SD$=0.55) than non-Title I ($N$=36) students ($M$=0.51, $SD$=0.46). Again, the results were not tested for significance. It was, however, observed that six of the eight Title I students had SASKS scores lower than the mean; and that only four students had overall negative SASKS scores, two of whom were Title I students. The results of the SASKS survey are in line with the achievement data in that, the data-to-concept curriculum may be less accessible to Title I students.

Males had a slightly higher average final SASKS score (*M*=0.58, *SD*=0.40) than females (*M*=0.36, *SD*=0.53). The females had a wider range of attitude scores (2.22) than males (1.33) on both pre and post-test (post test ranges indicated). The lower female average could be due to the fact that the only four students with negative scores were female. One of the females with a negative SASKS score I interviewed, however, indicated that she did, in fact, “like science a little bit because I want to be a vet.” Her interview hinted of previous experiences, which had affected her attitude, “To be honest this is the best science class I’ve ever had,” but she also stated, “I really don’t like science at all It’s hard.” Perhaps her apparent negative attitude from the SASKS was not really indicative of an overall negative attitude towards science. The numbers do not tell the whole story, however, as all four students whose SASKS score was negative were female and three were in the same class period.

Numerous teacher journal entries mentioned the struggles with this particular class period. One entry from September 14 stated, “Period 7 is going to be a challenge. Not much overall work ethic. Interesting bunch--many (1/3) seem to be disinterested in school in general. Lots of absences, tardies, etc.” One month later, I wrote, “Don't know if it's ability, desire, after lunch blues/highs--but an altogether different bunch.” While not tested for significance, there is a correlation of 0.342 between first semester grades and

SASKS scores for all students. When grouped together by class, the correlation is 0.95 (Table 6).

Table 6
*Final SASKS Scores and Semester One Grades by Class*

| | Average SASKS score (final) | 1st semester science grade |
|---|---|---|
| period 5 avg | 0.57 | 78% |
| period 6 avg | 0.56 | 83% |
| period 7 avg | 0.27 | 69% |

It seems then, that more positive attitudes result in higher grades and that possibly, a few students with negative attitudes may have an effect on entire classes.

While the overall trends do not indicate much change in relation to overall attitude, student interviews gave a slightly different perspective. One of the tasks during the interview was for students to identify two ways in which their prior learning experiences were different from their current experiences. All 10 interviewees indicated they noticed a difference in the lack of textbooks. One student simply stated, “the learning environment.” Another, “It’s better than all of my other science classes.” The interviewees only identified positive changes between prior and current science experiences. When I heard a student say, “it’s way more fun the way we do it now,” or “it was always so dull and boring,” or “I used to hate science, but now it’s fun,” I knew student attitudes were being changed.

Students identified various reasons during the interviews about why they prefer the data-to-concept model. One student claimed to like the data-to-concept model over traditional teaching methods because, “we do more group stuff and compare and stuff.” A second interviewee supported that claim, “we can confer with other groups—and the way that the experiments are led, we both get a chance to work.” Another student said, “the stuff we do here is a lot more hands-on,” compared to his previous science learning experiences. “You’re more involved in doing stuff,” said one student, which seemed to be a theme among those interviewed.

Even though students seem to prefer the data-to-concept model, my teacher journal reminded me that for students, changing to the data-to-concept model from a more traditional classroom is a big jump: “They are stuck on the "right" answer. Only one or two students offered possible reasons for the observations to the whole class.” There was definitely an adjustment period for students who had generally learned science in a more traditional manner. Every student interviewed indicated they had previously learned science in a more traditional manner.

This adjustment from a traditional science class was evident in my teacher journal: four of my first six journal entries related students wanting to know the “right’ answer. Students are so trained in finding the right answer and writing that answer down in the correct spot, they forget they can think. For the first few weeks, students slowly stopped asking for the right answer, except for a stubborn few. I did not make mention in my journal of students wanting to know the correct answer after our first unit. One student in particular this year reminded me of how frustrating the experience can be for students when near the end of the first semester, she said, "I have always gotten straight A's because I was an obedient student. Now, I have to think and this is the only class I don't have an A in." Asked if she liked this method of learning, she responded, "It's just so frustrating, why won't you just tell us the right answers… But it’s better than last year." With a little bit of training, most students seem to forget about the right answer question and begin to interact with each other to derive the best explanations for their observations.

Interviews supported the use of the data-to-concept curriculum as nine of ten interviewees chose the data-to-concept model over their previous learning experiences. When asked to explain why, I heard, "here, it's different. It's more like clues for you to figure it out, like, so you'll remember it." Another student explained, "I kinda prefer having the question to answer and maybe doing the experiment and if we still don't get it or maybe just after that reading it in the book to maybe confirm what we've learned." One student described, "just reading the textbook doesn't really stick in my mind, but actually doing interactive stuff kinda makes me remember." It seems that if given a choice, students prefer the data-to-concept model over more traditional approaches because the feel they learn better and enjoy it more.

How does the data-to-concept model impact teachers?

In a short write activity, I asked my colleagues in the science department to fill out a short questionnaire regarding their experiences with the data-to-concept model. When asked to summarize their experiences with the data-to-concept model using one word, two teachers responded with "rewarding" and two responded with "challenging." Numerous departmental discussions have reflected both the rewards and the challenges of teaching with the data-to-concept model. My November 17$^{th}$, journal entry reflects this after testing a new activity, "what do we need them to discover with this activity. Make that the sole focus. Liked test run now we need to refine.” After reflecting upon my own experiences and my shared experiences with my colleagues, it was determined that these two qualifiers describe the overall feelings of the department towards the model.

Teachers identified the benefits of the data-to-concept model on their own teaching. Responses included: “promotes diversity in the classroom,” “student participation increases and off-task behaviors decrease,” and “personally have developed a better, deeper, richer understanding of the content I teach.” Overall, teachers indicated, there are a variety of benefits to teaching using a data-to-concept model. From my own experiences, I have found that I am able to focus my time on developing meaningful lessons and less on grading. A student teacher in our department said, “I’m glad I got to teach here because this is not the way I was taught. This has been a very valuable experience.” All of these characteristics combined are indicative of why teachers think the model is rewarding.

Being that the primary focus is student achievement, teachers were also asked what they observed as benefits to students of the data-to-concept curriculum. Again the responses were varied: “learning is more efficient,” “this increases their self-confidence in and understanding of the course,” and three of the surveys indicated that students are more engaged learners. Throughout my journals, I noticed that students have to interact with each other in nearly every lesson. I have found that a good group dynamic is essential for success, so I often need to rearrange groups if the initial arrangements are not efficient. For the most part, students are engaged; according to my journals, I only had two instances in the first semester which I noted a major group dynamic issue.

From a student perspective, the impact on teachers using the data-to-concept model is a positive one, “I like the way you do it, make us find answers and then try to figure out if it’s right.” Another student related, “in 7th and 8th grade, I had the same teacher and we just like took notes and it wasn’t really fun. But like this year, like we do group stuff and compare and stuff.” Students noticed differences in the approach. One student remarked, “If you just tell us why something works, we really tend not to question it and we don’t actually learn anything about why it works; we just learn that it does.”

There are, however, challenges of implementing and teaching with a data-to-concept model, as indicated by the one-word summaries. One constant struggle is the external pressure to cover enough content, “It’s difficult to reach all of the standards because of implementation time.” One colleague stated, “It has made me carefully consider the content I teach.” Another challenge is, “holding back from telling students what they need to know and encouraging them to learn through their own personal experience.” One persistent challenge I noted in my journal was the time it takes to develop strong lessons and units, “More than anything it may indicate a rework of the unit to help students observe and describe the relationships better.” Another challenge is ensuring that the lessons are properly developed and that students have adequate scaffolding to complete the work. The questionnaires also reveal that student absences pose a persistent challenge, “as often concepts are developed as a result of small group discussion.” While there certainly are challenges, meeting those challenges provides a positive, rewarding experience for teachers.

# INTERPRETATION AND CONCLUSION

## Summary of key findings

In regards to the question, "How does the data-to-concept model of teaching science impact various sub-populations of students?" I found that in general students are making significant gains ($p$=<0.001) in their reasoning skills after two years of the data-to-concept curriculum as measured by the CTSR. This is consistent with a previous study conducted with Big Sky High School students by Mark Cracolice, The University of Montana, adding to the support of utilizing the data-to-concept model. There does not appear to be a difference in science achievement level based on gender or income status as indicated by the distributions of students in achievement levels on both the CTSR and MontCas. Statistical analysis revealed there is not a significant difference between gender ($p$=0.090) or income status ($p$=0.227). There does, however, appear to be a gap in science achievement based on Title I status. Title I students were disproportionately represented in the low-achievement group and were less likely to achieve advanced or proficient levels on the MontCas. Title I students who made gains, made significantly lower gains than non-Title I students ($p$=0.020). While students in general seem to improve their science reasoning skills, there seems to be an achievement gap based on Title I status.

Considering what factors may be predictors of achievement, I found that the strongest relationship existed between lower overall reasoning gains and lower achievement and Title I students. While some Title I students did make positive gains, the gains were lower than other students who made positive gains and they were more likely to be in nearing proficiency or novice levels on the MontCas. There did not seem to be further predictors of achievement.

In regards to the question, “How does the data-to-concept model affect student attitudes?” I found that students had a generally positive attitude towards science as indicated by the slightly positive overall SASKS scores and all interviewees responded positively regarding their experiences with the data-to-concept model. Interviews revealed students preferred data-to-concept model over more traditional textbook driven curricula. I also found that students could be persuaded that even reasonable explanations need testing. I discovered I need to help my students develop a stronger concept of the nature of science, specifically, the role of hypothesis testing and the goals and limitations of science. While not tested for significance, there may be a relationship between science grade and attitude.

Finally, I found that teachers prefer the data-to-concept model to more traditional methods of teaching. Teacher interviews and questionnaires indicated even with challenges, all teachers feel the data-to-concept model is superior to more traditional models of teaching science. While challenging, there are both personal and professional benefits to implementation of the data-to concept model as indicated by the questionnaires. Science teachers at Big Sky High School have committed to the data-to-concept curriculum and are now starting to develop uniform assessments to most accurately measure student achievement of learning expectations and standards. None of the teachers using the data-to-concept method were taught using the data-to-concept model, so there has been a steep learning curve. One colleague remarked there are no drawbacks to the data-to-concept model, “The worst inquiry based instruction is still better than the best traditional or expository instruction. The data supports this." While not everyone may be as passionate as this particular colleague, none of the teachers interviewed want to return to a more traditional approach of lecture-lab.

## Limitations of the study

There were a number of limitations to this study, which have implications for transfer. No account was made for teacher affect. Each classroom has its own unique environment. And although there is a very high amount of overlap in classrooms, no account was made for variations, which may impact student achievement. Along those same lines, little was done to remove outliers in the CTSR data set. Outlier data may result from students not taking tests seriously as they are not a graded assessment and the second test comes at the end of the school year when stress levels are high and students already feel a testing strain. A more precise measure of reasoning gain is possible with different statistical models, but for the purposes of this study, I was more interested in generalizations than exact gains.

Two different groups of Big Sky students have shown significant gains on the CTSR, but the apparent achievement gap of Title I students is the result of a census of one group. We have no data to inform us if our teaching practices have altered the gap in any way.  The data only indicates that for this particular group of students, there was an achievement gap.

Due to the independent nature of the data sets used in this study, no direct comparison could be made between attitude and achievement (as measured by CTSR and MontCas). One concern about the SASKS was that the first test was not administered until one month into school. Perhaps there was an attitude change in the first four weeks of school, which would not have been detected in the surveys. Nevertheless, the intended purpose was to make generalizations only.

## Further questions which remain unanswered

One primary area of further research is the relationship between Title I students and achievement level. One component worth investigating is the use of the CTSR—is the reading level appropriate? Would practical tasks designed to measure Piagetian reasoning reveal the same trends as the CTSR? It is also paramount to discover if an achievement gap exists based upon Title I status prior to starting the required two years of data-to-concept curriculum. We could then measure the effects of the data-to-concept model on the achievement gap. As it stands, the data only indicate there was an achievement gap within this cohort of students, but it does not indicate whether the data-to-concept curriculum increased, reduced or had no effect on the achievement gap. In relation to the above questions, it would also serve students and teachers to identify the root causes of the achievement gap so appropriate interventions could be utilized.

Discussion: implications for my teaching

In general, this study supports the use of a data-to-concept curriculum. I was encouraged by this study to find that students reasoning skills seem to improve and that students seemed to prefer the data-to-concept method to traditional teaching methods. The results further emphasize the need to continue developing and revising data-to-concept lessons to maximize student engagement with inquiry skills and processes. This study supports the use of the data-to-concept curriculum in my classroom and in the department at Big Sky High School.

I did find some confusion among students regarding the nature of science. It may benefit students to explicitly include lessons about the limitations and power of scientific understandings. There seems to be enough confusion about science as a way of understanding, at least in my classes this year, it indicates I may need to include an explicit nature of science lessons. In the past, I have used, “the checks lab,” found at http://www.indiana.edu/~ensiweb/lessons/chec.lab.html. This year I did not use the lesson—while I do not have data indicating students who complete the checks lab understand the nature of science better than students who do not complete the activity, I think that explicitly addressing the concept may help some students gain understanding. I also found that students need more practice with generating alternative explanations—I think this is an area our developed lessons/units could use some improvement; this is an area I will address as we meet this summer as a team to revise/develop curriculum.

Due to an apparent achievement gap between Title I students and non-Title I students, I will address literacy skills and give students more opportunities to read argumentative text to hopefully narrow any achievement gaps that may be present in the next cohort of students. I will also use released items from the MontCas as warm-up exercises to help students identify the types of questions they will be asked on the MontCas science test. While not necessarily addressing the content of the questions, seeing the phrasing and the style of questions will help students better understand how to interpret and respond to questions. As most students seem to prefer the data-to-concept model and most students show achievement gains I will continue to develop the data-to-concept model ensuring to address literacy skills to make achievement more equitable for all.

## VALUE

### Implications beyond my classroom

This study lends support for utilizing the data-to-concept curriculum. Teachers should be encouraged to explore inquiry models of teaching as the vehicle to deliver content. Both teachers and students alike expressed they preferred the data-to-concept model of teaching and learning to more traditional methods of teaching and learning. I have been part of professional discussions over the last few years where it seemed as if one could only choose inquiry or content. This, however, is a flawed argument if one considers inquiry methods as the mode of content delivery rather than being separate from the content. Traditional methods of teaching encourage a wide breadth of topics with little depth of understanding. On the other hand, inquiry methods tend to narrow the breadth of topics and encourage deeper, richer exploration. With the aim of helping students become better analysts and problem solvers, a data-to-concept curriculum provides learners with the opportunities to engage in the practices of science rather than remain passive absorbers of information.

This study also brings into focus a concern for many educators—the question of equity. Title I specialists and the science department have already set plans into motion to address the achievement gap between Title I and non Title I students at Big Sky High School. This will require teachers of the required two years of science to implement literacy strategies. Title I specialists will assess the CTSR for reading level and content specific vocabulary. Title I specialists will help us assess the nature of the achievement gap and implement strategies which will benefit all students. This study impacts my classroom, the science department and extends to the math department. There is a strong correlation between Title I status and proficiency level on the MontCas. In conversations with administration, there was an indication that we as a school may need to implement literacy strategies across all curricular areas especially as Common Core standards are implemented in the near future.

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# APPENDICES

# APPENDIX A

CLASSROOM TEST OF SCIENTIFIC REASONING

# CLASSROOM TEST OF

# SCIENTIFIC REASONING

***Multiple Choice Version***

Directions to Students:

This is a test of your ability to apply aspects of scientific and mathematical reasoning to analyze a situation to make a prediction or solve a problem. Make a dark mark on the answer sheet for the best answer for each item. If you do not fully understand what is being asked in an item, please ask the test administrator for clarification.

**DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO**

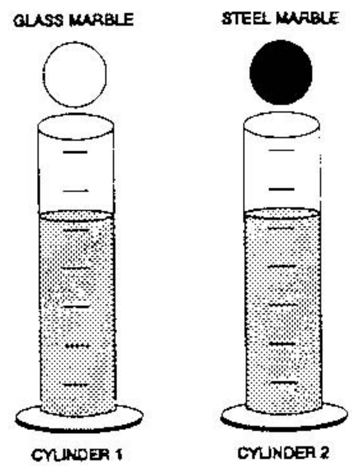
Revised Edition: August 2000 by Anton E. Lawson, Arizona State University. Based on: Lawson, A.E. 1978. Development and validation of the classroom test of formal reasoning. *Journal of Research in Science Teaching*, 15(1): 11-24.

1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct?*

   a. The pancake-shaped piece weighs more than the ball
   b. The two pieces still weigh the same
   c. The ball weighs more than the pancake-shaped piece

2. *because*

   a. the flattened piece covers a larger area.
   b. the ball pushes down more on one spot.
   c. when something is flattened it loses weight.
   d. clay has not been added or taken away.
   e. when something is flattened it gains weight.




3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape.

   Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one.

   When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*

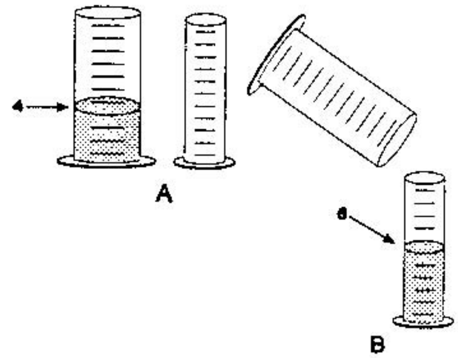
   a. to the same level as it did in Cylinder 1
   b. to a higher level than it did in Cylinder 1
   c. to a lower level than it did in Cylinder 1

4. *because*

   a. the steel marble will sink faster.
   b. the marbles are made of different materials.
   c. the steel marble is heavier than the glass marble.
   d. the glass marble creates less pressure.
   e. the marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).

Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*




a. to about 8
b. to about 9
c. to about 10
d. to about 12
e. none of these answers is correct

6. *because*

a. the answer can not be determined with the information given.
b. it went up 2 more before, so it will go up 2 more again.
c. it goes up 3 in the narrow for every 2 in the wide.
d. the second cylinder is narrower.
e. one must actually pour the water and observe to find out.

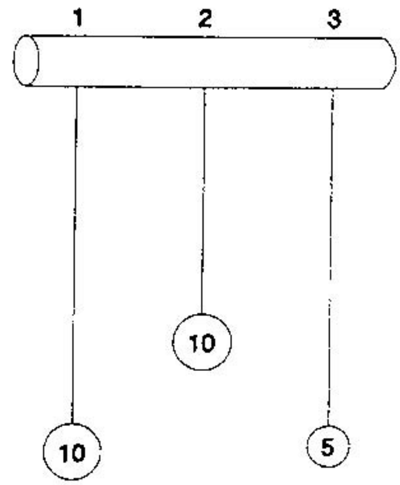
7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder?*

a. to about 7 1/2
b. to about 9
c. to about 8
d. to about 7 1/3
e. none of these answers is correct

8. *because*

a. the ratios must stay the same.
b. one must actually pour the water and observe to find out.
c. the answer can not be determined with the information given.
d. it was 2 less before so it will be 2 less again.
e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.



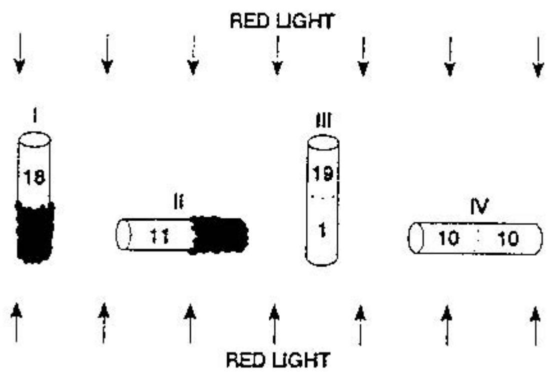

Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*

a. only one string
b. all three strings
c. 2 and 3
d. 1 and 3
e. 1 and 2

10. *because*

a. you must use the longest strings.
b. you must compare strings with both light and heavy weights.
c. only the lengths differ.
d. to make all possible comparisons.
e. the weights differ.

11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.




*This experiment shows that flies respond to* (respond means move to or away from):

a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

12. *because*

a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

# APPENDIX B

## SCIENCE SKILLS, ATTITUDES, AND KNOWLEDGE SURVEY

SASKS student survey

*This is a voluntary survey and participation or non-participation will not affect a student's grade or class standing in any way.*

NAME______________________ DATE ______________________

The following is a survey compiled from Anton Lawson's SASKS (versions 1, 2 and 3)
Use the following scale to respond to each of the following statements

**A. strongly agree B. agree C. don't know D. disagree E. strongly disagree**

_____ 1. Learning science is mostly memorization.

_____ 2. The primary goal of modern science is to explain natural phenomena.

_____ 3. A conclusion is a statement of what was observed in an experiment.

_____ 4. To be scientific, hypotheses must be testable.

_____ 5. A well-supported theory becomes a law.

_____ 6. Current scientific theories portray nature more accurately than those they replaced.

_____ 7. Scientists think atoms exist primarily because they have seen them through powerful microscopes

_____ 8. I like science.

_____ 9. If given a choice, I would not study science.

_____ 10. Hypotheses are derived from controlled observations of nature.

_____ 11. A hypothesis is a prediction of what will be observed in the future.

_____ 12. Hypotheses/theories can be disproved beyond any doubt.

_____ 13. A well-supported hypothesis becomes a theory.

_____ 14. Explanations that seem reasonable and make intuitive sense need not be tested.

_____ 15. To conclude that a hypothesis has been "supported" or "not supported," one must first compare observations with expectations.

_____ 16. I am good at science.

_____ 17. Science is useful for everyday problems.

_____ 18. Hypotheses/theories can not be proved to be true beyond any doubt.

_____ 19. To test a hypothesis, one needs a prediction.

_____ 20. The primary goal of modern science is to discover facts about nature.

_____ 21. Coming up with hypotheses requires creative thinking

All versions of the complete SASKS instruments are available at:
http://www.public.asu.edu/~anton1/LawsonAssessments.htm

# APPENDIX C

## IRB EXEMPTION

MONTANA STATE UNIVERSITY

# INSTITUTIONAL REVIEW BOARD

**For the Protection of Human Subjects**
**FWA 00000165**

960 Technology Blvd. Room 127
Immunology & Infectious Diseases
Montana State University
Bozeman, MT 59718
Telephone: 406-994-6783
FAX: 406-994-4303
E-mail: cherylj@montana.edu

*Chair:* Mark Quinn
406-994-4707
mquinn@montana.edu
*Administrator:*
Cheryl Johnson
406-994-4706 or 6783
cherylj@montana.edu

**MEMORANDUM**

**TO:** Brandon Honzel

**FROM:** Mark Quinn, Ph.D. Chair *Mark Quinn cj*
Institutional Review Board for the Protection of Human Subjects

**DATE:** December 1, 2011

**SUBJECT:** *"The Effects of an Inquiry-Based, Data to Concept Curriculum" [BH120111-EX]*

The above research, described in your submission of December 1, 2011, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal Regulations, Part 46, section 101. The specific paragraph which applies to your research is:

_X_ (b)(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b)(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

___ (b)(3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

___ (b)(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

___ (b)(5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

___ (b)(6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.