IMPROVING VISUAL DATA LITERACY SKILLS OF HIGH SCHOOL EARTH AND SPACE SCIENCE STUDENTS BY WEEKLY DATA ANALYSIS CURRICULUM

by

Miranda G. Suvak

A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

June 2017

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ABSTRACT

Students must be able to interpret and analyze visual data to be successful in science classes, on high stakes assessment testing, and in their adult life. Visual data includes graphs, tables, charts, and diagrams. Traditionally, students receive instruction and practice using visual data literacy skills repeatedly in elementary school, middle school, and high school. This is a challenging skill set, as it requires scientific logical thinking and interpretation of abstract information. Students practice and grow as they continue through school, but continually seem to struggle to achieve mastery of visual data literacy.

This project investigated how to improve student understanding, analysis, and use of visual data by focusing on a weekly treatment of Interpreting the Graph. Each week students focused on a piece of visual data that related to current class curriculum. Students worked in lab groups to understand and analyze the data. Class discussion allowed students to share their thoughts and discuss areas that were hard to understand.

Data collected for this project included a student survey before the treatment process that assessed student perception of their own abilities and skill in visual data literacy. Students then took a pretest with data literacy questions using graphs, tables, charts, and diagrams. Each week for six weeks students filled out an Interpreting the Graph student worksheet. Each week students also recorded their weekly progress and overall class progress in a graphing packet. At the end of the six week treatment process students took a posttest. Students filled out a student survey about their growth and confidence in data literacy skills through the project, and a selection of students were interviewed about their growth in visual data literacy skills.

The intervention seemed to show a positive impact on student learning and abilities. Students showed a 16.7% gain between pretest and posttest assessments. Through the course of the six week intervention, students showed an increase in confidence in visual data literacy skills, as well as showing improvement on the posttest assessment. Students improved their abilities to identify independent and dependent variables of an experiment. However, students showed limited growth in their ability to explain theoretical experimental methods used to create visual data seen in class, and in their ability to write explanations for patterns in visual data using numerical evidence from the data.

The key findings showed that students seemed to benefit from learning a methodical analysis procedure to work through interpreting visual data. Students also benefited from participating in regular class discussion about visual data as it pertains to the curriculum. These findings were used in continued discussion with students to help them focus on their own learning. The methods from the intervention were used in curriculum planning to change how visual data analysis was taught in Earth and Space Science classes in future years and shared with other secondary science classes to increase student skill in visual data interpretation and analysis within our school district.

INTRODUCTION AND BACKGROUND

I teach at Jenks High School, a large suburban school outside of Tulsa, Oklahoma, and the only high school in our town. Jenks High School (henceforth, Jenks) has students in 10^{th}-12^{th} grade, and this past year, we had approximately 2400 students. Jenks is well known in our region, and in some areas across the nation, for excellence. We are known for excellence in many areas: academics, sports, music, arts, drama, and many other areas. Our school culture still feels like a "small town" community, but we pride ourselves on continuous improvement and our students continually rise to the challenge.

Traditionally, Jenks used to be a wealthier suburb of Tulsa, with a demographic of mostly Caucasian students. However, as the city of Jenks has grown, and as people have moved into the district to take advantage of this school system, our current demographic shows a very mixed cultural heritage. Our largest ethnic groups represented include Caucasian, African American, Hispanic, Asian, and Native American. We also have a large Burmese population that has been brought to Oklahoma through refugee support groups in many area churches. Our Burmese students are a mixed bunch, but many of them have come from war-torn areas, and have not been in school in years, if ever, and do not speak or read English, and may not read in their own language. Jenks also is well known in our area for our special education services, so we do have families that move into our district so their students can take advantage of those services as well.

This past school year I taught three sections of zoology and two sections of Earth and space science. I worked on my capstone project with my classes of Earth and space science. My classes included 49 Earth and space science students, in two class sections of 25 and 24 students each. The students included 17 sophomores (10^{th} grade), 22 juniors

(11th grade), and 10 seniors (12th grade), with 31 male students and 18 female students. Earth and space science is a full-year class, covering two semesters that combine geology, oceanography, meteorology, and astronomy through the year. Earth and space science is open to any high school student. Students have all taken biology in ninth grade, and may then take science classes in any order they choose. The state of Oklahoma requires two more years of science. Jenks High School offers twenty-three science course offerings, so students may come into a science class with a varied background.

Earth and space science is offered as one of our general science classes, as opposed to upper courses like honors or advanced placement courses. Any student can come into Earth and space science and be successful. Students in class have a wide range of academic abilities, from students who find school easy to students who struggle with learning challenges or learning English as they learn science. This class is a high interest class, and is very popular, in part, because our school has a full size planetarium on the roof of the building. Students in Earth and space science have a weekly observational astronomy lab component up in the planetarium, taught by the planetarium director.

I have observed that students often struggle with creating, understanding, and analyzing visual data in science classrooms. Visual data includes graphs, tables, charts, and diagrams that explain scientific data and show scientific procedures. Visual data literacy is a skill that is practiced in elementary, middle, and high school, and continues on into college and adult life. Students have to use abstract thought to connect visual data to the processes they are illustrating, and make logical connections using the scientific method to understand what visual data is representing. Students must be able to create visual data by creating graphs, tables, charts, and diagrams to explain their laboratory inquiries and show their learning. Students must also be able to interpret and understand visual data collected by others and in scientific literature, as well as in popular culture like television, internet, and print. Students will constantly have to interact with visual data in their daily lives, and although many students many not continue on to be scientists, to be successful adults they will need to be able to interpret, understand, and analyze visual data to make decisions.

I have also observed with my own students that many students continually struggle to figure out independent versus dependent variables. And I have noticed that my students are very good at finding details and numbers on a graph, but also struggle with coming to general conclusions about patterns in the data and relating that to an experiment or real world application. Therefore, the major theme for my action research was that students struggle with visual data literacy skills. Some of the struggle has to do with the abstract nature of understanding and analyzing data, and students need to continually practice these skills as their brain develops these pathways. My review of relevant literature has shown that students are able to improve visual data literacy skills when they are taught the skills to analyze graphs and spend time discussing their interpretation and the implications of the data. However, students still struggle with data literacy skills across the world. More time needs to be spent finding out about how students learn data literacy skills. Students will benefit from more strategies as well as more time spent on analyzing and interpreting data.

In high school, students will be assessed on their visual data literacy skills by taking state science exams, as well as college entrance exams like the ACT. In Oklahoma, sophomores will now take a federally mandated science test, which is a new test that will be primarily focused on biology-based questions this year but may include physical science questions in future years. In past years, biology was the only high school science with a state end-of-instruction exam. Students across the state traditionally scored lower on the sections involving data literacy interpretation and analysis. Most high school students at our school also take the ACT college entrance exam at least once during their junior or senior years, but many students take the test multiple times to earn a target score to enter college and complete for scholarships. The ACT's fourth test is a science exam. Two to six of the seven passages usually assess students on visual data literacy skills by including graphs, tables, charts, or diagrams. The science section of the test is one of the most challenging sections for students, and often has one of the lowest student score averages. As a high school teacher, one of my curriculum goals is to practice and build visual data literacy skills so that students can be successful in science class, on assessment exams, and be prepared to do well in college, and finally, to function as a successful adult interacting with the visual data in daily life.

The following question was addressed during my action research project: will students be able to show an increase in skill and ability interpreting and analyzing visual data if they conduct weekly focused written analysis of visual data? The following sub-questions were also addressed: 1) Can students identify independent and dependent variables from visual data? 2) Can students interpret scientific experimental procedure from visual data? 3) Can students identify patterns in visual data and use that to make predictions on future situations?

The goal of this study was to increase students' visual data literacy skills in interpretation and analysis by incorporating focused weekly visual data literacy activities where students must "interpret the graph" and interact with visual data that relates to their course curriculum, and reflect on their learning progress by graphing their weekly progress individually and as a class.

CONCEPTUAL FRAMEWORK

All areas of science rely on data to learn about the natural world around us and come up with explanations about life, and furthermore, student comprehension can be improved when teachers incorporate more visual data into lessons. Scientists design and conduct experiments, collect data, and then perform analyses to address relevant questions in science. Scientists also look at each other's data, compare data, interpret data, and use data to make connections and explanations. To successfully learn about science, students must understand the role that data plays in all scientific facts and theories. Evidence shows that students in all areas of science continually struggle with interpreting and understanding scientific data, whether it is in the form of visual data like tables and graphs, or as written analysis (Ozgun-Koca 2001). This is a vital skill for students, not only to increase their awareness and understanding in science, but also in the world around them.

Visual data interpretation is used in all areas of life. Students see tables and graphs and hear statistics of studies on TV or the internet. They need to be able to interpret and understand graphs when dealing with topics like daily nutrition, economic or political news, or even to learn which car will be the best one to buy. Many students will not choose to continue on to major in a science field. But all students need to practice and become proficient in visual data literacy to be informed citizens able to interact and make informed choices in their adult lives (Coskie & Davis 2008).

Visual data includes graphs, tables, charts, and diagrams that explain scientific data and show procedures. Finson and Pederson (2011) define visual data as different from visual information that goes into our brain. Students must take visual information and do something with it. They must interpret, analyze or make connections to understand visual data, which is the process of visual data literacy. Students will need to be able to read the information presented in various visual formats, and be able to use that information to analyze scientific procedures for trends or patterns. Students should be able to use visual data as evidence to support a scientific claim or answer a scientific question. Many students make mental images of data as they learn, and students will interpret data based on their past experiences and personal bias. Because students may interpret data using different methods, they will need to be checked for understanding through the learning process. Coskie and Davis (2008) propose it is very important for students to learn the skills of visual literacy to understand complex and abstract information both in and out of science. Teachers are encouraged to teach students the skills on how to use different models in science, as well as discuss how to choose which model to use and the limitations and benefits of each model.

Data literacy is a key component of many of the Science and Engineering Practices of the Next Generation Science Standards for Earth science. In 5-ESS1-2 students are asked to create graphs. In 5-ESS1-1 students must critique explanations about data using evidence, data, or models. 5-ESS2-1 requires students to be able to develop models to describe a scientific principal. In 5-ESS2-2 students must use mathematics and computational thinking to analyze data and compare solutions. Finally, 5-ESS3-1 does not explicitly reference data literacy, but data literacy can fit into this standard. This standard is about students being able to evaluate and communicate information about science, including data from media sources (Next Generation Science Standards).

It is important to look at multiple strategies and continue to work on improving students' data literacy skills, as they are key elements in all areas of science. High school students will be tested on these skills in several versions of high stakes testing. Many U.S. states use the Next Generation Science Standards as a guide to their own state exams, many of which are used in some way to give students credit for a class or towards graduation requirements. The ACT college entrance exam also has many science data literacy questions. The New York Science Regents examinations offer exams in all four areas of science: Living Environment (Biology), Chemistry, Physics, and Earth science. The Earth science test from June 2012 was studied by LaDue et al. (2015). The Earth science test used diagrams, maps, graphs, tables, time charts, cartograms, and photo-realistic pictures. Each topic test was made up of 85 questions. Earth science used 83 visual representations, in comparison with 45 for Physics, 37 for Living Environment

(Biology), and 23 for Chemistry. On the Earth science test, the most common visual representations were diagrams (28), maps (18), graphs (11), and tables (9). Photo-realistic pictures, cartograms, and time charts were asked in three or less questions each.

It is interesting to note that students struggle with data literacy all over the globe. Tairab and Al-Naqbi (2014) focused on how secondary science students interpret and construct graphs. They worked with 10th grade students in the United Arab Emirates (which is on the Saudi Arabia peninsula in the Middle East) and Brunei Darussalam (which is next to Malaysia near the Indonesian Islands of the Pacific Ocean). They found that students did better on interpreting graphs than on constructing graphs. Students were best at interpreting when asked to read the graph for details, and poorest when asked to make conclusions or find patterns or trends in the graphs. One graph students did well on was a bar graph that showed the vitamin C concentration of six fruits. Students were asked questions about which fruit had the highest concentration of vitamin C and which had the lowest. Eight-seven percent or more students in both classes got these two questions correct. But, even though students were able to read the graph correctly for details, not as many students were able to make generalized conclusions about the pattern of data on the graph, and student scores were much lower for that question. One school dropped about five percent from their average on the first two questions, with 84% able to make generalized conclusions, while the other school dropped over thirty percent, with only 55% of students able to answer correctly.

Students also struggled when asked to look for connections between interactions of different variables on the graph (Tairab and Al-Naqbi, 2014). In that example, the graph showed several variables in a river over a 50 kilometer stretch. The x-axis was the distance downstream. The y-axis was unlabeled. The three lines across the graph showed the dissolved oxygen and number of fish and bacteria in the river. The problem gives the prompt that there is a source of pollution upstream of the start of the graph. Students are asked to make interpretations on what is happening based on what the lines on the graph are showing. Almost 70% of students were able to mark the point where the pollution started affecting the river, but almost 40% of students were not able to draw a general conclusion about how the three factors related to each other based on the information in the graph. It is interesting to see that these problems are universal.

The relatively low ability for students to make general conclusions and applications of graphic data is a cause for concern among educators. Many college classes, and even classes at the secondary level, use lecturing as a main teaching style. Many teachers use graphs in lecture and spend time in lecture discussing graphs and explaining what they mean. However, students do not seem to learn to interpret graphs by just listening to a lecture (Bowen & Roth, 1998). Students may struggle with being able to see all parts of the graph clearly from their position in the classroom. They may have trouble with both listening to what the professor is saying and visually taking in the graph, which may be exacerbated by teacher behavior, for example during the study by Bowen and Roth (1998) video clips often showed that professors would talk about a different area or idea while pointing to a different part of the graph. Students also lack field experience that gives them the background to internalize the research process and understand the principle the graph is sharing. The study concluded that in order to learn and interpret, students need allotted class time focused solely on interaction with graphs and have time to discuss them.

Students seem to continually struggle with graphing and data literacy. Ozgun-Koca (2001) analyzed the graphing skills of students in math and science, and the research showed that many students were taught the skills of graphing in class, but, like Bowan and Roth (1998) suggested, little class time was spent on interpretation and analysis. Using tools like probeware and computer graphing software can allow for more efficient graphing, and help students have more time to interpret data. Again, similar to Bowan and Roth (1998), Ogun-Koca (2001) also found that classrooms that incorporated graphing into the curriculum, as opposed to just teaching graphing skills, showed more student progress in graph interpretation.

Maltese et al. (2015) looked at the idea that students can improve data literacy skills with continued exposure and practice, and they studied college students from the freshman level to Ph.D. candidates on how well they were able to interpret visual data. Their study found that the number of STEM classes did not seem to correlate to student ability to interpret visual data. However, students at higher academic levels (Ph.D students versus freshman) did seem to be better able to interpret visual data. The study found the more important indicator of student success was being enrolled in classes structured so instructors took time to teach students to interpret the data used in class and took time in class to include data representation on a regular basis.

The next step to helping students learn data literacy skills is to start looking at how students internalize graphs, and what were the stages of learning. Friel and Bright

(1995) categorized skill components as “reading the data, reading between the data,” and “reading beyond the data” (p. 4). Students work along this continuum, increasing the level of visual literacy skills at each step. The study also categorized different types of graphs by level of difficulty for student comprehension. The easiest to interpret were circle graphs, then bar graphs and line graphs. More complex graphs have not been studied in detail, but seem more abstract and would be more challenging for students to understand. The study worked with 76 middle school students in their math classes, and concluded that students benefited from talking about graphs. While there was no particular framework mentioned in this study, the emphasis was shown on categorizing questions and data interpretation as being grouped as “reading the data,” “reading between the data,” and “reading beyond the data” and using those terms and ideas with the students while discussing their understanding of the data and encouraging students to analyze information more deeply as they moved more towards the “reading between the data” and “reading beyond the data” analysis questions. The data showed the students rose from 55% on the pretest to 70% on the posttest at being able to interpret the graph based on the model taught in class. Students grew better at analyzing graphs and predicting future data after experiencing class discussion where they were asked questions about the graph, but also questions about their thought process for analyzing the graph. Students also increased their use of mathematical strategies to analyze data, as only 60% used a math strategy on the pretest and 85% of students used a math strategy on the posttest.

There are many tools that students may use to help collect data, graph, and analyze data. Many classrooms have access to probeware, handheld sensory devices to gather data more accurately, or in ways we cannot see with our own senses. Many of these tools will interface with a computer to create tables and graphs. Students also may use computer software to create spreadsheets to present and analyze data efficiently. By incorporating the use of technology into data literacy lessons, students can continue to practice data literacy skills more efficiently (Sneider et al. 2014).

To help students become more skilled in data literacy, they need to focus on specific strategies to help learning. One tool available to help students is the Graph Choice Chart (Webber et al. 2014). This flow chart allows students to work their way through their research question and which type of data they collected to determine which type of graph is appropriate to create. By using the Graph Choice Chart on a regular basis in class activities, students can internalize the process of how to choose an appropriate type of graph to use in their data analysis.

Another technique to help students improve data literacy skills is to focus on comparative analysis of data. Smith and Genter (2011) found that students scored better on graph interpretation and analysis questions if they had been taught the graphing concept by being asked to compare and discuss similar types of graphs, versus if they had just been asked descriptive questions about multiple graphs individually. In the study by Smith and Genter (2011), participants were asked to interpret a stock-and-flow graph. The example graphs showed CO_2 emissions and removal, as well as atmospheric CO_2 levels. These were abstract concepts that most participants were not familiar with.

During the experiment, participants either saw the three sets of graph conditions sequentially on different pages or comparatively with two sets of graphs on the same page. The sequential group had a question on each page asking the participant to interpret the graph. The comparative group had a question on each page asking participants to find similarities and differences between the two graphs. The participants in the comparative group scored higher on analysis of example problems than did the participants in the sequential group. The studied concluded that when striving to get students to understand a certain type of graph or certain graphing principal, students can engage better with the graph if they are asked to compare two graphs that both share a common principle.

Students may also practice data literacy skills by practicing creating infographics. Lamb et al. (2014) created a program where teachers can model how to interpret data from infographics in several think-aloud sessions in the classroom. Students were invited to participate in the discussion of data interpretation that went along with the infographic. Students then researched a topic and created an infographic. The class shared their infographics in different ways, like a gallery walk or using Voicethreads. Students did peer evaluations and then edited their infographic based on their peer review comments. In this activity students took ownership of the data in their infographic and practiced ways to interpret it and communicate it with the class.

Students also engage in more discussion and thinking when using data from real experiments. Gould et al. (2014) found that students were engaged and were required to use problem-solving skills when using messy data, i.e., data that did not follow expected parameters. Messy data replicates how data is often structured and used by scientists, and students often have experience with messy data in their own lab experiments. Rarely does data form a perfect graph and show a complete explanation. When students use messy data, they have to engage in a discussion to think about why their data does not fit the expected parameters. Students have to think about how other variables not being studied in the experiment can affect the data. This process is more about students creating a claim and using the evidence from their data to support it than just finding the right answer.

Smith et al. (2014) showed that giving students focused curriculum that included looking at data, creating graphs, and interpreting data can improve student literacy scores. The program was based on the SeeIt online tool that allows students to look at data to analyze and compare graphs without using statistics. Instead students looked for patterns in the graphs to help make sense of the data and tell the "story" that the data represented. Students worked through the module in six to eight class periods. Activities varied from teacher presentations, student group work, and looking at information from two case studies. One example given was of a teacher presentation focused on how people can come to the wrong conclusion from looking at data in different ways. The scenario discussed stated that before the Crimean War it was thought most people in war died from combat injuries. Then Florence Nightingale created a graph to show that more soldiers died from infections from unsanitary hospitals than from combat. By looking at the graph, students were able to see the data did not support the idea that most people in war died from combat injuries, but instead more people died from infections received in hospitals after being injured in combat. Next students worked through a data activity where they created a graph by placing stickers on chart paper as high as they could reach. This helped students understand how to create and read a dot plot graph, and students analyzed the data to look for patterns in male versus female students in the class. One of the case studies used in the module asks students why giraffes have long necks. Students created possible answers, and then had to choose what data they would collect for an experiment, as well as predict what the data pattern would be to support their hypothesis. Students looked at a data set online of 100 feeding episodes. All of the data came from female giraffes. Students used the SeeIt website to create graphs of their data, analyze the graphs for patterns, and then write a claim using evidence from their data. The SeeIt module offered four other activities, divided among teacher presentations, student activities, and case studies. After working through the module, students showed a 25% improvement score on the post test. This study gave evidence to show that spending time in class on visual data literacy and having students practice visual data interpretation and analysis can improve student visual data literacy skills.

METHODOLOGY

The focus of this research project was to improve student visual data literacy skills. The treatment was intended to help students use abstract thought to connect visual data to scientific processes, and improve comprehension of what the data means in a scientific methodology. The following question was addressed during this project: will students be able to be show an increase in skill and ability at interpreting and analyzing visual data if they conduct weekly focused written analysis of visual data? The following sub-questions were addressed: 1) Can students identify independent and dependent variables from visual data? 2) Can students interpret scientific experimental procedure from visual data? 3) Can students identify patterns in visual data and use that to make predictions on future situations?

Participants

The students who participated in the study were enrolled in two sections of high school Earth and space science. Students in this class are enrolled all year, and so had already had a semester being introduced to Earth and space curriculum. The students in the class had a mixture of different abilities and motivations. There is usually high interest in the topics of class but many students have low motivation do the analysis and assessment in class activities. All Earth & space science students that I taught were included in the treatment group. A comparison group consisted of four Earth and space science sections that were taught by another teacher. The comparison classes took the same pretests, posttests and surveys, but did not participate in the treatment process. This design was utilized so that there would be a comparison of student growth in visual data literacy skills from just having access to visual data in the curriculum versus using a focused learning method as in the treatment group.

Intervention

Data collection began in January 2017 with students being introduced to the Interpreting a Graph procedure (Appendix A). Students took a pre-survey (Appendix B) to rate their thoughts about their own abilities and comfort level using visual data in class. Students were first given a pretest on visual data literacy skills. The pretest was made up of questions taken from released ACT science subtest questions that used visual data in the passage in the form of graphs, tables, or diagrams. All of the passages used on the pretest were Earth science topics. Student pretest scores were analyzed in several ways, including an analysis to see how students did using different skills and levels of Bloom's taxonomy of learning. Parts of this data analysis of pretest scores was shared with students during a class discussion with data graphs projected on the whiteboard in the front of the room. The discussion included information on student progress on the levels of Bloom's taxonomy of learning for data literacy skills.

After taking the pretest, students started the treatment process of using the Interpreting a Graph procedure to analyze visual data each Tuesday for the next eight weeks, January 10, 2017 through February 28, 3017. On a treatment day, students would start the class period by filling out the Interpreting a Graph student worksheet with the other students at their lab tables. Each week students would be given a different piece of visual data that was related to material in the Earth and space science curriculum. The visual data included graphs, tables, and diagrams that came from science textbooks related to the current week's curriculum topics. Lab table groups ranged from three to five students per table, based on class size. In each class, students were divided equally among lab tables, with a goal of three to four students per table. Once lab tables finished their group work, about ten to fifteen minutes into the period, the class came together to share observations from their student worksheets. The data was projected on the whiteboard in front of the class. Students from different lab tables were called on and/or volunteered their observations and asked questions about their misunderstandings of the data. Class discussion continued until the data had been fully explained and students were able to discuss the data and the experimental procedure behind it, as well as make connections between the data and the curriculum.

On Fridays during the eight week treatment period, students were given a visual data literacy assessment. The weekly assessment activity was created by choosing visual data passages from released ACT science subtests that covered Earth science topics related to the curriculum taught during the eight week treatment process. Assessments represented one ACT passage. The passage included graphs, tables, and/or diagrams, and asked five to six questions about interpreting the data. Students worked individually at their lab stations to fill out the assessment. Once students were finished, we graded the assessment as a class and discussed the answers. Students were given a graphing worksheet that included an individual student progress graph and a graph for class progress to record class average scores (Appendix C). Students recorded class averages for both class sections using different colored lines on their class graphs.

At the end of eight weeks of treatment process, students took the posttest, which was the same test given as the pretest at the start of the treatment process. This was also analyzed the same way the pretest was, i.e., to show student growth, and the data was shared with the class. We discussed how the class progressed, for example, students had their own scores for the pretest and posttest and were be able to see how they progressed. Then students completed the student survey after the treatment to see how their perception of their skills and understanding of data literacy have changed through the treatment process. A selection of six students was pulled to give student interviews and discuss their perceptions of learning through the treatment process. For the student interviews, student volunteers were randomly chosen using a random number generator. Three students were chosen from each of the two class sections that went through the treatment process. Students were interviewed individually during class or outside of class, depending on student schedules and availability. (Appendix D)

Data collection

Data was collected in a variety of ways. At the start of the treatment process, students took a pretest on visual data literacy analysis and interpretation. This was a short test that used multiple pieces of visual data and asked students to interpret, analyze, and show understanding of the visual data. At the end of the treatment, students took the same test as a posttest. The difference in the pretest and posttest scores was measured to see student growth during the treatment period for both the treatment class sections and the control class sections. Students of both treatment and comparison class sections also took a pre-survey and post-survey that asked questions about their own perceptions of how well they were able to interpret, analyze, and understand visual data literacy. These surveys were analyzed to see how student perception about their own skills in visual data literacy changed throughout the treatment process. Six student volunteers in the treatment classes were randomly selected to participate in individual student interviews, to further discuss student learning and how or if the treatment process had any impact on their own visual data literacy skills and confidence in interpretation, analysis, and understanding of visual data. During the eight week treatment process, student Interpreting a Graph weekly worksheets were collected. A selection of student worksheets were looked at to see possible growth in depth of student answers, as well as increased use of scientific logic and evidence to support analysis of visual data. Each week the weekly assessment grades were graphed as individual students (by students) and as class averages (by all), and this data was discussed in class to look for class progress and to reaffirm student goals of improving visual data literacy skills.

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.

Table 1
Data Triangulation Matrix Table

Questions	Data Source		
Focus Question: Will students be able to be show an increase in skill and ability at interpreting and analyzing visual data with weekly focused written analysis on visual data?	Pretest Scores	Interpreting a Graph Weekly Activity and teacher observation	Posttest Scores
Sub-question 1: Can students identify independent and dependent variables from visual data?	Student Pre-Survey	Interpreting a Graph Weekly Activity	Posttest Scores and Student Post-Survey
Sub-question 2: Can students interpret scientific experimental procedure from visual data?	Student Pre-Survey	Student Interviews	Posttest Scores
Sub-question 3: Can students identify patterns in visual data and use that to make predictions on future situations?	Pretest Scores	Interpreting a Graph Weekly Activity	Posttest Scores

DATA AND ANALYSIS

The purpose of this intervention was to see if students would be able to show an increase in skill and ability at interpreting and analyzing visual data with weekly focused written analysis of visual data. Data was collected from a variety of sources in an attempt to determine the impact of this emphasis on visual data.

The results of the intervention suggest a positive impact on student learning and abilities. Students in my class showed a gain of 16.7% between the pretest and posttest, while students in a comparable class showed a gain of 6.7% during the same time period. The pretest had a Mean score of 46% (n=39), with a standard deviation of 3.97. The posttest Mean rose to 55% (n=40) with a standard deviation of 4.62. The difference between the pretest and posttest was strongly statistically significant, $t(77)=9.2761$, $p<0.0001$. When comparing the posttest results between my class and a comparison class ($M=40\%$, $SD=5.09$, $n=99$), the results were again strongly statistically significant, $t(137)=11.8355$, $p<0.0001$. These scores show that my students' post test scores were much larger than would be expected by random chance alone, and provides strong evidence that the intervention may have caused students to score higher than expected on the posttest.

Within the class, students showed growth in their skills and abilities at interpreting and analyzing visual data. Each week students were given a new visual data set to analyze. On the first week, students struggled to understand the individual pieces of visual data and needed scaffolding to be able to interpret the data to explain a possible experimental method that could have been used to collect the data. The visual data analysis activity took over 30 minutes to complete the first week, with students taking over 15 minutes to fill in parts of their analysis worksheet, and some students had to leave parts of their worksheet blank because they did not know how to answer the analysis questions. During the following class discussion, there were many questions about what parts of the graph meant. We spent time allowing at least three students per class to come to the board and use a piece of data in the graph to support their claim about the pattern between variables shown in the graph. Through the weekly practice, students became more confident of their visual data interpretation, and by the end of the eight week intervention students were able to fill out their analysis worksheet (all questions) in less than ten minutes. On the eighth week, an additional 9% of the students were able to give evidence using data from the charts to support their claims for patterns between the variables shown within the visual data, and they were able to explain hypothetical experimental methods that could be used to collect the data presented.

One sub-question asked during this project was if students could identify independent and dependent variables within visual data. During the first week's data analysis practice, several students were unclear which variable was an independent variable, dependent variable, or something else in the graph. When asked, students struggled to come up with an explanation or definition of what independent variables or dependent variables were in an experiment. Students offered ideas like "the dependent variable depends on the independent variable," which showed they have covered these ideas in previous science classes, but as students were not able to expound on that idea or use it to predict which variable in the current example was labeled as an independent or dependent variable, they showed a low level of understanding of what independent and dependent variables represent in an experiment. By the end of the eight weeks of focused analysis on visual data, more students showed higher confidence in identifying variables in visual data, and this enhanced confidence as was evidenced by 20% more students being able to correctly answer questions identifying independent and dependent variables on the posttest. Students were also able to explain "the independent variable is what is being tested" and the "dependent variable is the data you write down."

This increased confidence in identifying independent and dependent variables was shown in student surveys, student interviews, and posttest scores. One student said, "I feel like I'm better able to identify variables." When asked what was most helpful in improving their own visual data skills, another student answered, "The independent variable and the dependent variable definitions." Before starting any focused practice on analyzing visual data, 42% of students rated themselves 3 out of 5 on being able to identify independent and dependent variables in visual data. After eight weeks of methodical visual data analysis, 66% of students rated themselves 4 out of 5 on being able to identify independent and dependent variables in visual data. This student data was supported by posttest scores. The posttest had six questions asking students to identify independent or dependent variables. On the pretest, those six questions showed a mean of 40%, with standard deviation of 0.0026. On the posttest, those six questions showed a mean of 60%, with a standard deviation of 0.2300. The difference between the pretest and posttest was extremely statistically significant, $t(77)=488.9535$, $p<0.0001$. A comparison class showed a mean of 38% (standard deviation 0.1431) of students answering those six questions correct on the pretest and dropped to mean of 32% (SD = 0.0961) of students answering correctly on the posttest. The difference between the intervention class's posttest and the comparison class's posttest was strongly statistically significant, $t(137)=1478.4911$, $p<0.0001$. This means that the intervention seems to show a positive growth in students being able to correctly identify independent variables and dependent variables in visual data.

The second sub-question asked if students could interpret scientific procedure from visual data. This concept was addressed in one question on the pretest and posttest. Students showed no progress on this question, and only 33% of students answered the question correctly on both the pretest and posttest. However, students did show improvement in being able to write out details of an experimental method from a visual data diagram. On the Interpreting a Graph worksheet, the seventh question asked students to "Describe what the experiment method might have been." Student answers were scored with a rubric from 0 to 4. The scale represented:

- 0 = No answer or answer that does not make sense with the question.
- 1 = Answer is just a few words, fragments of a sentence, or does not form a complete thought or explain a method.
- 2 = Answer uses multiple concepts or variables, tries to show a relationship, but does not get into a methodical procedure; may use technical language or talk about specific equipment.
- 3 = Answer explains multiple steps to start to explain a possible experimental procedure
- 4 = Answer uses a multi-step procedure that sounds like instructions for an experiment – including what equipment is used, how data is collected, and what type of data is collected.

Using this rubric, students showed an improvement overall with being able to write more detailed answers explaining experimental method from viewing a visual data diagram. During the first week, 75% of students (n=43) wrote answers that were scored a 2 on the rubric, meaning that the answers were basic, and just gave a simple statement about a possible experimental procedure that related to the data shown in the visual data diagram. An example of an answer scored a 2 was, "At the end of every year they go and measure ice in the sea." There were no scores higher than 2 during the first week. By the end of the eighth week, scores had shifted, and only 51% (n=41) of student answers were scored at a 2. However, 30% of student answers were scored a 1, which was up from 19% in week one. This may have been because after eight weeks of a repetitive procedure some students were less motivated to continue to try to write complete answers on the worksheet. The increase in lower scores also may have been due to the more abstract concept of data gathered about planets in space. Some students may not have had background knowledge of how data could be collected about planets in space, so may not have been able to come up with a possible procedure to collect the data shown in the visual data diagram. On the positive side, 12% of students (n=41) were able to create answers that were scored as a 3. These answers started to explain a procedure, and included more than one step to try to explain what type of data was collected. An example answer scored a 3 was, "Measure the distance between the planet and sun with AUs and time how long it takes to orbit around the sun." There is still work to be done on this skill. The goal is for students to be able to explain an actual experiment, with multiple steps, by looking at the visual data. Students who master this concept would be able to write out a procedure that looks like the methods section of an experiment, and details a methodical procedure with step-by-step instructions on how to do an experiment that would yield the visual data documented in the diagram. Students did show growth in this area, and were able to elaborate further if prompted verbally in class, but most students still struggled with writing more than the basic pattern down in this area. This seems to have less to do with understanding what the visual data represents as having little practice in having to work backwards to explain a procedure in enough detail that someone could actually do an experiment.

The last sub-question asked if students could identify patterns in visual data and use that to make predictions on future situations. This was another area that students struggled with. There were two areas that were challenging about this concept for students. During the first week I noticed that students struggled with having to explain a pattern shown by data in words (see Figure 1).

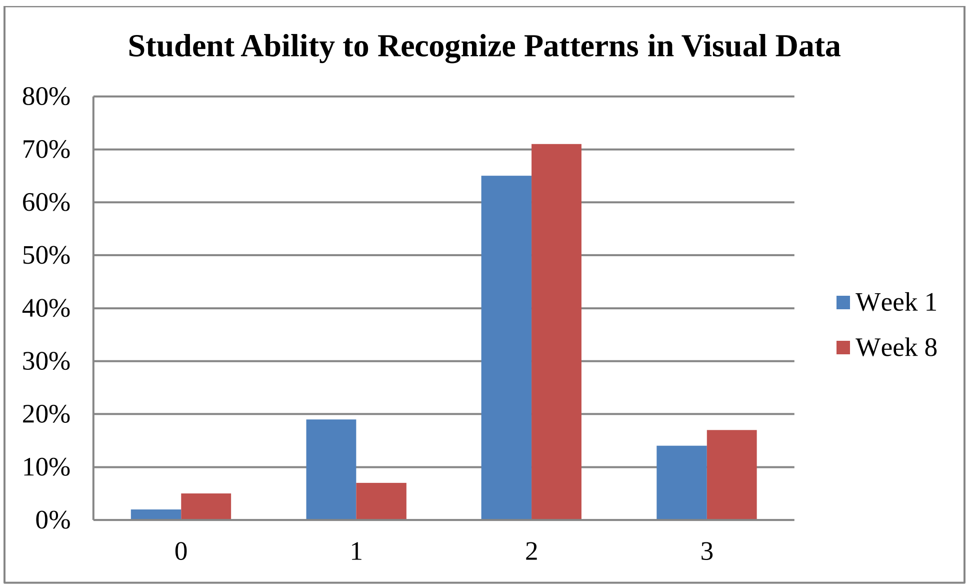

Figure 1. Student ability to recognize patterns in visual data, Week 1 (*N=43*) and Week 8 (*N=41*).

For many students, it seemed that they did see the pattern and understood the trend, but found the idea so obvious that it was a struggle to be able to explain it in words. The second struggle with most students was the idea of using numerical data from the visual data diagram as part of the explanation of the pattern. Some students just needed a reminder that using numerical data within the explanation was an expectation, but over half the class struggled with how to even use numerical data within a sentence as a support of pattern seen in the data. During the first week we spent ten minutes going over this concept in several different ways. I explained the expectation and asked students to discuss a sample answer within their lab table. After calling on several lab groups, it was clear that students were still struggling with how to even start this task, and students were reluctant to try. I called on 3 different student volunteers to come to the front of the class and touch the board, picking out specific numbers from the visual data graph. As a group, we crafted a sentence describing the pattern of the line on the graph using the number that the students touched on the screen. This was a skill we discussed many times over the next eight weeks, and students did show some improvement in their ability to write out explanations of patterns shown in data using numbers from the visual data diagram. During the first week's activity, 65% (n=43) of students wrote an answer that scored a 2. One student said, "The pattern is downwards but very nonlinearly." Another student stated, "Yes, over the years ice would go down and come back up slightly then back down, continuing a negative trend." By the eighth week of the intervention, more students were able to write more detailed answers that included numerical data. The first week 21% of students scored a 0 or 1, but by the eighth week only 12% of student answers scored as a 0 or 1. Most promising, 17% of student answers were scored at a 3, which was up from 14% of answers scored a 3 during week one. These answers incorporated numerical data from the visual data diagram to help support their answer, and tried to explain details about the pattern seen in the data. An example of an answer scored a 3 was, "Further away the more of a circular orbit the planets have.

Mercury is the closest to the sun and has a .205 ellipticity and the amount of ellipticity usually gets smaller further out. Ex. Venus has a ellipticity of 0.046 and Neptune has one of .011." When prompted in class, most students could use numerical data from the visual data diagram in a sentence describing a pattern shown in a visual data diagram. With more practice, more students should be able to use numerical data within their written answers without prompting from a teacher.

INTERPRETATION AND CONCLUSION

After working with my students for several weeks on learning a methodical process to analyze visual data, I saw my students' confidence and skill levels improve. At the start of the intervention, many students struggled with interpreting visual data, but also struggled with knowing how to start trying to analyze visual data. Students felt most challenged when visual data was complex or when the content was something unfamiliar to the student. Although the class did see progress and improvement, many students did not feel their individual progress was constantly improving, and student weekly assessment scores seemed to rise and fall various weeks depending on complexity of visual data or student familiarity with visual data topics. One area that seemed helpful from the intervention was using visual data as a weekly part of the classroom curriculum. My students also greatly benefited from the many classroom discussions with peer groups and as a whole class, where we talked about the visual data to promote understanding and when we went over the visual data assessment questions to explain how to solve them after the quizzes. At the end of the intervention, my students felt more confident in their abilities to interpret and analyze visual data, and their assessment scores showed that they had improved.

Many researchers have discussed students who find interpreting and analyzing visual data challenging, but whose students improved their visual data analysis skills after repetitive, methodical classroom practice. Tairab and Al-Naqbi (2014) worked with 10th grade students in the United Arab Emirates and Brunei Darassalam. Their students showed similar patterns to my students in that students were able to interpret basic graph details, but struggled with more abstract concepts like explaining patterns or making conclusions based on trends. Bowen and Roth (1998) worked with college students, but they also found that students struggled with being able to understand graphs if the student did not have the background knowledge to know about the topic of the graph. This is similar to the study by Ozgun-Koca (2001), who found that classrooms that incorporated visual data into the curriculum showed greater improvements in graph interpretation. This parallels my own experiences. My students showed improvement as they become more familiar with using a methodical process to interpret visual data, and as they increased understanding on the curriculum topics portrayed in the visual data.

The second key finding is that students need to spend time discussing and asking questions about visual data to learn how to analyze it. Several researchers showed that teaching students to analyze visual data and then using class time to talk about visual data on a regular basis helped students to improve their own visual data interpretation and analysis skills. The study by Maltese et al. (2015) found the most important indicator of student success in visual data comprehension was working with teachers who explicitly and regularly taught students how to interpret visual data. Friel and Bright (1995) found that students improved visual data literacy skills and were able to make predictions based on data when they were asked questions about the visual data and about their own thought process for analyzing the data. My students also felt that regular practice and discussion helped them to learn. When asked "What was most helpful in improving your visual data skills?" (n=40) one student answered, "Being able to talk through it with others and going over it." Students also answered that the most helpful part of the intervention was "more practice" (28%), "having a teacher explain what I got wrong" (23%), and getting to "see new types of graphs" (10%).

This intervention showed that students are able to improve visual data literacy skills if taught to use a methodical analysis method, and to participate in regular class discussion of visual data interpretation and analysis. My students showed increased confidence in their own visual data interpretation and analysis skills, and showed a 16.7% gain on the posttest assessment. There is still work to be done. Although students did show a gain overall, their progress through the intervention went up and down due to familiarity with curriculum content, and students still struggled with working backwards from visual data to explain a potential scientific method or working forward to be able to explain patterns from data in writing using numerical evidence from visual data. Students still need more practice through the year, and even in multiple years, to continue to increase the depth of their abilities to interpret and analyze visual data.

VALUE

This intervention was very valuable to my own learning, as well as my students' learning. The data showed that teaching students a methodical analysis method for visual data, with regular questioning and discussion of visual data that applied to current curriculum was valuable to student visual data analysis skills. I have been discussing how we use visual data within the Earth and space science class curriculum with my collaborating teacher, and we have made changes to next year's curriculum to include more visual data in each unit. We plan to teach students the "Interpret the Graph" method of visual data analysis at the start of the school year. Students will then use that method on a regular basis as we encounter visual data within the textbook, current events, and other areas of the curriculum. By working as a team, we will use common language and methods to help our students methodically analyze visual data. We have also decided to continue to incorporate sample ACT science subtest passages more often through the year. Working with my collaborating teacher, we have started putting together booklets with different ACT passages and plan to use them on a regular basis during class starting in the fall. We have decided to plan time in our class lessons for class discussion and regular feedback on assessment passages to allow students to reflect, question, and discuss how to analyze visual data. Through the next few years, we plan to share our curriculum plans and successes with other secondary science teachers in our district. We will share curriculum plans, ideas, and student assessment results informally in department meetings, and plan to offer a professional development workshop during one of our school service days next year where we will be able to go over these ideas in more detail. Our district has been discussing ways to help students improve visual data analysis skills over the past few years, so our information from Earth and space science classes will be helpful as our department continues to plan ways of helping all secondary science students improve their visual data literacy skills.

This action research treatment was very beneficial to my own professional learning. Working through the formal action research process has given me a process to delve deeply into a problem I wanted to help my students solve. One of the more important parts of this process has been the reflection built into the action research process. Teachers are constantly doing small informal assessments of student learning and using that to modify the curriculum multiple times through the year in small ways to help students as needed. The action research process allowed me to spend more time reflecting on the same topic. By going through the action research process, I was continually reflecting on my own progress and planning, as well as student progress. I found that when I came back to think about the same topic – improving students' visual data literacy skills – I approached the topic in different ways. Originally I was focused on creating curriculum activities to teach my students skills in reading graphs. As I moved through different parts of the process, I found I thought about visual data in different ways. After going through my literature review, I found myself thinking of how other teacher's activities might be helpful to my own students. This was the first time I have done a literature review focused on helping my students, and I found it extremely helpful to spend time reading about how other teachers have looked at helping their students with similar skills. The literature review provided validation that many students do struggle with visual data literacy, but also gave me ideas on ways that I could try to help my own students improve their visual data literacy skills.

Another benefit from the formal action research process was the ability to share a goal with my students, and then collect weekly data to use in class discussions and reflections with students. While working through the intervention activities with my students, I found that my students provided great insight to how they were learning and which things were challenging or helpful to their skill-building. Working with my students as collaborative partners increased my own understanding of my teaching style. This helped my own growth as a teacher, because I could analyze the student data and use that information to have focused conversations with students in class on certain skills. This also helped provide reflection points during weekly visual data activities, as we could discuss student areas of need and focus on those areas as we analyzed the next week's visual data.

Through this process of action research, both my students and I have benefited from our journey to learn more about analysis and interpretation of visual data in Earth and space science classrooms. My students have shown that their confidence and skill in interpreting and analyzing visual data have increased through using a methodical analysis method, "Interpreting a Graph," and participating in regularly questioning, discussion, and assessment of visual data within the class curriculum. This data has been used with students and collaborating teachers to make plans to change how visual data analysis is taught next year, in the hopes of helping future students continue to improve visual data literacy skills. As a teacher, I am able to be more effective in helping students learn visual data interpretation and analysis skills. By helping students improve their ability to use and understand visual data, my students will be better prepared for future science classes, but also to able to participate in everyday life where visual data is used in media, print, and video sources to share information. My students will be able to interpret visual data in their everyday life and use that to make informed decisions about their life, which will lead them to be independent, successful adults.

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APPENDICES

APPENDIX A

INTERPRETING A GRAPH STUDENT WORKSHEET

Interpreting a Graph

1. Topic – What is the graph about? ____________________

____

____

2. What type of graph is this? ____________________

3. Why is this an appropriate type of graph for this data? ____________________________________

____

4. What is the Independent Variable: ______________

______________________ Which axis? __________

5. What is the Dependent Variable: ________________

______________________ Which axis? __________

6. What question is being studied? _______________

____

7. Describe what the experiment method might have been. ____________________________________

____

____

____

8. Is there a pattern in the data? Describe using facts from the data. ______________________________
____
____
____
____
____
____

9. Use the data from the graph to answer the question you posed in #6. ______________________________
____
____
____

10. What are the implications of this data? Why would it be used or how? ______________________
____
____
____
____
____

APPENDIX B

STUDENT PRE/POST SURVEY

Student Survey: Visual Data Skills

Visual data includes graphs, tables, and scientific diagrams. Visual data is often used in science to explain scientific findings and share data. Please read the statements below. Choose which answer best represents your skill level at using and interpreting visual data.

Participation in this research is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

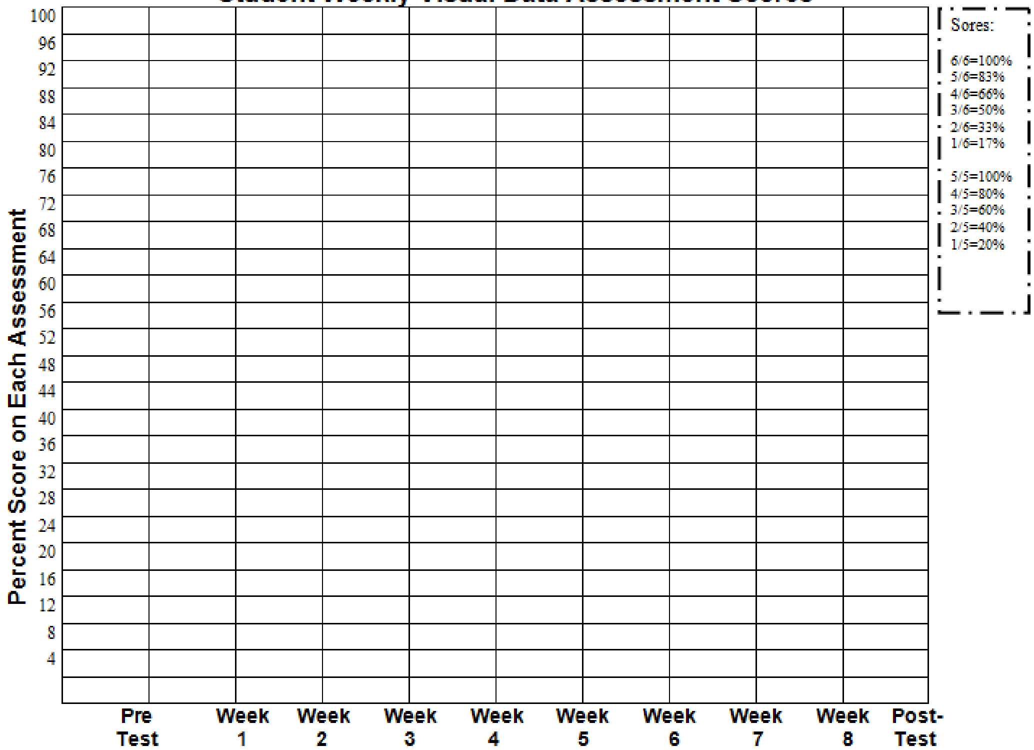
	No Experience: *I'm not sure if I can do this*	***Beginner:*** *I'm just starting to be able to do this*	***Advanced Beginner:*** *I can do this most of the time, but sometimes need help*	***Intermediate:*** *I can do this almost all of the time, and rarely need help*	***Expert:*** *I can do this skill well, and could help others learn how to do this skill*
1. *I can read and understand graphs, tables, and scientific diagrams.*					
2. *I can use a title to understand graphs, tables, and scientific diagrams.*					
3. *I can use X-axis and Y-axis labels to understand graphs, tables, and scientific diagrams.*					
4. *I can find the independent variable on graphs, tables, and scientific diagrams.*					
5. *I can find the dependent variable on graphs, tables, and scientific diagrams.*					
6. *I can use graphs, tables, and scientific diagrams to explain an experiment, even if I did not do the experiment.*					
7. *I can describe patterns or relationships in data using graphs, tables, and scientific diagrams.*					
8. *I can use evidence from graphs, tables, and scientific diagrams to support claims.*					

APPENDIX C

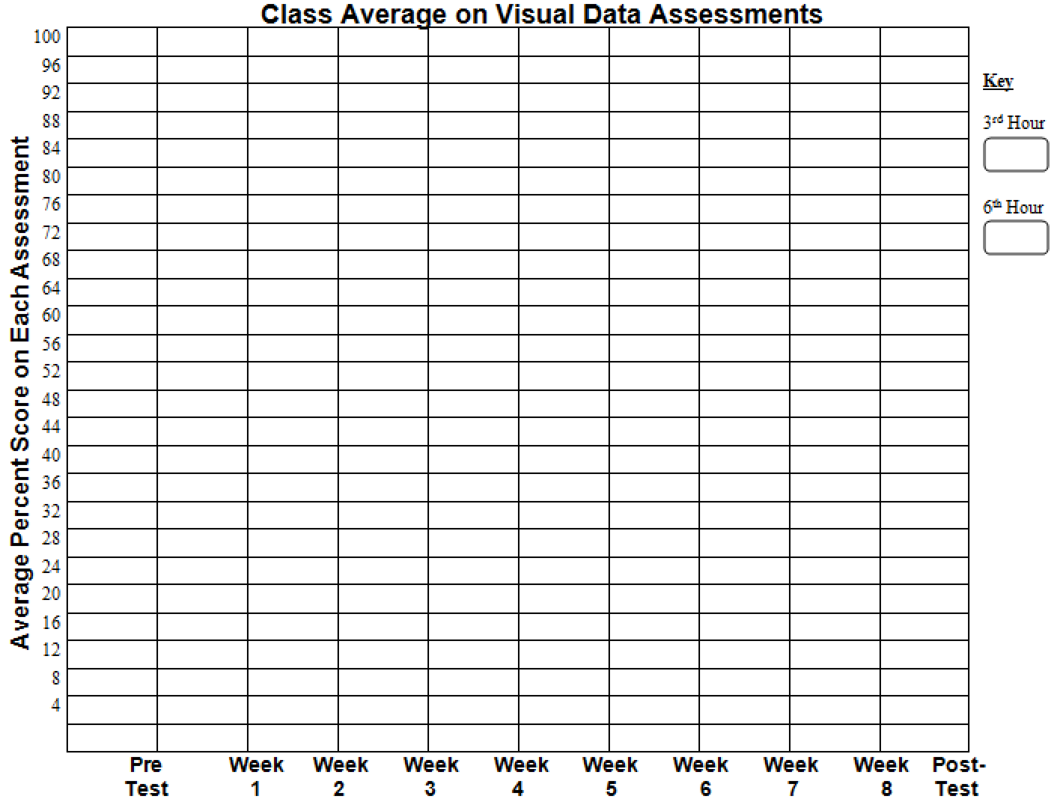
STUDENT WEEKLY ASSESSMENT GRAPHS

Student Name: ______________________________ Class Period: ____________

Student Weekly Visual Data Assessment Scores



Class Average on Visual Data Assessments



APPENDIX D

STUDENT INTERVIEW

Student Interview

Student volunteers from each class were randomly chosen for interviews. A random number generator was used to choose three students from each of the two treatment classes. Students were interviewed one at a time during class or outside of class, as permitted by student schedules.

Participation in this research is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

1. What is visual data?
2. Students were shown their answers from the Pre and Post Survey, which included the questions below. Students were asked to look at each survey question, and comment on their progress during the 8 week treatment period, discussing what how they thought their visual data literacy skills changed over time, if they did.
    a. I can read and understand graphs, tables, and scientific diagrams.
    b. I can use a title to understand graphs, tables, and scientific diagrams.
    c. I can use X-axis and Y-axis labels to understand graphs, tables, and scientific diagrams.
    d. I can find the independent variable on graphs, tables, and scientific diagrams.
    e. I can find the dependent variable on graphs, tables, and scientific diagrams.
    f. I can use graphs, tables, and scientific diagrams to explain an experiment, even if I did not do the experiment.
3. What was most helpful to you in improving your visual data literacy skills?
4. How can analyzing the parts of visual data in a methodical way help you to explain what the data means?
5. What do you still struggle with when interpreting visual data?
6. Why do you think it is helpful for you to learn how to improve your interpretation of visual data?