

THE EFFECTS OF DIRECT MATHEMATICAL INSTRUCTION IN
SCIENCE CLASSES ON MATHEMATICAL
BASED SCIENCE REASONING

by

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ABSTRACT

Students at Belgrade High School appear to have limited understanding of the interpretation, analysis, evaluation, reasoning, and problem-solving skills required in the natural sciences. I suspect that this is the result of inadequate direct instruction in mathematical based science reasoning skills. The goal of this project was for students to be able to use and articulate mathematical reasoning strategies when approaching scientific tasks. To accomplish this, sophomore level Biology (Genetics) curriculum was pervaded with mathematical instruction.

This project investigated the effectiveness of implementing direct mathematics instruction in sophomore level Biology courses to improve mathematics based science reasoning skills at Belgrade High School in Belgrade, Montana. Students explored Genetics based Biology concepts while receiving direct instruction on statistical analysis as a tool for developing scientific reasoning skills, such as, scientific claim, evidence, and reasoning.

Data collection for this project involved completion of scoring rubrics by both the student and teacher following a Genetics based laboratory exercise, as well as, a Genetics summative assessment concluding the three-week unit of study. Students were evaluated on a point scale that included: stating a claim, providing evidence, data-based reasoning, and making an argument.

The results indicated that by implementing direct Mathematics instruction on standards-based Biology concepts, students gained a greater understanding of Genetics concepts and were able to develop a more thorough claim, evidence, reasoning explanation for a standard Genetics laboratory investigation.

INTRODUCTION AND BACKGROUND

For the past two years I have been teaching 9th and 10th grade Science at Belgrade High School. This most recent school year (2016-2017), I taught three sections of Biology, two sections of General Biology, and one section of General Science. In total, I teach 138 students (70- Biology, 45- General Biology, 22- General Science) which I see approximately half each day with an alternating block schedule of 99-minute class periods. The courses titled “General”, are designed specifically for students that score below proficient in reading and/or math. Students in “General” courses test near, or on, the special education spectrum. While I see a lack of math-based science reasoning skills in my “General” courses, the focus of my study was on my Biology courses. I fully intend on expanding this action research project to those courses within the next year.

Belgrade High School, in Belgrade, Montana, is located ten miles west of Bozeman, Montana with a growing population of 7,600. Belgrade High School has a current (2015) enrollment of 838 students with a projected 2025 enrollment of 1,046. Of the current 838 students, 29% qualify for free/reduced lunch, 86% are proficient in reading, and 64% are proficient in math.

Using the Belgrade Public Schools grading scale of 64% and lower is a failure, the fact that 64% of the Belgrade High School students are proficient in math, in opinion is a failure. Daily I hear the groans and gripes of my students regarding the “impracticality” of math. They ask, “What is the purpose?” and, “What is the use?”. I believe science application is the solution to this problem. Without mathematics, STEM

(Science Technology Engineering Mathematics) becomes STE and that is a paradox that simply does not exist.

Students at Belgrade High School appear to have limited understanding of the interpretation, analysis, evaluation, reasoning, and problem-solving skills required in the natural sciences. I suspect that this is the result of inadequate direct instruction in mathematical based science reasoning skills. I want Belgrade High School students to be able to use and articulate mathematical reasoning strategies when approaching scientific tasks.

I will implement direct mathematical instruction and data analysis throughout my Biology Genetics science curriculum. Students should gain an understanding of using math as a strategy to reason scientifically. The primary question I will be researching is: what is the effect of direct mathematics instruction on mathematical science based reasoning? Secondary, I will be researching four sub-questions: (1) How do students currently learn math concepts? (2) What Biology concepts can be investigated using the Claim, Evidence, Reasoning model for scientific investigations? (3) How can the integration of math and science enhance science instruction for students? (4) How will the teacher know if student's math-based scientific explanations are improving?

CONCEPTUAL FRAMEWORK

The nature of science outlined by the Next Generation Science Standards (NGSS) reveals the multidimensional components that comprise scientific practices and understanding. Within the eight NGSS science and engineering practices, six use mathematics as a foundation of or tool for science. Brandon (2015) investigated how well

the dimensionality described in the nature of science component of the NGSS framework matched empirical data collected in a high school classroom setting. Treating the nature of science as comprising multiple dimensions, as outlined by the science and engineering practices, results in a better fitting model of science than when treating the nature of science as a single endeavor (Brandon, 2015). With mathematics having an overarching presence throughout the multidimensional nature of science, it too should have an interdisciplinary presence in the high school science classroom.

While the NGSS framework touts the importance of mathematics based science, that parallel is not always translated into classroom practice. In a descriptive study conducted by Baker (2015) where twenty middle school textbooks were examined, few presented opportunities for students to practice using mathematical skills as a tool for reasoning with scientific data. While half of the activities in the science textbooks included data, very few of the activities provided opportunities to learn how to record, analyze, and interpret data (p. 2716). Reasoning with data is the basis of scientific argumentation but the analysis done by Baker (2015) suggests that science textbooks provide limited support for reasoning with data.

When a practice as integral as reasoning with data is often neglected from textbooks, it takes a team of teachers working together to create authentic data learning experiences for their students. In *Integrating literacy, math, and science to make learning come alive*, Bintz (2006) worked through numerous scheduling constraints to develop and implement an inter-disciplinary team of teachers structured around getting middle school students actively engaged in data collection, analysis, and science based reasoning. After

reading the story of *Mr. Archimedes' Bath* to help students make connections between experimental design and variables, teams of students designed multiple experiments involving rubber band cannon. Students were responsible for the design, data collection and analysis, conclusion, and presentation of an experiment involving their team's rubber band cannon. At the end of the process, students reflected on what they learned and suggestions for further expansion of the interdisciplinary lesson. Students commented that they learned graphs make data a lot easier to look at, read, and understand (p. 36) and that they wish they could make more graphs (p. 36).

Similarly, in *Making sense of data* (Palmeri, 2009), developed interdisciplinary inquiry experiences for students to learn ways of documenting data and developing understandings of key scientific concepts. For example, to practice the use of collecting and organizing authentic data, Palmeri had students interview family members to generate lists of species that are in the Kingdom Animalia. After compiling a class list, students then needed to organize the data collected and collaborate on the best means to represent the mass of data collected. Watching students take accountability of data collection and analysis, allowed Palmeri to see common questions and points of confusion that arose during the process. These insights allowed further data-based lesson development for future units of study. After analyzing content goals, Palmeri found that scientific understanding is integrally tied to the ability to gather and analyze data, and using data to construct and communicate scientific explanations.

Additionally, in *Developing intuitive reasoning with graphs to support science arguments* (Grueber, 2011) analyzed engaging mathematical based science activities

from the Rational Numbers Project. The Rational Numbers Project scaffolds the use of math as a means of scientific reasoning using relevant, engaging student centered problems. Funded by the National Science Foundation since 1979, the reasoning behind the Rational Numbers Project parallels the evidence behind the science and engineering practices of the NGSS framework. In order to teach science as a practice, students need to be engaged in critical thinking (p. 49). For example, in *Dividing Fractions and Problem Solving*, sixth grade students used concrete and pictorial models to build meaning for arithmetic operations with fractions (Cramer, 2010).

In addition to the importance of building critical thinking strategies around data based instructional practices, Grueber expands upon the importance of using graphs as a tool in data analysis. It is important for students to learn how to use the thinking tools of science, one of the most important tools is graphs (Grueber, 2011). Once students have an understanding of the construction of and analysis of graphs, they become a crucial scientific reasoning tool that can be used for any scientific investigation.

An analysis of the research indicates that the nature of science is dependent upon the use and understanding of mathematics. Providing opportunities for students to immerse themselves in the collection and organizing of data and working through the reasoning of how to best represent and communicate their findings, is reflective of authentic science and is pivotal in the development of scientific reasoning. With further understanding of national standards, the use of data as a basis of scientific argumentation is expanding. Finally, to support the integration of mathematics and science, both subjects should be learned in the same way, requiring interdisciplinary collaboration.

METHODOLOGY

To increase student understanding and interpretation of mathematical based science reasoning skills, I will imbue Biology Genetics science curriculum with direct statistical analysis instruction, practice, and exploration. The goal of this study is twofold, (1) to help students use and articulate mathematical reasoning strategies when approaching scientific tasks and (2) to determine if direct instruction of key grade-level specific mathematical concepts improved student explanations of Biology topics. This study was reviewed and approved by the Montana State University Institutional Review Board.

The participants in this study were 70 students in my Biology course, including 35 male students and 35 female students. Of these students, 63 were sophomores and 7 were juniors. The Biology unit on genetics was the content area for treatment and the unit spanned the course of the third quarter of the school year.

Prior to creating the student-based surveys, investigations, and assessments, I needed to first reach out to the math department. The basis of my focus question was integrating mathematics and science, including the math department in the creation of my data sources ensured that my instruction and assessment of student knowledge used valid means that correlate to practices and standards used in the math department.

First, I surveyed four math teachers (Appendices A) regarding how they help students overcome struggles in math, what math based skills math teachers would like to have students practice in other classes, and if they had any suggestions for incorporating more math in the science classroom. Second, we correlated Next Generation Science

Standards and Common Core Math Standards for the Genetics unit. Third, I surveyed my Biology students on the interest in math and science. Lastly, I used direct instruction and independent laboratory investigation to assess student gains, misunderstandings, and comprehension.

The results from the math teacher survey indicated that math teachers help students overcome struggles in math by using multiple modes of practice, explanation, and multiple representations whenever possible. The math teachers were all in agreement that the math based skill they would like students to practice in other classes is data analysis, with one teacher stating, “Data analysis! Explaining your answer- rather than just providing a number, give a sentence saying what that number represents.” Finally, one math teacher was very enthusiastic when asked, “Do you have any suggestions for incorporating more math in the science classroom that could help your students as well?” The math teacher replied, “DO STATISTICS!!!!!!”.

In addition to surveying the math teachers, I also used a Common Core Math Standards and Next Generation Science Standards correlation matrix (Appendices B) developed by a colleague to isolate the math and science standards I would address during the Genetics unit. The NGSS standard of focus was, LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. The Common Core Math Standards that correlate with LS3-3 are HSF-IC-A1 (Make inferences and justify conclusions from sample surveys, experiments, and observational studies), 9-12. HSN-Q-A3 (Choose a level of accuracy appropriate to limitations on measurement when reporting quantities), and HSS-IC-B6 (Understand

statistics as a process for making inferences about population parameters based on a random sample from that population).

To confirm the use of the teaching practices stated by the math teachers and how Common Core Math Standards are addressed in math classes, I observed a sophomore level math class for one block period (99 minutes). Through surveying math teachers, correlating NGSS and MCCS, and observing math teaching practices, it was evident that applying direct instruction of standards based mathematical concepts to my standards-based Genetics unit could lend itself to enriching how students currently learn math concepts and explain student-led investigations.

The math teacher survey results guided my development of the data collection instruments used throughout this study. On the student side, first, all students completed the Math and Science Interest Surveys (Appendices C and D). The Math and Science Interest Surveys are concise tools to measure students' prior attitudes and connections with Math and Science. These responses were assigned numerical values on a 5-point Likert Scale ranging from: 1-Strongly Agree to 5-Strongly Disagree. After data collection, the scores were calculated to determine any variance in attitudes and connections with Math and Science.

All students received equal instruction on genetics, including, student-led laboratory investigations. For comparative purposes, a Treatment Group consisting of two sections of 46 students in total received direct instruction on conducting Chi-Squared Tests as a tool for providing evidence and reasoning when evaluating a genetics claim. The Control Group consisted of one section of 24 students and did not receive direct

instruction on using the Chi-Squared Test. The Control Group evaluated the same genetics claim and their evidence and reasoning was evaluated using the same QPOE₂ (Question Prediction Observation Explanation Evaluation) Investigation Rubric (Appendix E) as the Treatment Group.

To assess students' ongoing understanding and development of Math and Science connections I used two instruments throughout implementation for both student groups. The first was Muddiest Point which was used to gather information about student understanding of daily classroom content (Appendix F). I prepared the data by making observations on their responses in my Teacher Journal (Appendix G). After reflecting on common connections and misunderstandings, I incorporated the student responses into the next lesson.

After direct instruction of Chi-Squared Tests, I posed a related genetics problem that used the math concept and students completed the Muddiest Point. This is an instrument commonly used by the Belgrade High School math department to gauge student understanding.

The class period following the Genetics laboratory investigation, students completed a second instrument, Recall Summarize Question Connect and Comment (RSQC2) (Appendix H). The RSQC2 is a modular Classroom Assessment Technique. The five-step protocol guides students through a simple recall, summary, question, connect, and comment exercise focusing on the previous class lesson. The RSQC2 allowed me to compare detailed information on the students' recall, understanding, and evaluations of the previous lesson against their own. This instrument also informed me of

students' questions and comments that needed timely responses. The instrument also provided students with a framework for recalling and reviewing math and science concept connections.

Randomly selected students from both the treatment group and control groups were given the Genetics Questionnaire prior to the start of the Genetics unit, as well as, one class period prior to the end of the unit (Appendix I). I used Google Forms to administer this questionnaire so that I could accurately gather student responses to the questions asked and further ensure validity of their responses. Google Forms was chosen as a valid way to gather student opinions because through prior experience, students express their true thoughts and reflections less when asked to write them down because throughout the year teachers learn each student's distinct handwriting and this compromises the anonymity of questionnaires.

The Genetics Questionnaire was used to gather similar information about the students' knowledge of the Chi-Squared Test but to also evaluate the student's ability to use evidence and argument based reasoning to evaluate a genetics claim. The Genetics Questionnaire was developed using similar concepts to what students would explore while conducting the Genetics Investigation (Appendix J). Another set of data that was analyzed was a Genetics unit assessment (Appendix K). The Genetics unit assessment had a section that was formatted similarly to the data analysis and explanation sections of the Genetics Investigation. The Genetics unit assessment was used to check for retained understanding of key concepts and reasoning practices developed through the Genetics investigation.

Finally, teacher best practices were observed throughout implementation by keeping a journal. Journal responses were analyzed to notice any trends in personal reflection and if those trends impacted teacher best practice. Teacher observations were also recorded in the journal to help recognize any change in student understanding. The students' responses to the Classroom Assessment Techniques were also further analyzed for any noticeable increases in pedagogical practices. Table 1 summarizes my data collection methods.

Table 1
Action Research Triangulation Matrix

Focus Question: Will direct instruction of mathematical concepts improve students' explanations of Biology topics?			
Subquestions	Data Source		
Subquestion 1: How do students currently learn math concepts?	NGSS and Common Core Standards Alignment	Math Department Survey	Math Class Observation
Subquestion 2: What Biology concepts can be investigated using the Claim, Evidence, Reasoning model for scientific investigations.	NGSS and Common Core Standards Alignment	Math Department Survey	Teacher Journal
Subquestion 3: How can the integration of math and science enhance science instruction for students?	Math and Science Interest Survey	Teacher Journal	Genetics Investigation and Genetics Questionnaire (Pre and Post)
Subquestion 4: How will the teacher know if student's math-based scientific explanations are improving?	Teacher Journal	Formative Assessments- CATs	Genetics Investigation and Summative Assessments- Unit Assessment

DATA AND ANALYSIS

The primary research question, what is the effect of direct mathematics instruction on mathematical science based reasoning?, was divided into four subquestions. (1) How do students currently learn math concepts? (2) What Biology concepts can be investigated using the Claim, Evidence, Reasoning model for scientific investigations? (3) How can the integration of math and science enhance science instruction for students? (4) How will the teacher know if student's math-based scientific explanations are improving? Data from multiple sources was collected and analyzed for each subquestion.

Science and Math Interest Survey

The results of the Science Interest Survey and the Math Interest Survey showed that more students claim math as one of their favorite class (40.9%) than science (32.3%) (Figure 1).

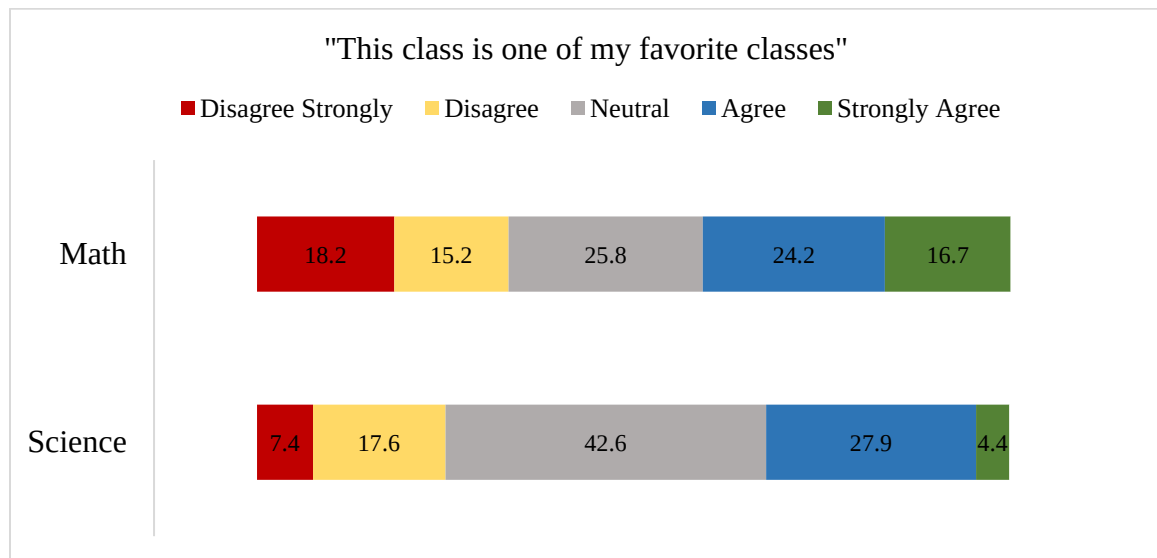


Figure 1. Math and science interest surveys- Question 1. (Math $N = 66$, Science $N = 68$).

Results were positive when presented with the statement, “I think math and science go together,” with a positive (Agree or Strongly Agree) of >70% (Figure 2).

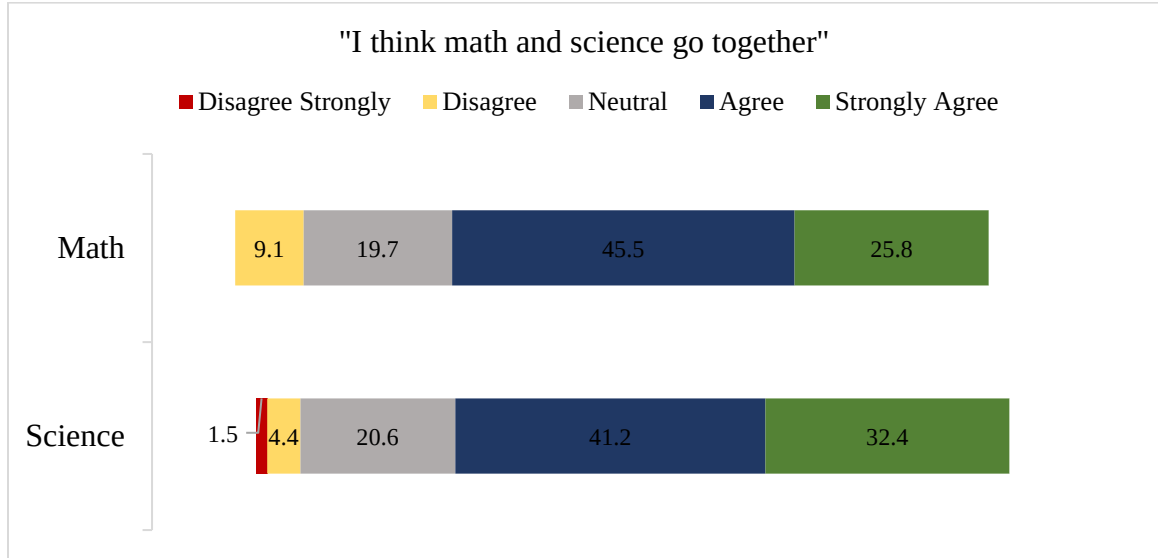


Figure 2. Math and science interest surveys- Question 7, (Math $N = 66$, Science $N = 68$).

When presented with the statement, “I think this subject should be TAUGHT in other class, not just this classes,” a majority (57.6%) responded neutral and 31.9% responded negatively (Disagree or Strongly Disagree) when the statement was posed with the subject as Math. When the statement was posed with the subject as Science, 35.3% responded neutrally and 42.7% negatively (Figure 3).

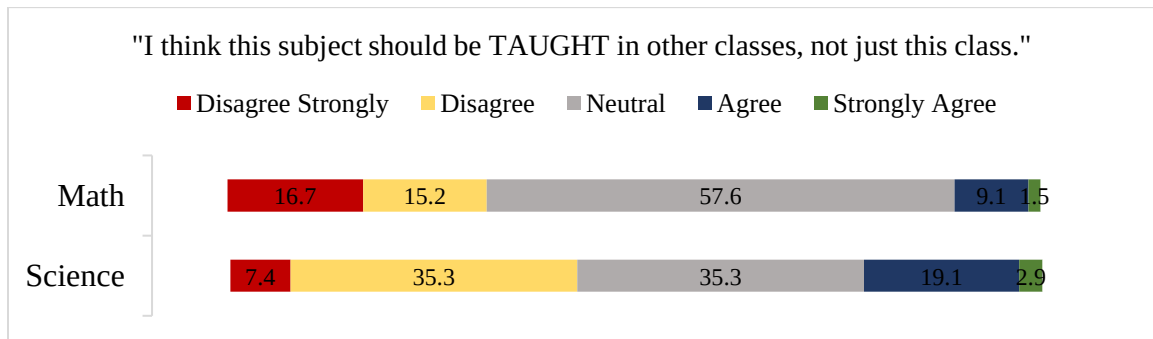


Figure 3. Math and science interest surveys- Question 14, (Math $N = 66$, Science $N = 68$).

When presented with the statement, “I think this subject should be USED in other classes, not just this class,” students responded significantly neutral-positive with an average neutral response of 35% and a positive response of >46% (Figure 4).

Full comparison between Math and Science interest can be found in Appendices L. One theme presented by the data suggested that while students have high confidence in learning and practicing a subject, they prefer to be taught the subject (1) by the teacher first showing them how to understand the concept and (2) within that class.

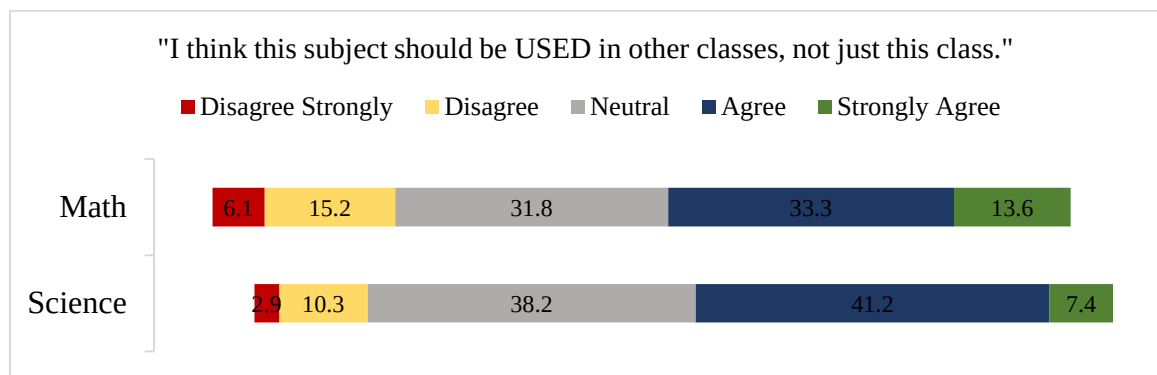


Figure 4. Math and science interest surveys- Question 15, (Math $N = 66$, Science $N = 68$).

Pre- and Post- Genetics Questionnaire

The results from the Pre- and Post- Genetics Questionnaire showed overall growth in knowledge of the purpose of Punnett Squares (Figure 5).

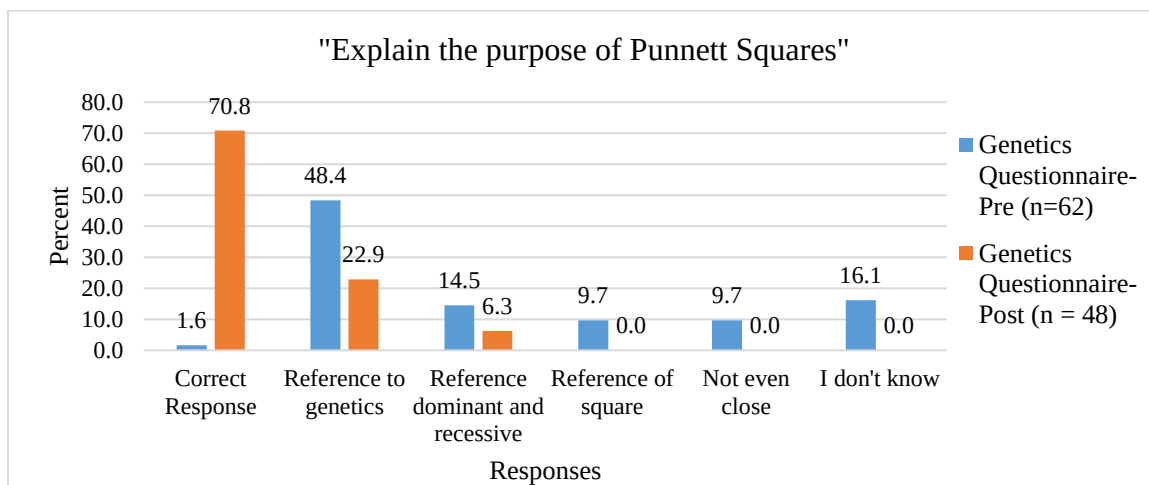


Figure 5. Genetics questionnaire pre vs. post- purpose of punnett squares, (pre $N = 62$, post $N = 48$). Correct response = relation to predicting the probability of outcomes in relation to offspring.

The results of Pre- and Post- Genetics Questionnaire- “What is an expected outcome for a genetic cross?”, showed a similar representation of overall growth in knowledge, specifically for expected outcomes from genetic crosses, such as a cross between two heterozygous parents (Figure 6).

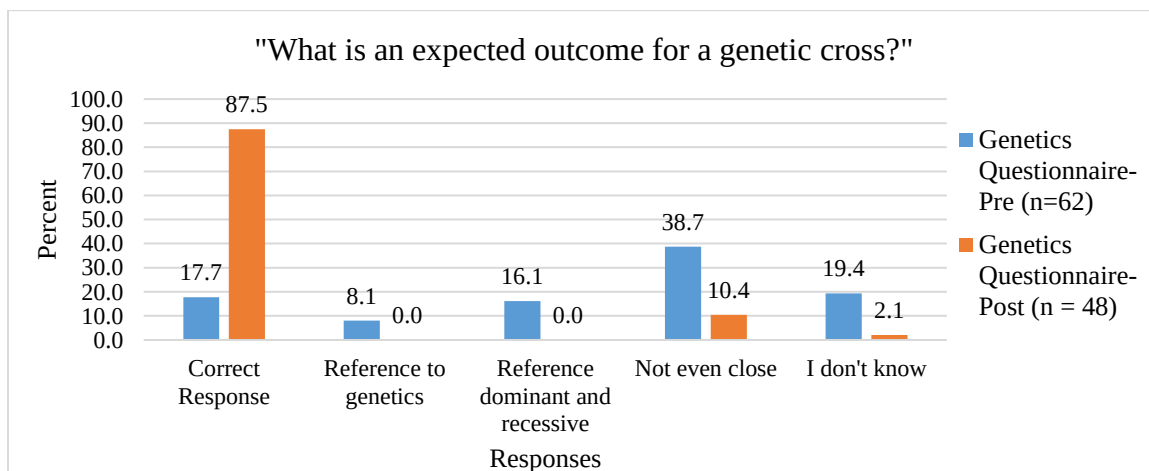


Figure 6. Genetics questionnaire pre vs. post- genetic cross expected outcomes, (pre $N = 62$, post $N = 48$). Correct response = relation to Mendel’s Law of Independent Assortment.

The remaining three questions on the Genetics Questionnaire were aimed at evaluating the integration of Genetics concepts following the claim, evidence, reasoning

model for scientific investigations with Common Core Math Standards. Students were asked, “After a genetics investigation, how would you prove that the numbers you did see weren’t just by random change?” The correct response for the treatment group was a reference to performing Chi-Square analysis. The correct response for the control group was a reference to Punnett square ratios (Figure 7).

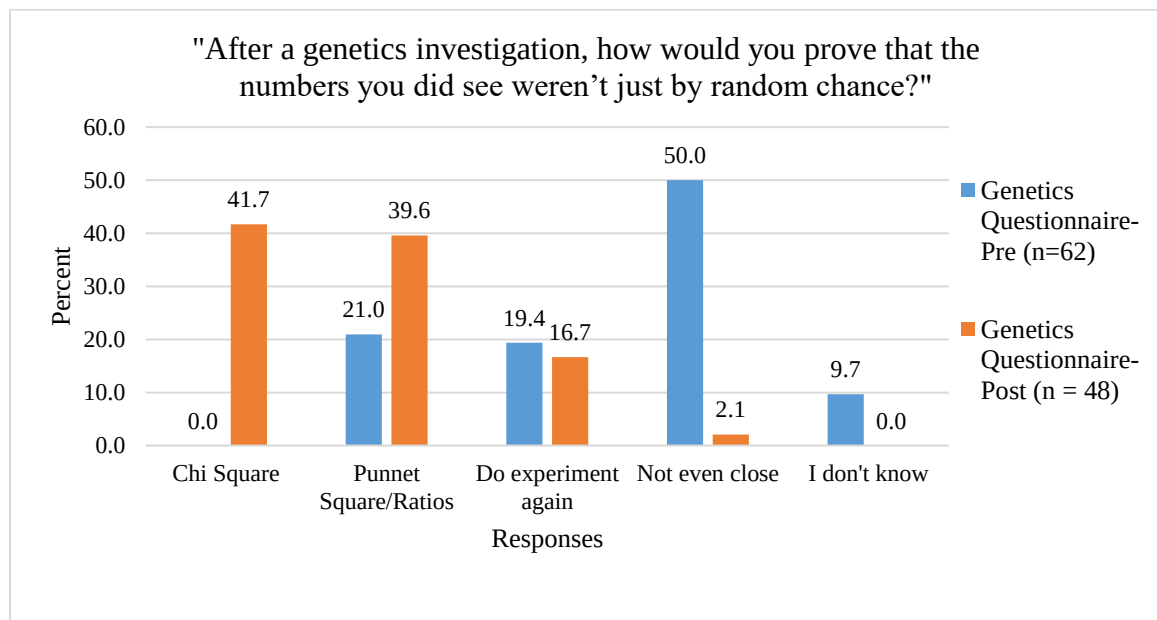


Figure 7. Genetics questionnaire pre vs. post- evaluating genetics claim, (pre $N = 62$, post $N = 48$).

A follow-up question was posed to students asking, “Why would you use this method?”, the data (Figure 8) showed a similar trend as evidenced in Figure 7. The correct response for the treatment group was a reference to checking for random chance, a hallmark of Chi-Square analysis. The correct response for the control group was a reference to checking for accuracy, a foundation of performing Punnett square ratios analysis.

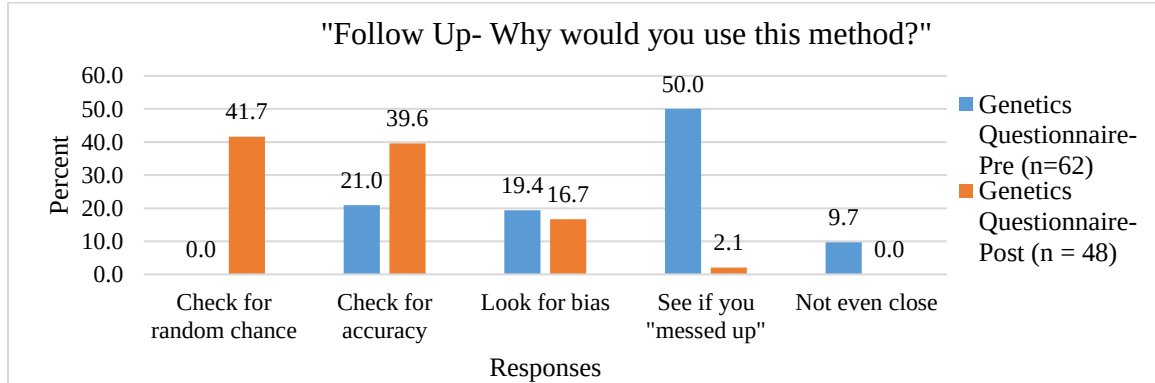


Figure 8. Genetics questionnaire pre vs. post- methodology, (pre $N = 62$, post $N = 48$).

The Genetics Questionnaire was one data source used to evaluate if integration of math and science enhanced science instruction for students. To evaluate how I would know if student's math-based scientific explanations were improving, students conducted an investigation evaluating the claim: Does Indian corn follow Mendel's Law of Independent Assortment?

Recall, Summarize, Question, Connect, Comment (RSQC2)

The class period following the investigation students answered a Recall, Summarize, Question, Connect, Comment (RSQC2). The data for both groups, treatment and control, showed students ranking "How to check data" as the most important idea from the previous class (Figure 9 and Figure 10).

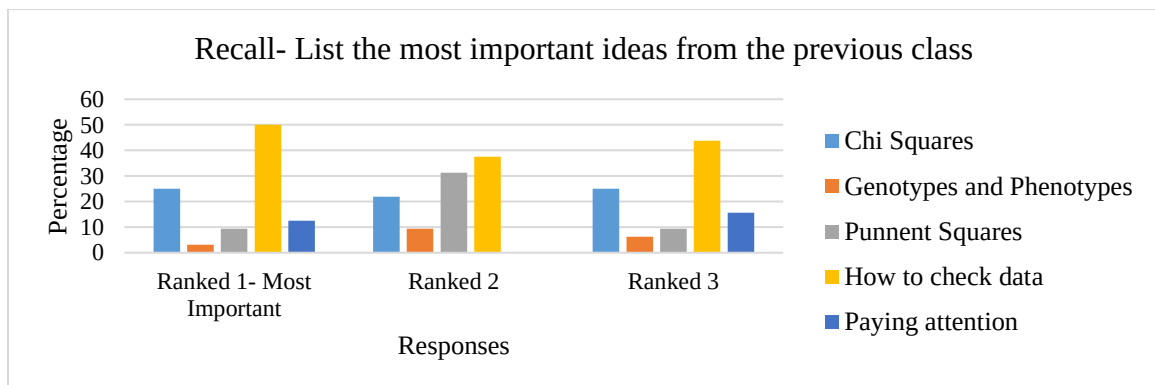


Figure 9. Treatment group RSQC2- recall, ($N = 32$). Legend: 1 = Most important, 2 = Second most important, 3 = Third most important.

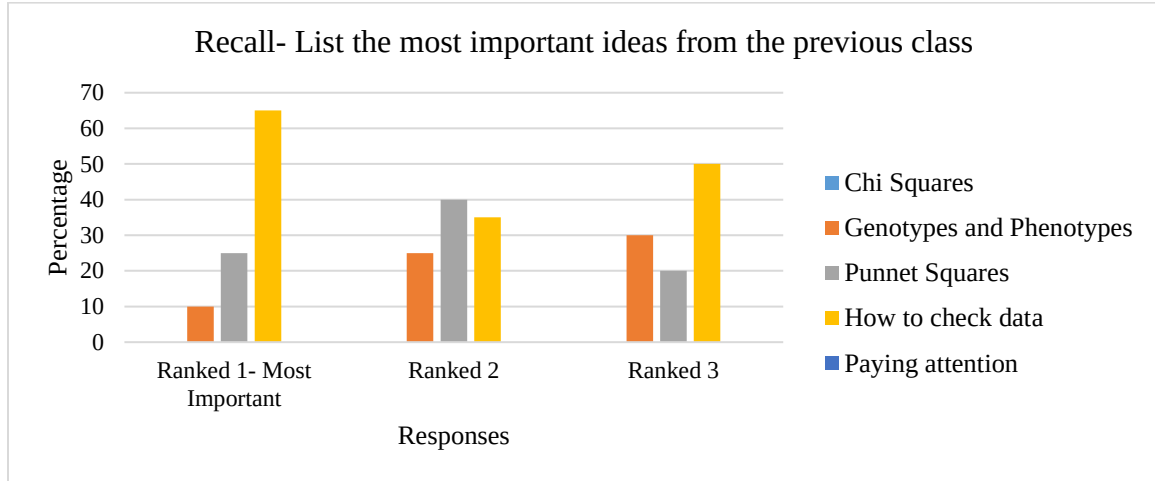


Figure 10. Control group RSQC2- Recall, (N = 20). Legend: 1 = Most important, 2 = Second most important, 3 = Third most important.

A trend seen in the treatment group is that ranking “How to interpret data” fell not only as the most important idea from the previous class but students who did not rank it as the most important, ranked it either as the second or third most important. In the control group, “How to interpret data” was also ranked as the most important idea and the third most important idea, but fell slightly to “Punnett squares” for the second most important. The data also shows key differences between the treatment group and the control group. In the treatment group, “Chi Squares” were ranked highly as either first, second, or third most important, whereas expected in the control group there was no mention of Chi-squares. Another difference being that students in the treatment group ranked “Paying attention” as either the most important or third most important idea from the previous class, whereas no students in the control group mentioned “Paying attention” as an important idea.

Notable differences between the treatment group and the control group emerged in the remaining RSQC2 categories: Summarize, Question, Connect, and Comment.

When asked to summarize the previous lesson in one sentence, the treatment group provided greater depth of understanding, whereas the control group described the actions of the lesson rather than the main idea of the lesson. A student in the treatment group summarized the previous lesson as, “We had to gather information and create chi squares to see if the corns were accepted by science to follow Mendel's Law of Independent Assortment.” In contrast, a student in the control group summarized the previous lesson as, “During the lab in our last class, we learned the basic steps of grown corn, we compared different hybrids of corn and their physical features, and recorded our findings and observations by completing an informational lab write-up.” This trend of the treatment group going into greater depth of understanding and the control group being rather descriptive continued throughout the unit of study.

This difference between the treatment group and control group was very evident when students were asked, “What is one question about the material from the previous class that you want answered?” The majority of responses from the treatment group stated, “I don’t have any questions.” While the majority of responses from the control group were variations of asking *why* there are differences in corn phenotypes. This difference in depth of understanding became further apparent in the students’ investigation write-ups.

Student Laboratory Investigation- Explanation

A second set of data used to help determine if student’s math-based scientific explanations were improving was evaluating the explanation section of students’ lab write-ups according to a standardized rubric that follows the claim, evidence, reasoning

model for scientific investigations. Each portion of the explanation (claim, evidence, reasoning, and makes an argument) are scored using half-point increments ranging from 0-1, 0 meaning not acceptable, 0.5 meaning needs improvement, and 1.0 meaning great!). The average explanation scores, broken down by subcategory, are shown in Figure 11.

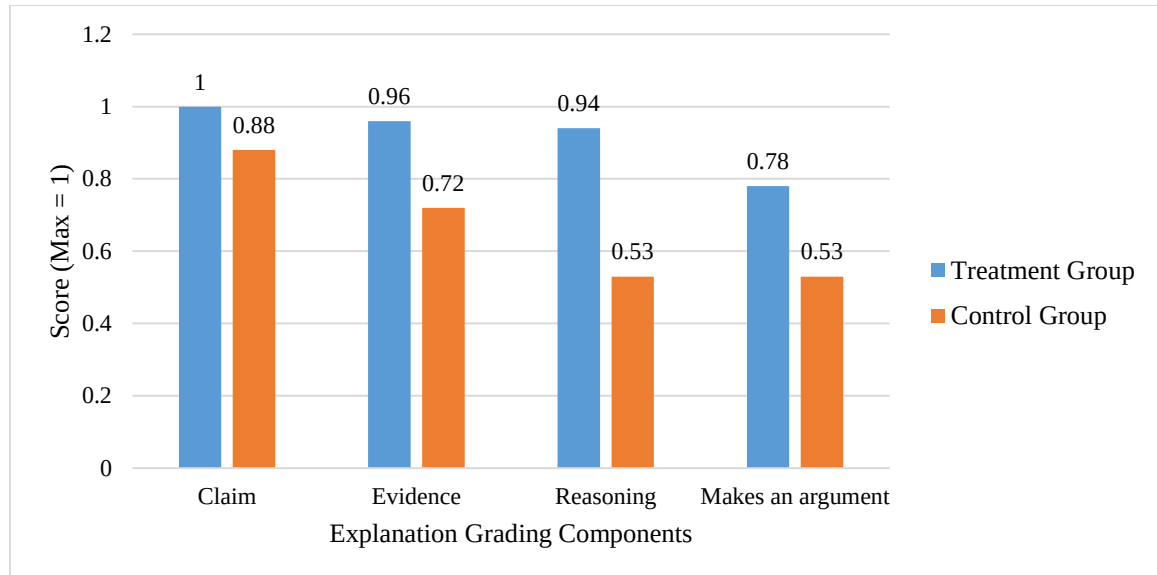


Figure 11. Average explanation lab scores, (treatment $N = 34$, control $N = 16$). Legend: 0 = Not acceptable, 0.5 = Needs improvement, and 1.0 = Great!.

The claim scores of the treatment group ($M = 1$, $SD = 0$, $n = 34$) was hypothesized to be greater than the claim scores of the control group ($M = 0.875$, $SD = 0.22$, $n = 16$). This difference was significant, $t(48) = 3.298$, $p = 0.001$. An example of a treatment group student's claim was, "The predicted color distribution for the corn offspring is incorrect. Mendel's Law of Independent Assortment does not apply" (Appendices M). An example of a control group student's claim was, "Yes, Indian corn follows Mendel's law of independent assortment" (Appendices N). Both students in the treatment and control group wrote a claim that answered the investigation question, "Does Indian corn follow Mendel's Law of Independent Assortment." Every student in

the treatment group scored a “1” when making their claim, whereas the average score in the control group was 0.88, with some students still writing a claim as a yes/no response, as seen the Pre-Genetics Questionnaire.

The evidence scores of the treatment group ($M = 0.96$, $SD = 0.14$, $n = 34$) was hypothesized to be greater than the evidence scores of the control group ($M = 0.72$, $SD = 0.26$, $n = 16$). This difference was significant, $t(48) = 4.20$, $p = 0.00006$. An example of a treatment group student’s evidence was, “Out of 203 total offspring, 8- were RP, 22 were rP, 72 were Rp, and 18 were rp”. An example of a control group student’s evidence was, “For the dihybrid cross kernel coloration & texture round and purple $111/196 = .57$ wrinkled & purple $37/196 = .19$ round & yellow $34/196 = .17$ wrinkled & yellow $14/196 = .07$ ”. Both these individuals scored a “1” as did a majority of students in the treatment group. Students in the control group that did not score a “1” responded in a positive/negative tone, “My data was correct” or “My data was incorrect”, similar to responding yes/no to the claim.

The reasoning section is where the divergence between the treatment group and the control group widened. The reasoning scores of the treatment group ($M = 0.94$, $SD = 0.16$, $n = 34$) was hypothesized to be greater than the reasoning scores of the control group ($M = 0.53$, $SD = 0.22$, $n = 16$). This difference was significant, $t(48) = 7.368$, $p = 1.00 \times 10^{-9}$. An example of a treatment group student’s reasoning was, “With 3 degrees of freedom, my chi-square value is 43.142, which gives a p-value of less than 5%, I therefore reject my null hypothesis. This means that <5% of the time when our observed data is this close to our expected value, is not due to random chance”. An example of a

control group student's reasoning was, "I selected my corn rows at random I performed at least 5 trials, & my observations were independent. My percentages in table 3 fit in the boundaries of Mendel's law." Students in the treatment group followed similar rhetoric to the student quoted previously. A majority of students in the control group described their procedures, similarly to the quoted control student, rather than providing reasoning for the claim and evidence they stated. The treatment group made references to "Chi-square value" and "random chance" in the reasoning section, which mirrors the results shown in the Post-Genetics Questionnaire. The control group made references to "Punnett squares" and "Accuracy", which also mirrored the results shown in the Post-Genetics Questionnaire.

The "makes an argument" scores of the treatment group ($M = 0.78$, $SD = 0.25$, $n = 34$) was hypothesized to be great than the "makes an argument" scores of the control group ($M = 0.53$, $SD = 0.22$, $n = 16$). This difference was significant, $t(48) = 3.371$, $p = 0.0007$. An example of a treatment group student's argument was, "This was a fair test because we combined data from five rows of corn kernels, did a punnet square and completed a chi-square test. I am a little confident with our data because we conducted 3 trials." An example of a control group student's argument was, "I am strongly confident because we selected our corn at random and conducted a minimum # of trials. We also had our results confirmed". The "makes an argument" subcategory was the lowest scoring, on average, for both the treatment and control group. In order to properly make an argument, students must go beyond the data and take a stance on the claim, evidence, and reasoning they stated.

Muddiest Point

Another assessment tool, the Muddiest Point, was used after direct instruction of Chi-square analysis for the treatment group and ratio analysis for the control group to help determine teacher best practices. I also kept a teacher journal to record and look at trends in my responses to students Muddiest Points and RSQC2 opinions. The trends represented consisted of comments that helped guide teacher best practices to fit student need. A common trend that appeared was students asking for additional examples and representations of Chi-square, for the treatment group, and ratios, for the control group. These responses were on-trend with the initial math teacher survey with multiple math teachers stating that the way they help struggling students is by various forms of practice and representations. After reflecting on the student responses and the math teacher survey, I incorporated additional representations and practice of Chi-squares, for the treatment group, and ratios, for the control group. The number of clarification questions and “I’m stuck” or “I don’t get it” comments decreased in both groups and when I proposed a final Muddiest Point to students, a majority did not fill one out and the results from those that did indicated that students were no longer stuck on the concept, with several students stating, “I am not stuck.”

Overall, reflecting on both the progress and comments from my students, as well as, reflecting on my own teaching practices during the Genetics unit provided a multifaceted benefit. Students benefitted from instruction that was tailored towards their misconceptions and “stuck” points. My teaching practice benefitted by not making assumptions of how I thought the lesson went and what I thought my next actions should

be but rather I was able to focus on the specific strengths and weaknesses of my students and correlate those to points in my instruction. Reflecting in my journal, as well as, reflecting on the student data sources allowed me to delve deeper into both my instructional practices and the construction of math-based science knowledge exhibited by students.

INTERPRETATION AND CONCLUSION

The data were analyzed to help determine if direct instruction of mathematical concepts improve students' explanations of Biology topics. The primary question is defined by the following four subquestions.

Subquestion 1: How do students currently learn math concepts?

My first question asked how do students currently learn math. I graduated high school in 2009 and during the relatively short period of time since I graduated high school and started teaching at the high school level, I have seen a pedagogical shift in math instruction.

Prior to treatment, to treat the nature of science as comprising multiple dimensions and to gain a depth of understanding regarding the mathematical basis of six of the eight NGSS science and engineering practices, I surveyed, discussed, observed, and modeled the teaching practices of the math teachers at Belgrade High School. From my observations of the math teachers I learned three guiding principles they follow, which I later followed in both the treatment and control sections of my Biology classes.

The guiding principles were (1) Let it Make Sense, strive to teach for understanding, the “why” something works, not only the “how”. (2) Remember Your

Goal, the goal being, to enable students to understand information around us. (3) Living and Loving Math, teachers show the way first with their attitude. These three principles that guide the math department, guided my math instruction and ultimately guided my entire unit. (1) Students need to know not just the “how” of scientific processes but the purpose, the relation to their everyday lives. (2) My goal as a science educator is to empower my students to understand, not memorize and recite. (3) Attitude is everything, I must show my passion and enthusiasm every day. A common comment I received at the end of the unit of study was, “What made learning best was the enthusiasm of my teacher.”

Through interviewing, observing, and modeling the math department I developed a connection that the nature of science is not a single endeavor, the same should apply to the teaching of science. Few science textbooks/curriculum modules present students with practice using mathematical skills for reasoning with scientific data. Through this treatment, as well as to a lesser extent with the control, I provided my students multiple opportunities to record, analyze, and reason with data. It took forming an integrated team with the math teachers and I working together to create authentic data learning experiences for my students, a majority of which have an additional year of math to complete prior to graduation. The problems generated were student centered and developed to use math as a means of scientific reasoning. The integration of mathematics and science throughout this treatment required true interdisciplinary collaboration that ultimately showed a statistically significant result.

Subquestion 2: What Biology concepts can be investigated using the Claim, Evidence, Reasoning model for scientific investigations?

Through the interpretation and analysis of aligning the Next Generation Science Standards and the Common Core Math Standards I found that all Biology concepts can be investigated using the Claim, Evidence, Reasoning model, with a strong emphasis on mathematical based science reasoning.

As Brandon (2015) stated, science should not be treated as a single endeavor but rather should be treated as multi-dimensional. The Claim, Evidence, Reasoning model for scientific investigations immerses students in the process of generating and appropriately investigating scientific questions

The primary focus of this study was implementing Chi-square analysis in two out of three sections of Biology and the use of ratios in the remaining sections to evaluate Genetics-based claims relating to Mendel's Law of Independent Assortment. Genetics was chosen as the primary Biology topic for this research study due to its data-heavy nature that provides students with claims that are applicable to their daily lives, evidence that can be analyzed in alignment with Common Core Mathematics Standards, and the ability for students to use the data they observed and analyzed to support or reject the original claim following the Claim, Evidence, Reasoning model for scientific investigations.

Specifically in this study, every Biology section completed an investigation of the claim, "Does Indian corn follow Mendel's Law of Independent Assortment?" and were evaluated on the thoroughness and depth of the explanations following the claim,

evidence, reasoning model for scientific investigations. As summarized by Baker (2015), students are provided limited practice and support with reasoning with data. Throughout the Genetics unit, reasoning with data was imbued in each instructional activity, investigation, and assessment.

Subquestion 3: How can the integration of math and science enhance science instruction for students?

Interpretation of the data suggests that direct instruction of Chi-square analysis improved student performance and depth of understanding of the key genetics concept, Mendel's Law of Independent Assortment. Also evidenced in Bintz (2006), integrating math and science truly did make learning come alive. Through the triangulation of data collected this trend is further documented.

The results of the Math and Science Interest Surveys show students believe math and science go together, while they wavered between neutral and negative in respect to either subject being taught in other classes, the data indicates that students perform higher when math is taught in a science class. Moreover, a student in the treatment group made a comment on their RSQC2 form that, "What I enjoyed most was the labs. What I found the most useful was using math for science."

During the exposure to the treatment, the integration of math and science increased. An additional piece of data that shows a positive change in the improvement in math-based scientific explanations was the Genetics Questionnaire. Positive change was evident in student responses after the three-week treatment period. The questionnaire also

showed an increase in applying math-based genetics concepts to various question formats.

Subquestion 4: How will the teacher know if student's math-based scientific explanations are improving?

The final piece of data that supports student performance and the use of direct instruction of mathematical concepts in conjunction with Biology topics were the average scores of the explanation portion of the genetics investigation. The difference between the scores from each component of the laboratory investigation explanation were proven to be significant. This conclusion aligns with Palmeri (2009) findings that scientific understanding is integrally tied to the ability to gather and analyze data, and using data to construct and communicate scientific explanations.

Throughout this study, my students' understanding of key Biology concepts was enhanced through the integration of math and science. Students connected and applied how they currently learn math concepts to Biology concepts through the use of scientific investigations that follow the Claim, Evidence, Reasoning model. This multidimensional direct instruction of mathematical concepts improved students' explanations of Biology topics.

VALUE

Students may not see the inherent benefit in using mathematics as a method of scientific reasoning until later in their educational career, or perhaps they will never make that intrinsic connection. But it is my goal that the reasoning skills they gain by both practices being paralleled in both math and science be able to be applied to new or novel

endeavors. Using mathematics in the science classroom serves to broaden students' repertoire of data analysis and reasoning. Mathematics need not be confined solely to math class, the same with science. Whether this approach gains wider acceptance as a valid method of teaching mathematics based scientific reasoning is dependent on further research that demonstrates its effectiveness at increasing students' ability to provide evidence, reason, and make an argument for or against scientific claims.

The results of this project have made me develop further questions that could be answered through continued action research:

- Will greater interdisciplinary efforts help increase math and science scores?
- What techniques can be employed to further support the interdisciplinary nature of mathematics based scientific reasoning?

This project sought to address a concern I have regarding the integration of mathematics in a science classroom. As a science teacher, it is not in my explicit job description to teach mathematics. However, mathematics is an essential part of science education, as the Next Generation Science Standards demonstrate. In this project, I used an approach to teaching mathematics that used my strengths in communication with others and personal interest in the nature of science. The exclusive content driven science classroom needs to start becoming a facet of the past. Instead, students should practice an integrated approach to science. My students demonstrated gains in depth of understanding when they practiced math based science reasoning. As one student stated, "What I found most useful was all that math that I can use!"

I implemented this treatment in my fourth year of teaching science and my second year at Belgrade High School. It took me one year to become comfortable with the science curriculum used and to start forming positive interdisciplinary goal based relationships with my colleagues. I've always had the desire to integrate math and science and this was a great opportunity. This treatment taught me the benefits and challenges of integrating math into science curriculum. As the data showed, my students generally responded well to this treatment. I attribute some of the demonstrated gains to the positive relationship I have with my students, across all sections. One student commented in their RSQC2 response, "What I enjoyed most was the enthusiastic teacher!" Throughout the treatment I tried my hardest to maintain a high level of enthusiasm no matter how many times students commented, "I'm stuck," or called me over to their desk numerous times to clarify the process and their reasoning.

I'd like to continue integrating math into my Biology curriculum. While this initial process was very time consuming, the significant data validation is going to drive my future integration endeavors. One thing is for certain, no man is an island and integration of curriculum relies heavily on integration between departments. My enthusiasm for math integration spread from me, to the math department, and to my students, for this reason, I feel this was a successful project.

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APPENDICES

APPENDIX A
MATH TEACHER SURVEY

Purpose:

I am currently developing my capstone project for my Masters of Science in Science Education. The focus of my project is as follows:

- 1) I want Belgrade High School students to be able to use and articulate mathematical reasoning strategies when approaching scientific tasks.
- 2) To accomplish this, I will pervade instruction in mathematical graphing and data analysis into my science curriculum.

Bottom Line: I am going to structure my science curriculum next year around using math and science TOGETHER.

What grade level(s) do you teach? _____

What class(es) do you teach?

How do you help students overcome particular struggles in math?

What math based skills would you like to see be taught in other classes?

Do you have any suggestions for incorporating more math in the science classroom that could help your students as well?

APPENDIX B

NGSS AND CCMS CORRELATION MATRIX

Math Standard	PS 1	PS 2	PS 3	PS 4	LS 1	LS 2	LS 3	LS 4	ESS 1	ESS 2	ESS 3
9-12.HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.	X	X	X			X			X	X	X
9-12.HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling	X	X	X			X			X	X	X
9-12.HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.	X	X	X			X	X		X	X	X
HSA.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.		X		X					X		
HSA-SSE-B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.		X		X							
HSA-CED-A.1 Create equations and inequalities in one variable and use them to solve problems.		X									
HSA-CED-A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales		X							X		
HSA-CED-A.4 Rearrange formulas to highlight a quantity of interest, using the		X		X					X		

same reasoning as in solving equations.												
Math Standard	PS 1	PS 2	PS 3	PS 4	LS 1	LS 2	LS 3	LS 4	ESS 1	ESS 2	ESS 3	
HSA-IF-C.7 Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.		X			X							
HSS-ID-A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).		X				X						
HSS-IC-B.6 Make inferences and justify conclusions from sample surveys, experiments, and observational studies						X	X					
HSF-BF-A.1 Write a function that describes a relationship between two quantities.					X							
HSF-IC-A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.						X	X					
HSF-IF-B.5 Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes.									X			
HSS-ID-B.6 Represent data on two quantitative variables on a scatter plot, and describe how those variables are related.									X			
MP 2 Reason abstractly and quantitatively.												
MP 4 Model with mathematics.												

Websites used:

<http://www.nextgenscience.org/overview-dci> (NGSS standards correlation)

<https://www.ixl.com/standards/common-core/math/high-school> (IXL Math - Sample problems)

APPENDIX C
MATH INTEREST SURVEY

Grade Level: ☐9 ☐10 ☐11 ☐12

Which math class are you currently enrolled in? _____

Is this your first time taking the math class you are currently in? ☐Yes ☐No

I am interested in finding out what you think about Math. Read each statement, and then circle the response that best describes how true the statement is for you.

Participation in this research in voluntary and participation or nonparticipation will not affect a student's grades or class standing in any way.

1. Math is one of my favorite classes.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
2. I enjoy talking to my friends and family about what I'm learning in my math lessons.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
3. I would like to be someone who uses math for a career.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
4. I enjoy "doing" math.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
5. I talk to my math teacher when I do not understand a math concept.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
6. I know my math scores.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
7. I think science and math go together.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
8. I'm good at math.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
9. I believe you can learn math in lots of places, not just in math class.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5

10. I keep track of my math tests, homework, and practice.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
11. Learning math concepts comes easy to me.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
12. I learn math best when the teacher first shows me how to solve the problems.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
13. I learn math best when I get to try and solve the problem first.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
14. I think math should be taught in other class, not just in math class.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
15. I think math should be used in other class, not just in math class.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5

APPENDIX D
SCIENCE INTEREST SURVEY

Grade Level: ☐9 ☐10 ☐11 ☐12

Which science class are you currently enrolled in? _____

Is this your first time taking the math class you are currently in? ☐Yes ☐No

I am interested in finding out what you think about Science. Read each statement, and then circle the response that best describes how true the statement is for you.

Participation in this research in voluntary and participation or nonparticipation will not affect a student's grades or class standing in any way.

1. Science is one of my favorite classes.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
2. I enjoy talking to my friends and family about what I'm learning in my science lessons.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
3. I would like to be someone who uses science for a career.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
4. I enjoy "doing" science.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
5. I talk to my science teacher when I do not understand a science concept.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
6. I know my science scores.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
7. I think science and math go together.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
8. I'm good at science.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
9. I believe you can learn science in lots of places, not just in science class.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5

10. I keep track of my science tests, homework, and practice.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
11. Learning science concepts comes easy to me.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
12. I learn science best when the teacher first shows me how to understand the science concept.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
13. I learn science best when I get to try and understand the concept first.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
14. I think science should be taught in other class, not just in science class.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5
15. I think science should be used in other class, not just in science class.	Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Disagree Strongly 5

APPENDIX E

QPOE2 LAB INVESTIGATION GRADING RUBRIC

Name: _____ Period # _____

/40

QPOE Lab Grading Rubric

Name of Lab: _____ Date Completed On: _____

QPOE	Great!	Needs Improvement	Not Acceptable
Question	☐ Label boxed by margin (1) ☐ Complete question written (1)	☐ Labeled but not boxed (0.5) ☐ Abbreviated question (0.5)	☐ No label whatsoever (0) ☐ No question written (0)
Knowledge Probe	☐ Label boxed by margin (1) ☐ Complete description of relevant information (1)	☐ Labeled but not boxed (0.5) ☐ Somewhat complete description of relevant information (0.5)	☐ No label whatsoever (0) ☐ Incomplete or no description of relevant information (0)
Prediction	☐ Label boxed by margin (1) ☐ Connected to question and prior knowledge(1) ☐ States a reasonable expected outcome (1)	☐ Labeled but not boxed (0.5) ☐ Connected to only the question or only to prior knowledge (0.5) ☐ States an expected outcome (0.5)	☐ No label whatsoever (0) ☐ No connection to either the question or prior knowledge (0) ☐ No expected outcome (0)
Investigation Plan	☐ Label boxed by margin (1) ☐ Each step written and numbered (1) ☐ Indicates multiple trials (1)	☐ Labeled but not boxed (0.5) ☐ Missing 1-2 steps (0.5) ☐ Does not state multiple trials (0.5)	☐ No label whatsoever (0) ☐ Missing 3+ steps (0) ☐ Does not state multiple trials (0)
Observation	☐ Label boxed by margin (1) ☐ Data table has title (1) ☐ Made with ruler (1) ☐ Includes quantitative observations (1) ☐ Includes qualitative observations (1)	☐ Labeled but not boxed (0.5) ☐ Data table missing title (0.5) ☐ Did not use ruler (0.5) ☐ Includes only qualitative OR only quantitative observations (0.5)	☐ No label whatsoever (0) ☐ Sloppy (0) ☐ Missing data (0)
Data Analysis	☐ Label boxed by margin (1) ☐ Graphical representation is nice and neat (1) ☐ Graph labeled: title, axis, units, and key (1) ☐ 2 sentence summary of trends (1)	☐ Labeled but not boxed (0.5) ☐ Graphical representation is fair (0.5) ☐ Missing 1-2 graph labels: title, axis, units, and key (0.5) ☐ 1 sentence summary of trends (0.5)	☐ No label whatsoever (0) ☐ Graphical representation is sloppy (0) ☐ Missing 3+ graph labels: title, axis, units, and key (0) ☐ 0 sentence summary of trends (0)
Explanation	☐ Label boxed by margin (1)	☐ Labeled but not boxed (0.5)	☐ No label whatsoever (0)

*Use complete sentences +1	☐ <u>Claim</u> - answers investigation question (1) ☐ <u>Evidence</u> - selected evidence supports the claim (1) ☐ <u>Reasoning</u> - links and justifies the claim and evidence. (1) ☐ Makes a strong argument (1) ☐ Subtitles are underlined (1)	☐ <u>Claim</u> - does not fully answer investigation question (0.5) ☐ <u>Evidence</u> - selected evidence somewhat supports the claim (0.5) ☐ <u>Reasoning</u> - links and justifies the claim OR evidence. (0.5) ☐ Makes an argument (0.5) ☐ Subtitles are not underlined (0.5)	☐ <u>Claim</u> - does not answer investigation question or is missing (0) ☐ <u>Evidence</u> - selected evidence does not support the claim or is missing (0) ☐ <u>Reasoning</u> - describes rather than justifies the claim OR evidence. (0) ☐ Does not make an argument (0) ☐ No subtitles (0)
Evaluation *Use complete sentences +1	☐ Label boxed by margin (1) ☐ Identifies 2+ sources of error (1) ☐ Accurately uses confidence chart with a complete sentence (1) ☐ Identifies 2+ things to do differently next time (1) ☐ Identifies 2+ related and testable investigation questions (1) ☐ Subtitles are underlined (1)	☐ Labeled but not boxed (0.5) ☐ Identifies 1 source of error (0.5) ☐ Uses confidence chart but inaccurately or with a sentence fragment (0.5) ☐ Identifies 1 thing to do differently next time (0.5) ☐ Identifies 1 related and testable investigation question (0.5) ☐ Subtitles are not underlined (0.5)	☐ No label whatsoever (0) ☐ Identifies 0 sources of error (0) ☐ Does not use confidence chart (0) ☐ Identifies 0 things to do differently next time (0) ☐ Identifies 0 related and testable investigation questions (0) ☐ No subtitles (0)
Application *Use complete sentences +1	☐ Label boxed by margin (1) ☐ Answers application question using complete sentences (1)	☐ Labeled but not boxed (0.5) ☐ Answers application question using incomplete sentences (0.5)	☐ No label whatsoever (0) ☐ Does not answer application question (0)
Habits of Mind *Use complete sentences +1	☐ Label boxed by margin (1) ☐ Identified 3+ habits of mind used (1) ☐ Connects each to the lab (1)	☐ Labeled but not boxed (0.5) ☐ Identified 2 habits of mind used (0.5) ☐ Limited connection to the lab (0.5)	☐ No label whatsoever (0) ☐ Identified 1 or fewer habits of mind used (0) ☐ No connection to the lab (0)

36-40 = A

32-35 = B

28-31 = C

26-28 = D

Below 25 = F

APPENDIX F
MUDDIEST POINT

After today's lesson, I am still "stuck" or confused about...

APPENDIX G
TEACHER JOURNAL

Date:

Lesson Taught:

Lesson Objectives:

- What I thought went well:
 - Why I thought it went well:
- What I can improve on:
 - Why I think I can improve:
- Actions for next lesson:

APPENDIX H

RSQC2 (RECALL, SUMMARIZE, QUESTION, CONNECT, AND COMMENT)

Recall- List the most important ideas from the previous class. Put a 1 next to the idea you think is the most important, put a 2 next to the idea you think is the second most important, continue this numbering trend with your list.	
Summarize- Write <i>one</i> sentence summarizing as many of your important points as possible.	
Question- What is one question about the material from the previous class that you want answered?	
Connect- Make one connection between what you have learned in the previous class and any of the classes before that.	
Comment- Write an evaluative comment about the previous class. For example, “What I enjoyed most/least was...What I found most/least useful was...”	

APPENDIX I
GENETICS QUESTIONNAIRE

This interview is completely voluntary and will not affect your grade.

1. Explain the purpose of Punnett Squares.
2. What is an expected outcome for a genetic cross? Give an example.
3. After a genetics investigation, how would you evaluate the following claim: Are the numbers we were expecting to see, the same as the numbers we actually observed?
4. After a genetics investigation, how would you prove that the numbers you did see weren't just by random chance?

APPENDIX J
GENETICS INVESTIGATION

(Treatment) Investigation Name: Mendelian Genetics and Corn

Investigation Question
☐ Does Indian corn follow Mendel's Law of Independent Assortment?
Knowledge Probe
☐ <u>Prior Knowledge:</u> In the simplest terms, color in the corn kernel (specifically in the endosperm layer) is purple (dominant allele, P). Yellow corn is actually the recessive form of kernel color (p), albeit a more familiar form to most of us. Similarly, the shape of the kernel is familiar to us as a smooth rounded shape in sweet corn. If sweet corn is dried the water in the sugar solution will evaporate and leave a small residue of sugar and a "wrinkled" appearance. "Field corn," which is the predominant type of corn that you see growing along the highways, is not sweet, but starchy (containing at least one dominant R allele). So when it dries, the (larger volume of) insoluble starch remains and the kernel is round. This field corn is destined to be consumed largely as animal feed, but also as raw material for biofuels. So, the corn that comes to mind for most of us - sweet corn - is a mutant two ways - homozygous recessive for both color (pp) and shape (rr)! ☐ How is the sweet corn we eat a mutant? ☐ What are the four phenotypes of corn kernels? ☐ <u>Secondary knowledge:</u> ☐ Define Mendel's Law of Independent Assortment. ☐ What is the expected fraction/ratio of offspring phenotypes for the following crosses (R = round, r = Wrinkled, P = purple, p = yellow): ☐ RR x rr PP x pp ☐ Rr x Rr Pp x Pp ☐ RRPP x rrpp ☐ RrPp x RrPp
Prediction/Hypothesis
☐ Indian corn (will/will not) follow Mendel's Law of Independent Assortment because...(give a logical reason why).
Investigative Plan
Monohybrid Cross 1. Grab an ear of corn from the monohybrid tub 2. Describe the overall appearance and texture, draw and color a small picture of it 3. Count the number of kernels in five rows on your ear of corn and record the number in your data chart. 4. Repeat with a different monohybrid cob Dihybrid Cross 5. Grab an ear of corn from the dihybrid tub 6. Describe the overall appearance and texture, draw and color a small picture of it

7. Count the number of kernels in five rows on your ear of corn and record the number in your data chart.

Observation

☐ Create data charts to record your results

☐ **Monohybrid Cross- Kernel Coloration**

Phenotypes	# of Kernels	Ratio (Number counted/ total)	Picture
Total (for 5 rows)			

☐ **Monohybrid Cross- Kernel Texture**

Phenotypes	# of Kernels	Ratio (Number counted/ total)	Picture
Total (for 5 rows)			

☐ **Dihybrid Cross- Kernel Coloration and Texture**

Phenotypes	Number Counted	Ratio (Number counted/ total)	Picture
Total			

Data Analysis

☐ Look at your data, **highlight** any questionable data, determine what is valid and reliable. How might you be able to reorganize and/or manipulate this data.

☐ For your monohybrid crosses, did you obtain a 3:1 ratio? If you did, then the genes did assort independently! If you did not, then the gene may be found on the same chromosome and do not assort independently and the deviations from your observed data might be due

to something besides chance...to find out perform a chi-square test on one of your monohybrid crosses.

Phenotype	Observed	Expected	O-E	(O-E) ²	[(O-E) ²]/E
Totals					

dF = _____ Sum = _____ Accept or Reject? _____

- ☐ What do you propose the parent genotypes to be for this monohybrid crosses?
- ☐ What do you propose the offspring genotypes to be for this monohybrid crosses?
- ☐ Show a Punnett square for one of your monohybrid crosses. Include a key.
- ☐ For your dihybrid crosses, did you obtain a 9:3:3:1 ratio? If you did, then the genes did assort independently! If you did not, then the gene may be found on the same chromosome and do not assort independently and the deviations from your observed data might be due to something besides chance...to find out perform a chi-square test.

Phenotype	Observed	Expected	O-E	(O-E) ²	[(O-E) ²]/E
Totals					

dF = _____ Sum = _____ Accept or Reject? _____

- ☐ What do you propose the parent genotypes to be for each of your dihybrid?
- ☐ What do you propose the offspring genotypes to be for each of your dihybrid cross?
- ☐ Show a Punnett square for your dihybrid cross. Include a key.

Explanation- use your dihybrid data

- ☐ Claim – The answer to my question
- ☐ Evidence – The scientific data to support my claim.
- ☐ Reasoning – The argument that shows how my claim is supported by evidence.
- ☐ Confidence level

Evaluation

- ☐ What are the sources of error in this investigation? (2 or more)
- ☐ What would you do differently next time? (2 or more)
- ☐ What question would you like to pursue next? (2 or more)

Application

☐ How might this lab apply to your everyday life?
Reflection
☐ Which habits of mind were most beneficial to you in this investigation? Why? (3+)

(Control) Observation and Data Analysis**Observation**

- ☐ Create data charts to record your results

☐ **Monohybrid Cross- Kernel Coloration**

Phenotypes	# of Kernels	Ratio (Number counted/ total)	Picture
Total (for 5 rows)			

☐ **Monohybrid Cross- Kernel Texture**

Phenotypes	# of Kernels	Ratio (Number counted/ total)	Picture
Total (for 5 rows)			

☐ **Dihybrid Cross- Kernel Coloration and Texture**

Phenotypes	Number Counted	Ratio (Number counted/ total)	Picture
Total			

Data Analysis

- ☐ Look at your data, **highlight** any questionable data, determine what is valid and reliable. How might you be able to reorganize and/or manipulate this data.
- ☐ For your monohybrid crosses, did you obtain a 3:1 ratio? If you did, then the genes did assort independently! If you did not, then the gene may be found on the same chromosome and do not assort independently and the deviations from your observed data might be due to something besides chance...
- ☐ What do you propose the parent genotypes to be for each of your monohybrid crosses?
- ☐ What do you propose the offspring genotypes to be for each of your monohybrid crosses?
- ☐ Show a Punnett square for one of your monohybrid crosses. Include a key.
- ☐ For your dihybrid crosses, did you obtain a 9:3:3:1 ratio? If you did, then the genes did assort independently! If you did not, then the gene may be found on the same chromosome and do not assort independently and the deviations from your observed data might be due to something besides chance...
- ☐ What do you propose the parent genotypes to be for your dihybrid cross?
- ☐ What do you propose the offspring genotypes to be for your dihybrid cross?
- ☐ Show a Punnett square for your dihybrid cross. Include a key.

APPENDIX K
GENETICS UNIT ASSESSMENT

Genetics Unit Assessment- Treatment

You got this!

ID: A

Problem

60. A scientist crossed a true breeding purple corn and a true breeding yellow corn. His results are shown in the data table below.

Phenotype	Observed
Purple	195
Yellow	55
Total	250

- a. For this monohybrid crosses, did the scientist obtain a 3:1 ratio? If they did, then the genes did assort independently! If they did not, then the gene may be found on the same chromosome and do not assort independently and the deviations from your observed data might be due to something besides chance...to find out perform a chi-square test on one of your monohybrid crosses.

Phenotype	Observed	Expected	O-E	(O-E) ²	[(O-E) ² /E]
Total					

- b. Evaluate the scientist's investigation:

Claim - The predicted color distribution for the corn offspring is (correct/incorrect). Mendel's Law of Independent Assortment (applies/does not apply).

Evidence - Out of ___ total offspring, ___ were ___ (phenotype) and ___ were ___ (phenotype).

Reasoning - With ___ degrees of freedom, my chi square value is ___, which gives me a p value between ___ % and ___ %, I therefore (accept/reject) my null hypothesis. This means that ___ % of the time when our observed data is this close to our expected value (is/is not) due to random chance.

- c. What does all of this mean? Write a three sentence description in **plain and simple terms** as to: What the scientist was trying to investigate:

What were his results:

Why was a Chi Square test performed?

What does it mean when you accept a Chi Square test? (simple terms)

Genetics Unit Assessment- Control

You got this!

ID: B

Problem

60. A scientist crossed a true breeding purple corn and a true breeding yellow corn. His results are shown in the data table below.

Phenotype	Observed
Purple	195
Yellow	55
Total	250

- a. For this monohybrid crosses, did the scientist obtain a 3:1 ratio? If they did, then the genes did assort independently! If they did not, then the gene may be found on the same chromosome and do not assort independently and the deviations from your observed data might be due to something besides chance...to find out calculate the ratios of the monohybrid crosses.

Phenotype	Observed	Ratio	Mendel's Expected Ratio
Total			

- b. Evaluate the scientist's investigation:

Claim - The predicted color distribution for the corn offspring is (correct/incorrect). Mendel's Law of Independent Assortment (applies/does not apply).

Evidence -

Reasoning -

- c. What does all of this mean? Write a three sentence description in **plain and simple terms** as to: What the scientist was trying to investigate:

What were his results:

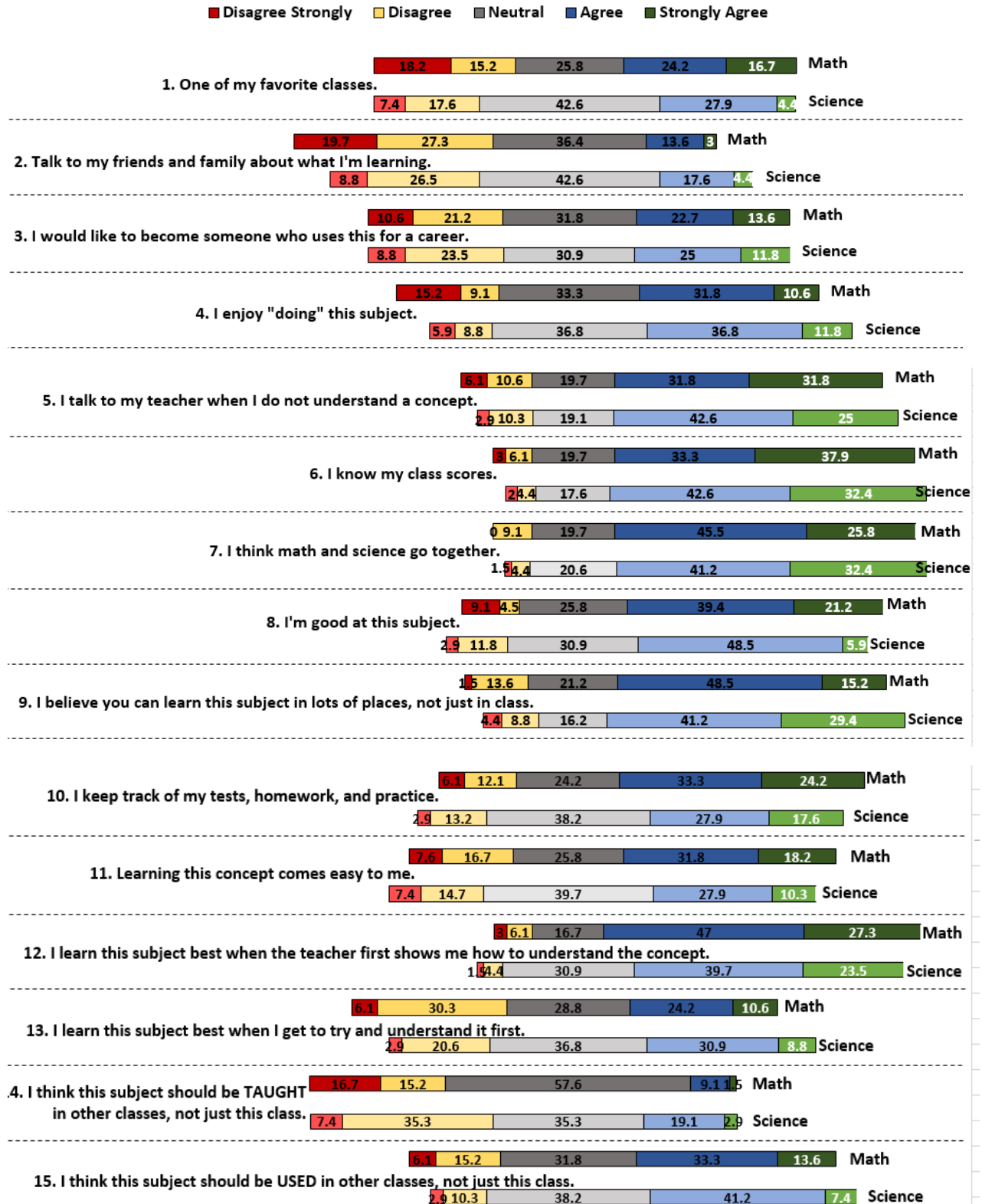
Why did you calculate the ratios from your data?

What does it mean when you accept Mendel's laws, in relation to your data? (simple terms)

APPENDIX L

SCIENCE AND MATH INTEREST COMPARISON GRAPH

Science and Math Interest Comparison



APPENDIX M

TREATMENT GROUP STUDENT SAMPLE EXPLANATION

Explanation

Claim: The predicted color distribution for the corn offspring is incorrect. Mendel's law of Independent Assortment does not apply.

Evidence: Out of 203 total offspring, 80 were RP, 33 were P, 72 were Rp and 18 were rp.

Reasoning: With 3 degrees of freedom my chi-square value is 43.142, which gives me a p value of less than 5%. I therefore reject my null hypothesis. This means that 25% of the time when our observed data is this close to our expected value is not due to random chance.

Fair test: This was a fair test because we combined data from five rows of corn, randomly chose punnet squares and completed a chi-squared test.

Confidence level: I am a little confident with our data because we conducted 3 trials.

APPENDIX N

CONTROL GROUP STUDENT SAMPLE EXPLANATION

Explanation

Claim - yes Indian corn follows Mendel's law of independent assortment

Evidence - for the dihybrid cross kernel coloration + texture round + purple $\frac{111}{196} = .57$ wrinkled + purple $\frac{37}{196} = .19$ round + yellow $\frac{34}{196} = .17$ wrinkled + yellow $\frac{14}{196} = .07$

Reasoning - I selected my corn rows at random, I performed at least 5 trials, + my observations were independent. My percentages in table 3 fit in the boundaries of Mendel's Law.

Confidence level - I am strongly confident because we selected our corn at random + conducted a minimum # of trials. We also had our results confirmed.